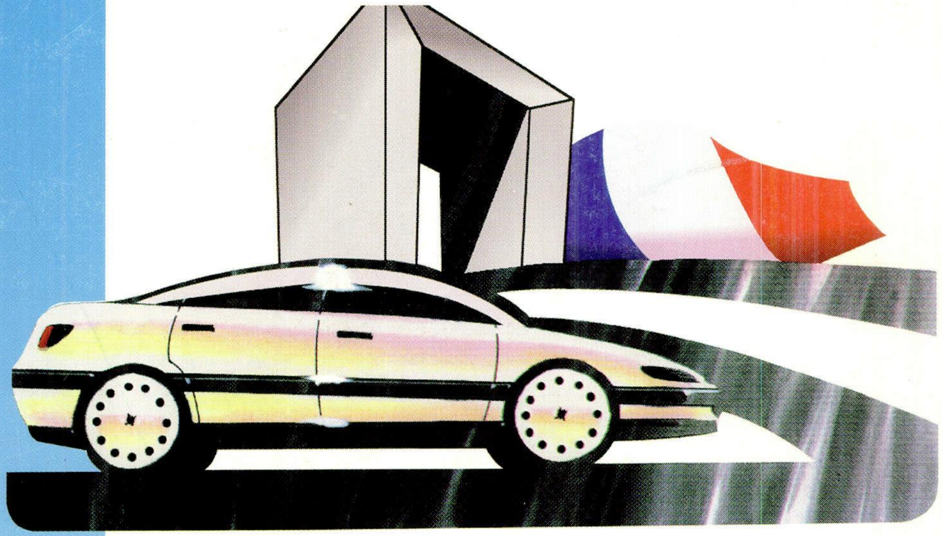


13th INTERNATIONAL TECHNICAL CONFERENCE ON EXPERIMENTAL SAFETY VEHICLES

13th CONFÉRENCE TECHNIQUE INTERNATIONALE SUR LES VÉHICULES EXPÉRIMENTAUX DE SÉCURITÉ

PROCEEDINGS VOLUME 1

PARIS LA VILLETTE
CITÉ DES SCIENCE
ET DE L'INDUSTRIE
PARIS, FRANCE
NOVEMBER 4 - 7, 1991

13TH INTERNATIONAL CONFERENCE ON EXPERIMENTAL SAFETY VEHICLES

VOLUME 1

The Thirteenth International Technical Conference on Experimental Safety Vehicles

Sponsored by:
U.S. Department of
Transportation
National Highway Traffic
Safety Administration

Hosted by:
French Government

Held at:
Paris, France
November 4-7, 1991

Foreword

This report of the proceedings of the Thirteenth International Technical Conference on Experimental Safety Vehicles was prepared by the National Highway Traffic Safety Administration, U.S. Department of Transportation.

We wish to thank the authors and all those responsible for the excellence of the material submitted, which aided materially in the preparation of this report.

For clarity and because of some translation difficulties, a certain amount of editing was necessary. Apologies are, therefore, offered where the transcription is not exact.

Introduction

The International Experimental Safety Vehicles (ESV) Program originated under NATO's committee on the Challenges of Modern Society (CCMS) and was implemented through bilateral agreements between the United States Government and the governments of France, the Federal Republic of Germany, Italy, the United Kingdom, Japan, and Sweden. The participating nations agreed to develop experimental safety vehicles to advance the state-of-the-art in safety engineering and to meet periodically to exchange technical information on their progress.

To date, twelve international conferences have been held, each hosted by one of the participating Governments. These conferences have drawn participants from government, the worldwide automotive industry, and the motor vehicle safety research community. International cooperation in motor vehicle safety research continues at the highest level. As work on experimental safety vehicles was completed, the research program expanded to cover the entire range of motor vehicle safety. The ESV Conferences now serve as the international forum through which progress in motor vehicle safety technology is reported.

The proceedings of each Conference have been published by the United States Government and distributed worldwide. These reports, which detail the safety research efforts underway worldwide, have been recognized as the definitive work on motor vehicle safety research. We are sure that this outstanding example of international cooperation seeking reductions in motor vehicle deaths and injuries will continue its past success.

Attendees

AUSTRALIA

Brian Fildes
Monash University
Accident Research Centre

Michael Griffiths
Roads & Traffic Authority

Peter Makeham
Dept. of Transport

Jack McLean
University of Adelaide

BELGIUM

Tadaomi Akiba
Nissan European Tech. Center

Kazuhito Asakawa
J.A.S.I.C.

Kazuhiko Hayashi
Toyota Motor Europe

Yoshihiro Heishi
Nissan European Tech. Center

Herbert Hennsler
C.E.E.

Susumu Ino
Daihatsu Motor Co., Ltd.

Henk Mannekens
Nissan European Tech. Center

Masami Misaki
Nissan European Tech. Center

Hideo Obara
Nissan European Tech. Center

Keiichi Okabayshi
Toyota Motor Europe

Ushio Ueno
Toyota Motor Europe

Yves Van der Straaten
General Motors Europe

Hans Van Driessche
Honda Motor Europe

Daniel Verdiani
Commission of European
Communities

Udo Westfal
ACEA

BULGARIA

Krouin Valkov
Ministry of Transport

CANADA

Duncan McPherson
University of British Colombia

James Newman
Biokenetics Assoc. Ltd.

Stephen Read
University of Waterloo

Christopher Wilson
Road Safety & Motor Vehicle
Regulations

CZECHOSLOVAKIA

Vojtech Rieger
U.S.M.D.

DENMARK

Per Frederiksen
Justice Ministry - Road Safety Div.

Ib Rasmussen
Ministry of Justice/Road Safety

FRANCE

Alain Achard
Renault

Francois Alonzo
I.N.R.E.T.S.

Yves Aubin
Comite des Const. Franc. d'Auto.

Claude Aubry
Autoliv Klippan

Eugene Auffray
F.F.C.

Daniel Augello
Renault

Jean-Jacques Azuar
Chausson Engineering

Jean Barge
E.C.I.A.

Marc Behaghel
Comite des Const. Franc. d'Auto.

Agnes Bellini
L.A.B./PSA - Renault

Farid Bendjallal
L.A.B./PSA - Renault

J. M. Berard
D.S.C.R.

Roger Biard
I.N.R.E.T.S. - L.C.B.

Pierre Bigot
P.S.A. Peugeot Citroen

Georges Blanc
Automobile Normalisation Bureau

Charles Blanot
Renault - Direction des Etudes

Jean Bloch
I.N.R.E.T.S.

Jean-Claude Bluet
I.N.R.E.T.S.

Felix Bocaly
Peugeot S.A. Research

Marc Bocque
Peugeot S.A.

Serge Bohers
Peugeot S.A.

Jean Bonnoit
I.N.R.E.T.S. - LBA

Veronique Bordes
I.N.R.E.T.S. - LBA

Antoine Bossard
Automobiles Peugeot

Patrick Botto
Renault - IRACBA

Laurent Bouchard
Renault - IRBA

Robert Bouquet
I.N.R.E.T.S. - L.C.B.

Denis Bourcart
Autoliv Klippan

Jean-Luc Brard
Peugeot S.A. Research

Pierre Brun
P.S.A.

Francoise Brun-Cassan
L.A.B./PSA - Renault

Gilles Brutel
Peugeot S.A. Research

Jean-Loup Burgaud
Ecole Centrale de Paris

Marie-Christine Cailleret
Renault - IRACBA

Herve Calmelly
Matra Automobiles

Serge Care-Colin
C.E.T.E. de l'Est

Roland Caroff
Peugeot S.A.

Nelson Casadei
Renault, Research Directorate

Francoise Cassan
Renault

Claude Cavellero
I.N.R.E.T.S. - LBA

Dominique Cesari
I.N.R.E.T.S. - L.C.B.

Francois Chamouard
Renault - Biomech./Accident Lab

Paul Charlety
Autoliv Klippan

Remi Chavanne
Automobiles Peugeot - Sochaux

Martine Chereau
Peugeot S.A. Research

Claude Chevalier
Fondation M.I.A.F.

Jean Chevrier
R.A.T.P.

Jean-Pierre Cheynet
U.T.A.C.

Alain Clerc
Automobiles Peugeot

Pierre Colinot
P.S.A. Direction des Etudes

Paul Philippe Cord
LIVBAG

Franck Dauvilliers
Renault - AARMT

Christophe de Baynast
Peugeot S.A. Research

Pascal Deloof
INRETS - CRESTA

Igor Demay
Automobiles Citroen

Andre Deperrois
P.S.A.

Jean Derampe
Peugeot S.A.

Veronique Desgardins
Automobile Citroen

Lambert Detoux
F.F.C.

Louis DeVaulx
P.S.A.

Serge Diet
Renault

Georges Dobias
I.N.R.E.T.S.

Claude Dolivet
I.N.R.E.T.S. - L.C.B.

Marie-France Dondel
Renault - Direction des Etudes

Regis Dornez
Renault

Yves Drouadaine
Framasoft CSI
Tour Fiat

Alain Dubos
Renault

Alain Duchesne
Davey Bickford

B. Durand
D.S.C.R.

Marc Ellenberg
C.E.T.E. de l'Est

Philippe Eurin
Ministere, Recherche/Technologie

Denis Even
TELMA

Leonce Evin
Auto Klippan

Jean-Pierre Faidy
P.S.A. DRAS

Gerard Faverjon
L.A.B./Peugeot Renault

Andre Fayon
Renault

Michel Ferlay
I.N.R.E.T.S.

Francis Ferrandez
I.N.R.E.T.S.

Serge Ficheux
U.T.A.C.

Claude Fline
Ministere Recherche/Technologie

Helene Fontaine
I.N.R.E.T.S.

Jean-Yves Foret-Bruno
Renault

Arnaud Froumajou
Peugeot S.A. Research

Jean Fructus
U.T.A.C.

Philippe Gaches
Peugeot S.A. Research

Gilles Garret
Autoliv Klippan

Bernard Gauvin
D.S.C.R.

Louis Germain
Renault Vehicules Industriels

Olivier Gignoux
Renault

Jean-Claude Goaer
Renault

Camille Gontier
Ecole Centrale de Paris

Christian Goualou
P.S.A./E.C.P.

Silvie Goujon
Peugeot S.A. Research

Raymond Guasco
F.I.E.V.

Louis-Robert Guy
PYROSPACE

Mouloud Haddak
I.N.R.E.T.S./L.C.B.

Jean Hamon
P.S.A. DRAS

Jean-Marie Heinrich
L.A.B./PSA - Renault

Claude Henry
L.A.B./PSA - Renault

Francois Hordonneau
Renault

Jean-Francois Huere
Peugeot S.A. Research

Christophe Jacob
Renault - AARMT

Jacques Jolivet
Autoliv Klippan

Marco Klingler
INRETS - CRESTA

Serge Koltchakian
Renault - Biomech./Accident Lab

Michel Kozyreff
Autoliv Klippan

Jean Jacques Laine
C.E.T.E., Nord Picardie

Marc Laliere
Renault Automobiles Centre Technique

Patrice Larguier
P.S.A. - DRAS

Francois Laurent
Peugeot S.A. Research

Aime LeCalve
Renault

Jean-Yves LeCoz
L.A.B./PSA-Renault

Evelyne Lepoivre
Renault

Francois Leygue
Ministry of Transport

Richard Loinard
PYROSPACE

Roland Lucquiad
U.T.A.C.

Philippe Mack
Renault

Jean-Paul Magnier
Davey Bickford

Vincent Maillard
E.C.I.A.

Bruno Marguet
GEC ALSTHOM - CIMT

Gerard Martigny
Peugeot S.A. Research

Veronique Martin
Automobiles Citroen

Yves Martin
Automobiles Citroen

Therese Martinet
Peugeot S.A.

Gerard Mauron
Peugeot S.A. Research

Jean-Pierre Medevielle
I.N.R.E.T.S.

Menard
INNOVATION 128

Serge Morlan
PYROSPACE

Francois Mounier-Poulat
Renault Vehicules Industriels

Richard Najchaus
Renault

Henri Novel
Huliez France

Sean O'Riordain
I.N.R.E.T.S. - L.C.B.

Laurent Oudenard
Renault - IRBA

Jean-Frederic Outters
Automobiles Citroen

Jean Pages
F.I.E.V.

Christian Perotto
LIVBAG

Claire Petit
Renault - IRBA

John L. Phelps
O.I.C.A.

Yvette Pincemaille
L.A.B./PSA - Renault

Sophie Planque
Renault - AARMT

Yves Portier
A.P.S.A.D., Direction Automobile

Daniel Pouget
Renault

Alain Priez
Renault - IRACBA

Eric Ramaioli
Renault

Michelle Ramet
I.N.R.E.T.S. - L.C.B.

Philippe Ranc
Automobiles Citroen

Raymond Ravenel
Comite des Const. France D'Auto

Jean-Pascal Reille
Renault, Direction des Etudes

Francois Renaudin
SERAM, lab. de Biomecanique

Joel Rio
Renault

Nicholas Rogers
IMMA

Jean-Paul Rouet
SAGEM

Patrice Roulois
Heuliez Automobiles

Nakoto Sakai
NIPPONDENSO

Rene Sallen
Automobiles Citroen

Patrick Siarry
Ecole Centrale de Paris

Donggang Song
Renault - IRACBA

Olivier Soulie
Automobiles Peugeot-Sochaux

Jean-Pierre Spagnol
Autoliv Klippan

Georges Stcherbatcheff
Renault

Christian Steyer
Renault

Xiang-Tong Tao
INRETS LCB

Philippe Tardivon
P.S.A. Direction des Etudes

Claude Tarriere
Renault

Christian Thevenet
C.C.F.A.

Christian Thomas
L.A.B./PSA- Renault

Pierre Toursel
Peugeot S.A. Research

Xavier Trosseille
Renault

Jerome Uriot
Renault - IRBA

Harold Vallee
L.A.B./PSA - Renault

Gilles Vallet
I.N.R.E.T.S.

Jacques Van Bunderen
Autoliv Klippan

Kyriakos Vavalidis
Autoliv Klippan

Philippe Ventre
Renault

Michele Vergne
Fondation M.I.A.F.

Roel Verhoog
CESA

Louis-Claude Vrignaud
Siemens Automotive S.A.

Gilbert Walfisch
Renault

Remy Willinger
I.N.R.E.T.S.

GERMANY

Horst Albrecht
Volkswagen AG

Winfried Asmuth
TUV Rheinland

Toshio Ban
Honda R & D Europe

Hartmut Burger
Volkswagen AG

Bo Cavell
Autoliv GmbH

Horst Dalibor
Volkswagen AG

Karl Frederick Ditsch
Ministry of Transport

Jens Eberius
Porsche AG

Harald Eggelmann
Mercedes-Benz AG

Willi Elsenheimer
Adam Opel AG

Eberhard Faerber
Federal Highway Research
Institute

Joerg Fellerer
Bayerische Motoren Werke AG

Detlef Frank
Bayerische Motoren Werke AG

Joachim Franz
Siemens AG

Bernd Friedel
Federal Highway Research
Institute

Wolf-Richard Frielingsdorf
Mercedes-Benz AG

Klaus-Peter Glaeser
Federal Highway Research
Institute

Jurgen Grandel
DEKRA

Johann Guggenberger
Siemens AG

Josef Haberl
Bayerische Motoren Werke AG

Hans Hagen
Karl Kassbohrer Fahrzeugwerke
GmbH

Lothar Heider
Mercedes-Benz AG

Wolfram Hell
University Munich

Thomas Hummel
HUK - Verband

Dimitrios Kallieris
University of Heidelberg

Karl-Heinz Kartenberg
Porsche AG

Jorg Kerwath
Honda R & D Europe

Kikuzo Kitaori
Mitsubishi Motors Europe, B.V.

Juergen H. Kloeckner
BASt, Federal Highway Research
Institute

Hubert Koch
Industrie Verband Motorrad

Bernhard Koonen
TUV Rheinland e.V.

Gerald Krabbel
Technische Universitat Berlin

Bernd Kraemer
TUV Rheinland e.V.

Hans-Joachim Kraft
Bayerische Motoren Werke AG

Heinz Kunert
SEKURIT-Glas Union GmbH

Klaus Langwieder
HUK - Verband

Bog-Soo Lee
Institute of Automobilengineering

Heinz Leffler
Bayerische Motoren Werke AG

Herbert Loffelholz
Federal Industry of Transport

Horst-Georg Marks
Volkswagen AG

Gunther Menzel
Volkswagen AG

Yoshimoto Nagamoto
Mazda Motor Corp.

Hiroyaki Nishioka
Toyoda Gosei Co., Ltd.

Michael Popp
Universitat der Bundeswehr

Berud Richter
Volkswagen AG

Ernst-Rudiger Rohr
Mercedes-Benz AG

Klaus Rompe
TUV Rheinland e.V.

Willibald Roth
Kolbenschmidt AG

Dieter Schaper
Electrolux Autoliv

Thomas Scharnhorst
Volkswagen Research Forschung
Fahrzeugtechnik

Dieter Scheunert
Mercedes-Benz AG

Andreas Schindler
TUV Rheinland e.V.

Friedrich-Karl Schlotterbeck
European Components
Deutschland

Achim Schmitz
TUV Rheinland e.V.

Gerhard Schontag
Mercedes-Benz AG

Ruprecht Sinnhuber
Volkswagen AG

Alexander Sporner
HUK Verband

Armin Starck
DEKRA

Hans-Eggert Tonnesen
Anton Ellinghaus GmbH & Co. KG

Hidenori Uki
Mitsubishi Motors Europe B.V.

Hans-Josef Vasen
Kolbenschmidt AG

Jesko Veenhuis
Volkswagen AG

Elmar Vollmer
Audi AG

Klaus Von Versen
Engineering Systems International

Lothar Wech
T.U.V. Bayern eV.

Hanns-Peter Weisbarth
Bayerische Motoren Werke AG

Ulrich Wezel
Porsche AG

Frank Wolf
Mercedes Benz AG

Robert Zobel
Volkswagen AG

HUNGARY

Csaba Siklos
Ministry of Transportation

IRELAND

Denis Wood
Wood and Associates

ISRAEL

Ran Cohen
A.D.A.

ITALY

Elisabetta Amici
Centro Sviluppo Mayterial

Pierluigi Ardoino
Fiat Auto SpA - Centro Sicuarezza

Andrea Benedetto
Fiat Auto SpA - Centro Sicurezza

Dante Bigi
Fiat Auto SpA - Centro Sicurezza

S. Buscaglione
Fiat Auto SpA - Centro Sicurezza

Stefano Buscaglione
Fiat Auto

Fissore
Fiat Auto

F. Fissore
Fiat Auto SpA - Centro Sicurezza

F. Fossati
Fiat Auto SpA - Centro Sicurezza

C. Lomonaco
Ministero dei Trasporti

Fabrizio Luccetti
Fiat Auto SpA - Centro Sicurrezza

Lamberto Milani
Italdesign

Silvia Monticelli
Fiat AutoSpA - Centro Sicurezza

A. Pastorino
Fiat Auto SpA - Centro Sicurezza

Claudio Schinaia
Ministero dei Trasporti

F. Zacchilli
Ministero dei Trasporti

JAPAN

Akihiko Akiyama
Honda R & D

Kenji Araki
Sumitomo Metal Industries, Ltd.

Yoshinori Boda
M.I.T.I.

Mr. Clepkenn
Nissan Motor Company, Ltd.

Hidehiko Enomoto
Hino Motors, Boxy Research
& Development

Naoto Fukushima
Nissan Motor Company, Ltd.

Satoshi Fukushima
Toyota Motor Corporation

Kenichi Goto
Japan Automobile Research
Institute

Takeshi Harigae
Japan Automobile Research
Institute

Kazuo Higuchi
Honda R & D, 12th Research
Section

Kaneo Hiramatsu
Japan Automobile Research
Institute

Masaki Hitotsuya
Fujitsu Ten Ltd.

Kiyoshi Honda
Honda R&D, 12th Research Section

Noritoshi Horigome
Ministry of Transport

Masaru Igarashi
Suzuki Motor Corporation

Haruyuki Ikesue
NSK, Ltd.

Namio Irie
Nissan Motor Company, Ltd.

Hirotoshi Ishikawa
Japan Automobile Research
Institute

Shin-ichi Ishiyama
Toyota Central R & D Labs, Inc.

Keiji Isoda
Mitsubishi Motors Corporation

Kazuyoshi Katou
Toyota Motor Corporation

Junichi Kishimoto
Nippon Koki Co., Ltd.

Toru Kiuchi
Toyota Motor Corporation

Ikuya Kobayashi
Fujitsu Ten Ltd.

Akira Koike
Hino Motors, Vehicle Research
& Exper.

Norio Komoda
Toyota Motor Corp. R&D Planning

Yutaka Kondoh
Toyota Motor Corporation

Ichiro Kurawaki
Yamaha Motor Co., Ltd.

Keiji Kusaka
Kawasaki Heavy Industries, Ltd.

Tohru Kuwahara
Isuzu Motors Limited

Hiroyuki Matsumoto
Mazda Motor Corporation

Inukai Mitsuo
Tokai Rika Co., Ltd.

Toshihito Miyagawa
Toyota Motor Corporation

Kyoichi Miyazaki
Japan Automobile Research Institute

Yoshiyuki Mizuno
Nissan Motor Co., Ltd.

Itsuro Muramoto
Nissan Motor Company, Ltd.

Kosuke Nagao
Ashimori Industry Co., Ltd.

Kenji Nakagawa
Toyobo Co., Ltd.

Akihisa Nakamura
I.A.T.S.S.

Muneo Nishizawa
Takata Corp.

Hideo Obata
CRC Research Institute Inc.

Akihiro Ohtomo
Nissan Motor Company, Ltd.

Katsumi Oka
Honda R&D, Tochigi Center

Shinichi Sakamoto
Suzuki Motor Corporation

Toshiaki Sakurai
Mitsubishi Motors Corporation

Shouichi Sano
Honda R&D Co., Ltd.

Michihisa Sasonoi
Suzuki Motor Corporation

Kazuhiro Seki
Honda R & D

Katsuhiro Sekine
Pyro Safety Device Co.

Iichi Shingu
Toyota Motor Corporation

Teruhisa Sugita
Takata Corp.

Katsunobu Sumida
Toyota Motor Corporation

Norio Sumitomo
Toyobo Co., Ltd.

Keizo Suzuki
Tokai Rika Co., Ltd.

Moriyuki Taguchi
Yamaha Motor Co., Ltd.

Nobuhiko Takahashi
Nissan Motor Company, Ltd.

Hideo Takeda
Takata Corporation

Masatoshi Tanaka
Daihatsu Motor Co.

Toshi Tanaka
Sensor Technology Co.

Katsunori Taneda
Japan Automobile Research Institute

Izumi Tokunaga
Ministry of Transport

Junji Tonomura
Suzuki Motor Corporation

Yutaka Tsukiji
Mazda Motor Corporation

Takahiro Tsuruga
Toghigi R&D Center

Hiroshi Ueno
Nissan Motor Company, Ltd.

Shuji Yamaguchi
Toyota Motor Corporation

Kuniaki Yamakuse
Honda Motor Co., Ltd.

Takenori Yamamoto
Honda R&D., Ltd.

Yugi Yokoya
Toyota Motor Corporation

Hiroshi Yoshida
Mitsubishi Motors Corporation

Keigo Yoshida
Honda R & D Co., Ltd.

KOREA

Youngtai Choi
Korea Auto. Test & Res. Instit.

NETHERLANDS

Anna Agter
Ministry of Transport and Public Works

Hans Ammerlaan
Ministry of Transport

Peter De Coo
TNO Road Vehicles Research Institute

Hans Driever
TNO Road Vehicles Research Institute

Hans Huijbers
Ministry of Transport

Paul Jacobs
Volvo Car BV

Edgar Janssen
TNO Road Vehicles Research Institute

Dirk Landheer
Eindhoven University of Technology

Henk Lupker
TNO Road Vehicles Research Institute

Jaap Maartense
Volvo Car BV

Gerard Meekel
Ministry of Transportation and Public Works
Department of Road Transportation

Yashishi Mizutani
Tokai Rika Co., Ltd.

John Nieboer
TNO Road Vehicles Research Institute

Joop Pauwelussen
TNO Road Vehicles Research Institute

Jan Paul Peters
Yamaha Motor Europe N.V.

Bernard Reys
TNO Road Vehicles Research Institute

Albert Roelfsema
Volvo Car BV

L.T.B. Van Kampen
Institute for Road Safety Research

Carla Van Moorsel
Ministry of Transport

Jan Van Santen
J.P.M. Van Santen Public Relations

Fred Wegman
Institute for Road Safety Research

Jac Wismans
TNO Road Vehicles Research Institute

Willem Witteman
Eindhoven University of Technology

RUSSIA

Serguei Efjmenko
State Science and Technology Committee

Anatolie Ejov
City of Moscow

Vladimir Federov
Ministry of the Interior

Vladimir Fedorov
Inspection D'Automobiles de la Russie

Evgenii Semenov
Foundation for Road Safety

Igor Vengerov
S.T.C.E.C.

Igor Venguerov
Technical Center

SPAIN

Javier Alvarez-Montalvo
Ministry of Industry and Commerce

Mercedes Menendez
I.N.T.A.

SWEDEN

Rune Almquist
Volvo Car Corporation

Roger Alven
Alvatec AB

Sture Andersson
Electrolux Autoliv

Nils Bohlin
Bohlin Consulting/Olstorp

Per Branneby
Saab Automobile AB

Gustaf Celsing
Autoliv Svenge AB

Anders Eugennson
Volvo Car Corporation

Erik Falk
Volvo Car Corporation

Lennart Fremling
Swedish Road Safety Office

L. Yngue Haland
Electrolux Autoliv AB

Soren Hedberg
Swedish Road Safety Office

Jan Holmgren
F.T.S.S.

Jan Ivarsson
Volvo Car Corporation

Goran Kahler
Saab Automobile AB

Janusz Kajzer
Chalmers University of Technology

Birgitta Kamren
Folksam Research

Magnus Koch
Volvo Car Corporation

Maria Koch
Folksam Research

Anders Kullgren
Folksam Research

Tony Landh
Saab Automobile AB

Kas Larsson
Saab Automobile

Stefan Larsson
Volvo Truck Corporation

Thomas Lekander
Swedish Road Safety Office

Anders Lie
Folksam Research

Mats Lindquist
Saab Automobile AB

Per Lovsund
Chalmers University of Technology

Bjorn Lundell
Volvo Car Corporation

Fritz Hugo Martin Mellander
Volvo Car Corporation

Gert Nilson
Chalmers University of Technology

Curt Nordgren
Assoc. of Swedish Auto. Manuf. (BIL)

Hans Norin
Volvo Car Corporation

Anders Ohlund
Volvo Car Corporation

Jan Olsson
Autoliv Svenge AB

Michael Persson
Volvo Car Corporation

Jan Petzall
Chalmers University of Technology

Bengt Pipkorn
Chalmers University of Technology

Kare Rumar
Swedish Road & Traffic Res. Institute
V.T.I.

Lennart Strandberg
Swedish Road & Traffic Res. Institute
V.T.I.

Mats Svensson
Chalmers University of Technology

Sven-Erik Svensson
Volvo Car Corporation

Claes Tingvall
Folksam Research

Thomas Turbell
Swedish Road & Traffic Research
V.T.I.

SWITZERLAND

Robert Kaeser
ETH Zurich

Urs Maag
University of Montreal

Masahiko Naito
Auto. Stand. International Center

Gottfried Treviranus
Universtat Zurich

Felix Walz
Institute of Forensic Medicine

UNITED KINGDOM

Gordon Bacon
M.I.R.A.

John F. S. Bidgood
RAC Motoring Services

Philip Bly
Transport & Road Research Laboratory

Alan Bowker
UK Transport Dept.-Vehicle Inspectorate

Jeanne Breen
PACTS

David W. Burleigh
Britax Excelsior Ltd.

Bryan Chinn
Transport & Road Research Laboratory

Keith Clemo
M.I.R.A.

Laurence Clift
ICE Ergomanics

Anthony Denniss
T.R.R.L.

William H. Dixon
Society of Motors Manufacturers & Traders

Mark Dorn
RSEL, Middlesex Polytechnic

Eric Dunn
Department of Transport

Alan Dyche
First Technology Systems

Nigel Earle
Ford Motor Company, Ltd.

Malcolm Eden
Ford Motor Company, Ltd.

Paul Fleming
Breed Automotive

Geoffrey Fletcher
Ford Motor Company, Ltd.

Alan Randell Giles
Rover Group, Ltd.

K. Goense
Airbags International

John Harris
Transport & Road Research Laboratory

Julian Hill
University of Birmingham

C. Adrian Hobbs
Transport & Road Research Laboratory

Frederick John Hope
Hope Technical Developments, Ltd.

John Anthony Jeyes
U.K. Department of Transport

Christopher Kavanagh
Airbags International

Douglas Kendall
M.I.R.A.

Michael Lewis
Rolls Royce Motors Ltd.

Richard Lewis
Ford Motor Company, Ltd.

Richard Lowne
Transport & Road Research Laboratory

Murdoch Macaulay
TRRL

Murray Mackay
University of Birmingham

John Miles
Ove Arup and Partners

Andrew Morris
University of Birmingham

Pat Murphy
U.K. Department of Transportation

Ian Douglas Neilson
P.A.C.T.S.

Robert Newton
ICE Ergonomics

Rock Nigel
ICE Ergonomics

Muir Parker
First Technology Safety Systems

Steve Parkin
University of Birmingham

Geoffrey Platten
Ogle Design Ltd.

Mostafa Rashidy
Ford Motor Company, Ltd.

Adrian Keith Roberts
Transport & Road Research Laboratory

Brian Robinson
Transport & Road Research Laboratory

Peter Roy
RSEL, Middle Polytechnic

Majid Sadeghi
Cranfield Impact Center

Geoffrey Savage
RSEL, Middlesex Polytechnic

Peter Victor Skuse
Rover Group, Ltd.

Peter Slater
Ford Motor Company, Ltd.

Viv Stephens
M.I.R.A.

Richard Sturt
Ove Arup and Partners

Peter Thomas
ICE Ergonomics

S. Valkenburg
Airbags International

Roger Vingoe
HW Structures Ltd.

John Wall
Transport & Road Research Laboratory

Edmund Ward
ICE Ergonomics

Paul Wellicome
M.I.R.A.

Nigel Wemyss
Ogle Design Ltd.

Christopher Williams
Ford Motor Company, Ltd.

Christopher Witherington
RSEL, Middlesex Polytechnic

UNITED STATES

Steven Anderson
ASL

Kenichi Ando
Jetro New York

Robert Arnold
Motor Vehicle Manufacturers' Assoc.

Robert A. Assunacao
Morgan Melhuish et al.

Thomas Baloga
Mercedes-Benz NA

Douglas Bennett
U.S. House of Representatives

Barry Berson
Hughes Aircraft

Donald Bischoff
NHTSA

Russell Brantman
Breed Automotive

Alex Butt
American Suzuki Motor Corp.

Terence Chorba
Centers for Disease Control - F36

Carl Clark
Safety Systems Company

Robert M. Clarke
NHTSA

Scott Cooper
U.S. House of Representatives

Jerry Ralph Curry
NHTSA

Gregory Dana
Association of International Auto. Manufacturers

Robert Davenport
University of Zurich

George Davis
NHTSA

Bruce Decker
Toyota Motor Sales, U.S.A.

Robert Denton
Robert A. Denton, Inc.

Kennerly H. Digges
University of Virginia

James Donovan
Wilson, Elser, Moskowitz, Edelman, Dicker

Deborah Ederer
First Technology Safety Systems

William Randall Edwards
Chrysler Corporation

Karl-Heinz Faber
Mercedes-Benz of North America

Eugene Farber
Ford Motor Co., Ltd.

Michael Finkelstein
Michael Finkelstein & Associates

David Finnegan
U.S. House of Representatives

John Fleck
J & J Technologies Inc.

Donald Friedman
Liability Research

Thomas Fugger
Kinematics Research

Junichi Fukuda
Honda R&D North America, Inc.

Peter Fuller
University of Louisville

Yoshihiro Goi
Mitsubishi Motors of America

James Hackney
NHTSA

Dietmar Haenchen
Volkswagen of America

Chester L. Hale
American Honda Motor Corp., Inc.

Toni Harrington
Honda North America, Inc.

Philip Hight
Accident Research & Analysis

Ralph Hitchcock
NHTSA

Jan Holgren
First Technology Safety Systems

William Hollowell
NHTSA

Toshio Horiuchi
Nissan Research & Development

Saburo Inui
Toyota Motor Corp, Services of N.A.

Joseph Kanianthra
NHTSA

Joseph Kennebeck
Volkswagen of America, Inc.

Tawfik Khalil
Motor Vehicle Manufacturers Association
GM Corporation

Albert King
Wayne State University

William King
Ford Motor Company, Ltd.

Tadao Kobayashi
American Honda Motor Corp., Inc.

William Leasure
NHTSA

Robert LeFevre
General Motors Corporation

John Leinonen
Ford Motor Company, Ltd.

David Lemmon
University of Cincinnati

Paul Lisovicz
Morgan Melhuish et al.

John Lisowski
Morgan Melhuish et al.

Francois Louis
Renault USA

Richard H. Lucki
PSA - USTR

James Mahern
Honda R&D North America, Inc.

Seiji Matsumura
Kawasaki Motors Corp., USA

Ed Michel
Harley Davidson, Inc.

Manabu Morisaka
Toyota Motor Corp. Services of N.A.

Robert Munson
Ford Motor Company, Ltd.

John R. Musgrave
Coburn, Croft & Putzell

Alberto Negro
Fiat Auto USA, Inc.

George Nield
Assoc. of International Auto. Manufacturers

Satoshi Nishibori
Nissan Research & Development

Linda O'Connor
NHTSA

Brian O'Neill
Insurance Institute for Highway Safety

John Orlando
U.S. House of Representatives

George L. Parker
NHTSA

Helen Petrauskas
Ford Motor Company, Ltd.

Elaine Petrucelli
A.A.A.M.

George Pittara, Jr.
First Technology Safety Systems

Wes Pittman
Vehicle Consultants Inc.

Gordon Plank
R.S.P.A.

Priyaranjan Prasad
Ford Motor Co., Ltd.

Nagarajan Rangarajan
G.E.S.A.C.

Ronald Robbins
Consultant

David Romeo
Romeo Engineering

Anthony Sances
Medical College of Wisconsin

Albert Schlecter
Chrysler Corporation

Greg Schmeling
Harley Davidson, Inc.

Henry Seiff
M.V.M.A.

Tariq Shams
G.E.S.A.C.

William Shapiro
Volvo Cars of North America

Philip Sheets
Kawasaki Motors Corp., USA

Philip Siracuse
American Suzuki Motor Corp.

Howard M. Smolkin
NHTSA

John Snider
The University of Tennessee

Douglas W. Toms
American Honda Motor Corp., Inc.

Frank Turpin
NHTSA

James Ughetta
Wilson, Elser, Moskowitz,
Edelman, Dicker

Chris Von Will
First Technology Safety Systems

William H. Walsh
NHTSA

Ronald Wasko
Motor Vehicle Manufacturers'
Association

Emroy Watson
Yamaha Motor Corp.

Bill Weber
Hughes

David Weir
Dynamic Research, Inc.

Marc Weiss
Naval Biodynamics Lab

Kenneth Yadvish
Lester, Schwab, Katz & Dwyer

Albert Yamada
Masaoka & Assoc.

Narayan Yoganandan
Medical College of Wisconsin

John Zellner
Dynamic Research, Inc.

Karl-Heinz Ziwica
B.M.W.

Volume 1. Opening Ceremonies Thru Session 5
Contents

SECTION 1. OPENING CEREMONIES

SECTION 2. GOVERNMENT STATUS REPORTS

Chairman: Howard M. Smolkin, United States

SECTION 3. TECHNICAL SESSIONS

Technical Session 1: Crash Investigation and Data Analysis

Chairperson: Fred Wegman, The Netherlands

Technical Session 2: Safety Improvements from Advanced Vehicle/Highway Technology

Chairperson: Claudio Schinaia, Italy

Technical Session 3: Specialized Road Users

Chairperson: Kenichi Goto, Japan
Co-Chairperson: Kaneo Hiramatsu, Japan

Technical Session 4: Safety Improvements from Advanced Vehicle/Highway Technology

Chairperson: Bernard Durand, France

Technical Session 5: Side Impact Occupant Protection

Chairperson: Richard Lowne, United Kingdom
Co-Chairperson: Ian Neilson, United Kingdom

Volume 2. Session 6 Thru Session 10
Contents

SECTION 3. TECHNICAL SESSIONS (CONTINUED)

Technical Session 6: Light Vehicle Rollover
Chairperson: William Leasure, United States

Technical Session 7: Crash Avoidance Research

Chairperson: Kare Rumar, Sweden

Technical Session 8: Biomechanics and Dummy Development

Chairperson: Dominique Cesari, France

Technical Session 9: Frontal Crash Protection

Chairperson: S. Christopher Wilson, Canada

Technical Session 10: Heavy Truck Safety

Chairperson: Bernd Friedel, Federal Republic of Germany

Section 1
Opening Ceremonies

Welcoming Address

Jerry Curry, Administrator

National Highway Traffic Safety Administration
Department of Transportation
United States

The date is January 25, 1971, the place is Paris, the event is the First International Technical Conference on Experimental Safety Vehicles. It is appropriate to return to this beautiful and famous city for the 20th anniversary year conference.

Many of us, perhaps most, were not here in January 1971. Yet we are pioneers no less, because we pick up the challenge and move ahead, just as the far-sighted researchers, and engineers, and government managers of that day did.

We have one advantage: Hindsight. We can see and measure progress of the past two decades. We can be comfortable in the knowledge that what we are doing is right.

One of those 1971 pioneers was Robert Brenner, the Chief Scientist for my agency, the sponsoring National Highway Traffic Safety Administration. Dr. Brenner's closing reflections at that first conference included this borrowed quote (and I am paraphrasing).

". . . We should never expect to employ in practice all the motive power of the combustibles used . . . this effort could be more harmful than useful . . . the economy of fuel is only one condition which should be fulfilled . . . . In many cases it is secondary . . . it must often yield precedence to safety . . ." Many people committed to auto safety might have said that, even today.

But these were not the words of a government leader, or an automotive industry official, or even of an advocacy group. No, this was the observation of Jacques Carnot, a Frenchman and a legend in scientific and engineering circles. Today we can still appreciate his insight.

Dr. Brenner of NHTSA also made another statement, a simple declaration of fact pertinent to the times . . . he said: "and then there are 55,000 or more who die every year in the United States in traffic crashes."

Today I can recast that line as follows: And then there are the 45,529 who died last year in the United States in traffic crashes.

Another statement of fact, but a remarkable difference in numbers; the more so when the astounding growth in the totals of drivers, cars and miles traveled is considered.

Winston Churchill said "History will be kind to me, because I intend to write it." We don't need to write anything about the fruits of conferences like this one. We can look at the record and see pure accomplishment in the statistics.

Doug Toms, who held my job in 1971, attended the second ESV Conference and commented: "Now we have a worldwide effort on experimental safety vehicles."

That wasn't quite true. We took steps to correct that this year. We invited the nations of Eastern Europe to USSR participate, and I am gratified that a number of them have accepted . . . Bulgaria, Czechoslovakia, Hungary, and the Union of Soviet Socialist Republics. So for the first time these nations will be able to share in the technical wisdom that flows in such abundance at ESV Conferences. And I am pleased too that Korea also takes part for the first time.

The record of the 1970's and 1980's says clearly that the junction of nations which we have achieved through ESV conferences resulted in a crash-worthy passenger car.

Not a perfect car; we are still experimenting, after all. But a very fine car—a vehicle with improved frontal crash protection, with stronger sides, a friendlier interior and better occupant restraints.

And most of all, restraining systems that rob the crash forces of much of their capacity to kill and cripple.

In the United States only last year we stepped forward again, introducing an improved side impact protection standard that will be tested dynamically; this standard alone will save another 500 lives in the United States every year.

You will talk at this conference about what remains to be done with the car. Rollover propensity for example. And anti-lock brakes, which happily, in America, are becoming a standard item without the necessity of a government requirement.

But another challenge remains on the horizon, waiting to be addressed in depth. Not a new subject, because the failures of the driver have always been recognized as a root problem of vehicle crashes.

When then-U.S. Secretary of Transportation John Volpe asked an early ESV Conference whether industry could design a really safe car that also offered good engine performance, reduced emissions, attractive styling, and susceptibility to mass production at a reasonable price, it was an arrow to the bullseye.

Now we have a new target. I pose the query this way: Can we design a really safe driver, one capable of dealing with any traffic emergency, and unexpected situation? Can we snatch a crash-bound driver from the jaws of tragedy?

Might we call this driver an ESD—an experimental safety driver, symbolic of the search for crash-free operation? Of course we can't achieve perfection, but we can reach for it.

The course of major research in the 1990's should, in our view, be directed to making *drivers better*. Be cautious with my phrase. I didn't say making *better drivers*. Although the attempt to raise driving skills through training and education remains a desirable objective.

The massive effort mounted to reduce impaired driving has been demonstrably effective, for example. But making drivers better is an entirely different art form, almost a new frontier, accommodating the machine to the human, rather than vice versa.

The time is here to acknowledge that drivers inevitably make mistakes. The error-free driver is beyond our scope. But the virtually crash-free driver may be within the probable realm if we can extend the right kind of helping hand.

The 1990's and beyond will be the era of electronic intervention, the insertion of an automatic warning or response to avert a crash situation before the driver finds himself in the web of disaster. This sounds like electronic legerdemain, but there will be no magic short of long and painstaking research in what we now call "Intelligent Vehicle Highway Systems."

Measuring the human capacity to absorb the wizardry of the special sensors, and monitors, and braking and steering overrides, and a potential multiplicity of dials and gadgets presupposes the human factors research that determines whether humans will be helped or hurt by a specific device.

Another facet, then, is creating a realistic experimental environment where real people are cast into real highway situations fraught with danger—yet absolutely without hazard.

This will be the role of an advanced driving simulator. which we are studying in the United States. Technology will promote the cause of safety only with disciplined application, and the simulator may give us that disciplined approach.

The ultimate benefits appear clearly worth the investment, an extra half-second's warning of imminent danger can reduce rear-end and intersection crashes about half; as well as 30 percent of crashes with oncoming traffic.

Extend the added warning time to a full second, and approximately 90 percent of the crashes can be avoided. All of this has relevance for every driver in every nation. But it perhaps has the particular appeal of helping the older driver. In the United States the proportion of older drivers is expanding.

Older drivers experience known physiological changes that affect vision and reaction time, for example. But not at the same rate, and not necessarily at the same age.

Perhaps the extent of the driving privilege, carefully sculpted as to type and range, could virtually be prescribed for the individual, based on demonstrated capabilities and limitations.

"Limitations" is the key. Eliminate them, or compensate for them. How to do that becomes the research challenge for the 1990's.

Through the ESV prism we see car and driver as a paired entry on one side of the safety equation. Solving for safety inevitably requires a melding of car and driver in a tandem solution. That's what IVHS and simulation should offer motorists of the world.

These ESV conferences in my experience have been one of the most exceptional information exchanges in the auto safety marketplace. People bring good ideas and take away good ideas. They listen.

Very much the opposite of the psychiatrist who at the end of the day always looked as bright and cheerful as he did first thing in the morning.

A colleague asked him how he could sit hour after hour listening to all those horrible problems and still look so good at 5 P.M. The psychiatrist replied: "Who listens?"

We have no non-listeners here, and plenty of excellent talkers. I know this will be, as always, a superb conference.

Keynote Address

Jean-Michel Berard
Minister of Delegation for Road Safety
Arche de la Defense
France

I am pleased to open this Thirteenth International Conference on Experimental Safety Vehicles, which is being held in Paris for the third time, and to welcome you to Paris and to this Science and Industry complex, which I view as a place ideally suited to your work.

I wish to thank all those who assisted with the preparations for this conference and who will ensure, in the days ahead, that it proceeds smoothly and is a complete success.

The improvement in the design and equipment of vehicles clearly constitutes an essential factor for progress in the area of road safety. For this reason, the French Government, in conjunction with its EEC partners, is making a concerted effort to encourage research in this field and the earliest possible incorporation of the findings in standard vehicles.

Reducing unsafe road conditions can only be viewed today in the context of a comprehensive approach that takes into account the entire driver-vehicle-traffic-infrastructure system. Indeed, it is important for technological innovations to be designed and optimized based on the road situation and the actual behavior of users. Therefore, modern communications technology applied to vehicles must permit us to increase considerably the number of parameters taken into account to improve analysis of driving situations and to ease the burden placed on drivers by the great increase in driver-controlled mechanisms. If one considers all the parameters that need to be known at all times and all the functions that the driver must control in real time, it is clear that he is incapable, in most emergency situations, of evaluating correctly what action to take or how to handle the vehicle accordingly. Automatic steering must provide a response in these cases of driver failure.

Other than these extreme cases, adapting to real driving behavior must be an ongoing concern of all research. The topics addressed at this conference demonstrate that this approach is now an important area of interest in your discussions.

Moreover, it is encouraging to note that the research conducted in Europe within the framework of the EUREKA program is beginning to be applied to experimental vehicles suitable for driving, some of which will be on display this week.

Presentation of Research Policy

A very large number of research projects have been developed in recent years with a view to improving the safety of vehicles, such as, in particular, the PROMETHEUS program, which was started by the makers of European automobiles within the framework of EUREKA. Others include the DRIVE program of the Community and the DRIVE 2 program, which is still being defined. Lastly, there is the French program "Safe Vehicles and Road Safety" which the French Government has just approved.

The PROMETHEUS program has studied and developed numerous functions capable of improving safety, by warning the driver of a possible loss of control or collision, by providing assistance in difficult situations, or by improving opportunities for emergency calls.

An initial phase that demonstrates the technical feasibility of these different functions has been completed and European car makers demonstrated these functions for the first time very recently in Turin. The exposition illustrates these new possibilities, particularly with respect to PEUGEOT-CITROEN cars.

Even more recently, the Commission of the European Communities launched a large-scale "Drive 2" call for bids for a project to test the technical feasibility and public acceptance of new provisions aimed at more efficient and safer management of road traffic. The managers of the French infrastructures have, by and large, responded to this call. The final results are still unknown, but we think that several experiments involving urban and inter-urban traffic will be conducted in France. The French Government will fully support these operations and will carefully follow up on and evaluate them, with a view to determining the most attractive options and adopting the policies necessary for their implementation. I am pleased that, for the first time, a technical session is being devoted to this important matter.

The gains to be expected with respect to primary safety should not overshadow the research aimed at improving the passive safety of vehicles. Progress in the design of structures and the characteristics of materials make it possible to improve the protection of occupants from frontal and lateral impacts. Making optimal use of protective devices is important. The "COVER" experimental safety vehicle, presented by RENAULT, provides an example of new possibilities for the protection of occupants at speeds of impact higher than those tested on the basis of current regulations.

The objectives of the new French program entitled "Safe Vehicles and Road Safety," which is based on more detailed studies on accidents, are even more ambitious. State-of-the-art experimental vehicles will illustrate the actual possibilities explored by research. Greater compatibility will be sought between the different types of vehicles, with a view to making protection inside vehicles and their external damage resistance potential as effective as possible.

A specific program will be devoted to trucks. The object is to improve the dynamic stability of truck-and-trailer combinations and seek ways to reduce the damage potential of the trucks. Finally, research will focus on socio-economic questions with a view to better understanding the role of new technology in relation to the real needs of drivers. I hope that this new program prepared by PEUGEOT-CITROEN, RENAULT, and INRETS within the framework of PREDIT will lead to rapid and concrete results, thereby ensuring the completion of a significant phase.

This effort, which is quite exceptional with respect to research, will be maintained, of course, by important progress in the area of industrial and regulatory plans aimed at reducing unsafe road conditions in France.

Industrial and Regulatory Matters

It is therefore clear that since the last ESV conference, great progress has been made with respect to research in all sectors pertaining to road safety, and the scope and variety of the programs already undertaken bode well for the continuation of this progress. The effective improvement of safety on our roads is linked to the application of the findings of this research, which implies joint action between car makers and public entities.

I note with interest that, for the first time, matters pertaining to the modern methods of linkage between the road and vehicles appear on the program of this conference. In fact, I believe that in the past, this conference devoted attention to matters linked to passive safety, while safety involves, first and foremost, an effort to avoid accidents.

From this perspective, I think it necessary to address the question of speed.

There can be no consistent road safety policy without a policy on speed. This applies to both active and passive safety. Speed is also an issue in considerations regarding the emission of pollutants, in particular gases contributing to the greenhouse effect, and energy consumption. I therefore think it necessary to define an international approach to this problem soon and, in the interest of efficiency, I think that it would be appropriate to begin with trucks, for which the problem is the most serious and the solution well under way at the international level. In this area, with the electronic steering systems of Diesel engines, speed limiters that are totally integrated into the engine can be envisioned in the near future. In other words, they would be foolproof, would ensure optimal fuel economy, and would minimize polluting emissions in the actual traffic conditions of vehicles.

Given this fact, improvements envisioned in the active safety of vehicles will not succeed in eliminating all road accidents, and it is therefore necessary to employ strategies used for a long time to protect occupants of vehicles in cases of impact.

In this regard, it would be appropriate to build in a system of protection for occupants in the case of lateral impacts and to improve the protection of occupants in the case of frontal impacts.

The formulation of up-to-date regulations on lateral impacts has been long and complex. It was recently achieved in the United States and is in the process of being successfully completed in Europe. It is clearly desirable for American and European methods to be harmonized over time, when sufficient experience is gained regarding their application and the progress that can reasonably be expected with respect to new models has been achieved. I am certain that this question will be one of the most important on the agenda of the Fourteenth ESV Conference.

For protection in cases of frontal impact, Europeans have long believed that seat belts are essential and that wearing them should be mandatory under all circumstances and wherever possible. The findings of studies of actual accidents show that the protection offered by seat belts is excellent in the case of small crashes, very good in the case of moderate crashes, but inadequate in the case of more serious crashes. For this reason, numerous innovations have been presented or will be presented by car makers in the months to come, with a view to offering added protection. I have in mind in particular a new design of the air bag that is specially made for the European market and adapted to small and medium-sized cars.

These quite important technological changes have been developed spontaneously by car makers. This proves that safety has become an important marketing feature. The time has now come to change the regulations, taking into account these innovations, and to define the adapted technical and administrative framework that permits actual safety to be improved with the greatest international openness.

Therefore, this Thirteenth International ESV Conference is opening under the best circumstances, and I earnestly hope that the work that will be carried out this week will be as fruitful as it promises to be.

Awards Presentations

Awards for Safety Engineering Excellence

Chairman: George L. Parker

In recognition of and appreciation for extraordinary contributions in the field of motor vehicle safety engineering and for distinguished service to the motoring public.

Federal Republic of Germany

Josef Haberl
BMW AG

Since 1977, Mr. Haberl has been dedicated to improvement in the area of occupant protection. He was an essential part in the development of the first BMW air bag system. Mr. Haberl and his department were decisive in promoting safety devices such as the ergonomic rear restraint system, automatic belt height adjustment, the seat-integrated belt system, and the mechanical belt pretensioner resulting in simplified handling, increased comfort and ultimately a higher usage rate. All systems have led to a more efficient restraint function during the crash and have contributed to a remarkable increase of occupant protection in real traffic accidents. Mr. Haberl is deserving of particular recognition.

Dr. Dimitrios Kallieris
University of Heidelberg

Dr. Kallieris has been associated with the Institute of Forensic Medicine at the University of Heidelberg since 1969. His early research efforts included quantification of the mechanical loading and failure characteristics of a variety of human tissues as well as the development and construction of an automotive crash simulation facility at the Institute. Dr. Kallieris has conducted more than three hundred biomechanical impacts using the Institute's crash simulation facility investigating the human automobile occupant's interaction with a variety of restraint systems in frontal impacts, the quantification of response and injury of humans in side impacts, and the impact response of pedestrians during vehicular collisions. For all his efforts, Dr. Kallieris is recognized.

France

Nelson Casadei
Renault

Mr. Casadei has worked in the field of automotive safety engineering for 22 years. He leads Renault's crash testing department. Significant contributions have been made in crash precision, reproducibility of tests, and results reliability. Renault has produced three Experimental Safety Vehicles within the last 20 years due to the performance of Mr. Casadei and his engineering group. For Mr. Casadei's contributions and that of his engineers in the field of crash test methodology, special recognition is given.

Jean DeRampe
Peugeot Sa

Mr. DeRampe's commitment to automotive safety engineering has been clearly demonstrated since 1972, when he began work for Peugeot to develop occupant protection in side impact crashes. His work has taken him into the field of passive restraint systems for rear seat occupants. He has also shown it is possible to build a small, fuel efficient car while protecting occupants and pedestrians. Mr. Derampe is deserving of special recognition for these occupant protection accomplishments.

Francis Ferrandez
INRET'S

Mr. Ferrandez has contributed to the development of a "diagnosis analysis" method focusing on how an accident happened and explaining its occurrence and severity. He is also responsible for a more comprehensive procedure involving the analysis of accident mechanisms specifically dealing with primary safety and covering various aspects of the driver/vehicle/road system. For his contributions to vehicle safety, Mr. Ferrandez is recognized.

Michel Kozyreff
Electrolux Autoliv

Mr. Kozyreff has carried out numerous research and feasibility studies involving safety belts and air bags for frontal and side impacts. All safety restraint systems recently installed in motor vehicles by French car makers were developed by Mr. Kozyreff and his R&D team. Mr. Kozyreff has strongly supported the air bag concept among French motor vehicle manufacturers since 1985. He has been an active supporter of the Eurobag. Recognition is given Mr. Kozyreff for his overall contributions in the area of safety restraints.

Italy

Dr. Ing. Paolo Scolari
Fiat Auto S.p.A

Dr. Scolari has been responsible for Fiat Auto Engineering since 1970. Dr. Scolari manages and coordinates all research/development and design activities concerning new company models, paying particular attention to both active and passive safety. In addition, he has given unrelentless dedication to the safety of motor vehicles in the area of small size and weight. Dr. Scolari is recognized for his varied contributions to automotive engineering safety.

Japan

Namio Irie
Nissan Motor Co., Ltd.

Mr. Irie is a pioneer in vehicle safety research and development of advanced chassis technology for Nissan. In 1971 he was in charge of Nissan's ESV program for vehicle layout planning, as well as the R&D activities concerning seat belt and air bag occupant protection systems. Subsequently, in the development of a safety concept car, he was instrumental in advancing research in vehicle handling and safety, and the driver-vehicle system from the standpoint of crash avoidance safety. Through this work he played a key role in establishing basic foundations for research in vehicle dynamics. In addition he has also been vigorously involved in research on active chassis control, bringing about major innovations in vehicle safety performance. We acknowledge Mr. Irie's outstanding achievements.

Yutaka Kondo
Toyota Motor Corporation

Mr. Kondo has been actively involved in research and development of vehicle safety technology since 1963. In 1977, he made a major contribution to the development of the Duplex Emergency Locking Retractor System for safety belts and has been especially active in the development of air bags. He displayed outstanding leadership in organizing a consortium of manufacturers for the technical development and merchandising of air bags. He was a major contributor to the electronic air bag system on the 1989 Lexus LS 400, the first air bag to be adapted to a tilt and telescopic steering column. Mr. Kondo is deserving of this special recognition.

Katsumi Oka
Honda R&D Co., Ltd.

Mr. Oka is recognized for his contributions to the improvement of crashworthiness of Honda production cars, especially in the body structure. One of his achievements is the establishment of the body structure for small and light vehicles with excellent crash performance at a speed of 35 mph. Mr. Oka has actively promoted the development of unique occupant protection devices such as the Honda Pretensioner and Honda's passenger side air bag. He leads the development of an all aluminum vehicle body structure which is crashworthy. Through his many achievements, Mr. Oka has contributed greatly to the improvement of automotive safety.

The Netherlands

Prof. Dr. Jac Wismans
TNO Road-Vehicles Research Institute

Since 1978, Dr. Wismans has worked in the field of injury biomechanics and passive traffic safety at the TNO-Road Vehicles Research Institute. Dr. Wismans actively promotes the contribution of injury prevention by the improvement of safety in road traffic and he supports international cooperation in these fields. He has been a strong motivator of the use of mathematical simulation in injury prevention research. Under his supervision the MADYMO crash victim simulation program has been developed into a successful research and development tool, which is now used worldwide by research institutes, manufacturers and other organizations.

Sweden

Magnus Koch
Volvo

Mr. Koch is Principal Scientist at the Volvo Automotive Safety Center. His work covers a diversity of disciplines such as vehicle test transducer and measurement systems technology, computer applications for test data acquisition, stereo photogrammetry, crash test dummy development and use, test data evaluation and experimental statistics. His work and knowledge have been instrumental in the development of several ISO Standards and the development of a crash recorder for installation in cars. He has been mentor for a number of students from Chalmers University of Technology who do projects or thesis work in the industry, increasing the awareness of safety technology at the engineering schools ultimately benefiting automotive vehicle safety. Mr. Koch is to be commended for his dedication to furthering the advancement of motor vehicle safety.

Olle Nordstrom
Swedish Road and Traffic Research Institute

Since 1960 Mr. Nordstrom has been involved in research at the Swedish Road and Traffic Research Institute dealing with vehicle dynamics, brakes, and tires. He has been responsible for many studies on braking and handling over the years including research on the braking and handling performance of car/trailer combinations, antilock braking performance, influence of brake imbalance on performance stability of heavy vehicle combinations and heavy vehicle antilock braking performance. Much of his work resulted in proposed or adopted regulations.

Mr. Nordstrom was also involved in the Swedish RSV program. Mr. Nordstrom was project manager for the construction of a large test facility at VTI for testing steering and braking characteristics of truck and passenger car tires, especially on ice. For his contributions to motor vehicle safety over a long period of years, Mr. Nordstrom is deserving of special recognition.

United States

Dr. Priya Prasad
Ford Motor Company

Dr. Prasad has accomplished significant engineering research. Dr. Prasad pioneered extensive spinal research which is presently used in the designs of aircraft ejection seats and vehicle occupant restraint systems. He has conducted important research on head injuries resulting in formulating the risk of head injury as a function of the Head Injury Criteria (HIC). He conducted pioneering research on the injury potential of out of position occupants during air bag deployment. Dr. Prasad has analyzed a number of structural math models which, have led the worldwide auto industry to adopt standardized data sets for modeling crash test dummies and have also resulted in improvements to publicly available crash simulation software.

Ronald S. Zarowitz
Chrysler Corporation

Mr. Zarowitz conceived and managed Chrysler's Integrated Child Seat program working with engineers Matthew E. Dukatz, Fred C. Kresky, Jeffrey T. Lambert, James P. Lezotte, Robert W. Murphy, and George S. Popa, who were responsible for the design and execution of this major advance in child restraints, which is expected to set a world-wide trend among automobile manufacturer's. The Integrated Child Seat represents a significant improvement in providing a convenient and effective child restraint system, which will increase usage and benefit thousands of children and their parents. Mr. Zarowitz and his team of experts are commended for their advancement of child restraint occupant protection.

Special Awards of Appreciation

In recognition of and appreciation for outstanding leadership and extraordinary contributions in the field of motor vehicle safety.

United States

Dr. Leonard Evans
General Motors

Dr. Evans as a research scientist has contributed significantly to the understanding of factors influencing automotive safety. During the 1970s he conducted pioneering observational research on driver risk-taking by vehicle following distances and with safety belt use. In the 1980s he developed methods of crash data analysis that have objectively quantified the life-saving effectiveness of occupant restraints, the importance of vehicle mass and seating position, and relative risk differences due to occupant age, gender and alcohol use. Dr. Evans' research is internationally respected.

Karl-Heinz Faber
Mercedes-Benz of North America, Inc.

Mr. Faber has played a key role in bringing to the United States market significant safety features such as the Mercedes-Benz Supplemental Restraint System and Anti-lock Brakes as standard equipment, as well as the industry's first automatic rollover bar for convertibles. He has championed programs to promote Europe's PROMETHEUS highway safety project and did pioneer work in bringing about cooperation between that program and the emerging U.S. Intelligent Vehicle/Highway Systems initiatives. For these and numerous other contributions to motor vehicle safety and for his outstanding managerial leadership in this field Mr. Faber is especially recognized.

Section 2
Government Status Reports

Chairman: Howard M. Smolkin, United States

Commission of the European Communities

Daniel Verdiani
Directeur General
Direction and Generale III

Introduction

Mr. Chairman:

I wish to thank you, on behalf of the Commission of the European Communities, for the invitation to submit to this conference the activity report of the European Community on motor vehicle safety.

We are grateful for this opportunity to report, to this unique gathering of experts from the world over, on the achievements and the future goals of the various Community policies affecting the improvement of highway safety. These areas of concern are basically our policy with regard to completing the internal market, and our transportation policy.

EEC Motor Vehicle Type-Approval

As you know, the number one European Community objective is the completion of its internal market, in order to ensure the free circulation of persons, goods, capital, and services.

In the motor vehicle sector, this task will be implemented by establishing the EEC motor vehicle type-approval system, which is scheduled to become operational on January 1, 1993, and become mandatory, after a three-year trial period, beginning in 1996, for any new type of vehicle sold in the Community.

Aside from its economic impact, the EEC type-approval will at the same time contribute significantly to the improvement of not only road safety, but of the environment as well. Indeed, the 1985 Single Act requires that the Commission establish a high level of protection as the basis for its proposals on the harmonization of member-state laws on health, safety, and environmental protection.

Full harmonization will ensure that the strict technical standards set forth in the Special Directives for the type-approval procedure will be applied throughout the member States without exception.

Most of the Special Directives that are a part of this type-approval procedure have been adopted. Those relating to tires, safety glass, weight, and dimensions, and those concerning speed limiters for commercial vehicles and buses, hitching devices for tow trucks, and commercial vehicle cabins, are at a fairly advanced stage in the Community decision-making process.

Existing special guidelines are updated on a regular basis in accordance with technical progress achieved in this field, to ensure the high level of protection required.

Since the last ESV Conference, amendments have been incorporated into the requirements of the Directives on Breaking; installation of seat belts; conduct of the steering mechanism upon impact; the rear field of vision; and the lateral protection of commercial vehicles.

To supplement the Community regulations in the area of medium-term vehicle safety, the Commission is working on several projects; I shall mention only two of them, which shall be the subject of reports submitted during this Conference: the protection of the most vulnerable segment of the road user population; and the protection of vehicle occupants in case of lateral impact.

The Commission relies essentially on two approaches when it establishes the technical bases for its Directives. First, it obtains the expertise available in the member States and from the specialized agencies, industry and consumer organizations, particularly with the assistance of groups of experts in which all fields are represented, such as the group that has earned a reputation, even within the EEC, under the acronym "ERGA-Safety".

In addition, the Commission initiates, as necessary, specific research programs which it usually coordinates and, to a great extent, finances.

One such program was called "BIOMECANIQUE" (1978-82), which was followed by a program to develop the "EUROSID" testing dummy, completed in December 1986.

More recently, we participated in an international research program on improved protection of vulnerable users, pedestrians and cyclists, from impact with automobiles, and we are preparing to join an international program to compare various options with regard to lateral impact testing to ensure coordination and evaluation of results.

Transportation Policy

In addition to the regulations on vehicle manufacturing, the Community is making, and will continue to make, an even greater contribution towards improving highway safety through its transportation policy.

The Community institutions, its Parliament, Council, and Commission, confirmed in a 1985 resolution that road safety was an essential aspect of EEC transportation policy. And let us not forget that 1986 was proclaimed European Highway Safety Year.

Important accomplishments either made or proposed under this policy include Community guidelines in the following areas, among others:

- weight and dimension of commercial vehicles;
- European driver's license;
- periodic inspection of vehicles in service;
- limiting the speed of commercial vehicles;
- wearing of seat belts;
- measures against drunk driving.

Furthermore, this policy allows the Community to promote research projects such as the creation of a European data base on highway accidents, not to mention the "DRIVE" and "PROMETHEUS" programs that should contribute significantly to the improvement of road safety.

In order to ensure a foundation for future road safety efforts, the Commission recently asked a group of high-level experts to draft a report identifying areas of necessary and feasible Community action. This report contains numerous suggestions on measures that can be taken with respect to both vehicle construction and road traffic. On the basis of this report, the Commission will draft appropriate proposals and submit them in due time to the Council and the Parliament.

Relations between the EEC and Other International Organizations

I cannot conclude my report, Mr. Chairman, without mentioning the Community's relations with other international organizations in the area of safety regulations.

Although our priorities are focused on the internal market, we do not ignore the broader context which efforts to improve safety both require and deserve.

The Chairman of the European Experimental Vehicle Committee has just referred to the excellent cooperation that has existed between the Commission and this important scientific institution since its creation.

The above-mentioned Committee has successfully counseled us in our establishment and scientific management of the BIOMECANIQUE and EUROSID programs. I hope that such cooperation will continue and increase when it becomes necessary to establish highly technical international regulations such as those regarding the performance of vehicles when subjected to frontal and lateral impacts.

The United Nations Economic Commission for Europe in Geneva is for us the ideal forum for comparing the experiences of lawmakers and industrialists representing the world's economic blocs.

The Commission is an active participant in the work of group of experts WP 29, which keeps it informed on its own activities, and will also participate as necessary in the study programs initiated by WP 29, such as the program on the lateral impact test.

In this perspective, we hope that the revision of the 1958 Agreement will allow the European Community to accede to it as it is, and that this Agreement will be open to all countries throughout the world interested in vehicle safety.

Finally, I should like to mention the European Economic Space, which as you know was the subject of a recent agreement between the Community and the European Free Trade Association, and which will soon make it possible to unite these two economic blocs in the area of interest to us here, among others.

Conclusions

Mr. Chairman, I hope that I have succeeded in providing to this esteemed Conference, to which I offer every wish for deserving success, a comprehensive overview of the activities of the European Community in this domain.

Thank you for your attention.

Germany

Karl-Friedrich Ditsch

Ministry of Transport

Twelve years ago the 7th ESV Conference was held in Paris. On this present occasion, too, we were pleased to accept the kind invitation of the French Government to come to Paris, and I am particularly honoured to present my government's status report for the 13th Conference.

The Unification of Germany

Since the last ESV Conference, the chief political event for the Federal Republic was the unification of the country on 3 October 1990. On this date the German Democratic Republic became an integral part of the Federal Republic of Germany. Federal German law also came into force in the former German Democratic Republic at this time. Exceptions and transitional arrangements have been introduced to alleviate the problems which this event was expected to create. A number of transitional arrangements have also been introduced in the field of road traffic. Different regulations apply for instance to maximum speeds on motorways (100 km/h/130 km/h recommended speed) and other roads in non-built-up areas (80 km/h/100 km/h). There will also be a difference in the maximum permissible blood alcohol content (0 mg/80 mg per 100 ml) for a transitional period. One factor of importance to the vehicle owner is the fact that a number of vehicles will need to be retrofitted with rear seat belts, hazard warning systems and uniform tyres before their general inspection. Warning triangles and first aid kits will also have to be carried. The Regulations Governing Third Party Motor Insurance and the Act Governing Motor Vehicle Tax have also been in force since the start of the year.

Legislation Governing Road Traffic

The trial introduction of 30 km/h zones which was outlined in the Federal Government's last status report and which was intended to increase road safety has proven successful, the appropriate provisions for such being incorporated into the German Road Traffic Regulations on 1 January 1990. Numerous towns and cities have since introduced 30 km/h zones in residential areas lying outside networks of major roads, legal regulations often being accompanied by structural measures. Similarly "traffic-restraint" zones can now be established in commercial sectors and speed limits of less than 30 km/h can be imposed. Such steps are envisaged in particular for areas of historical interest in order to keep the number of traffic signs at an acceptable level.

The last status report also outlined a "fewer traffic signs" model, and this has now been successfully concluded. As a result of this work, a new guideline has been drawn up by the Federal Ministry of Transport which is intended to assist municipalities and local authorities in improving the marking of roads. The measures are directed in the main at reducing road marking for stationary traffic and at improving signposting.

The Ordinance Governing the Transport of Hazardous Goods by Road has been improved following a serious tanker truck accident in Herborn in 1987. In an effort to enhance active safety, the brake systems of heavy vehicles carrying hazardous goods must, as of this year, be fitted with an anti-locking system (ALS), automatic adjusters for brake lining wear and heavy-duty retarder systems which function independently of the service brake. The Federal Government is also looking to anchor these requirements in the European Agreement Concerning the Carriage of Hazardous Goods by Road which applies for international traffic.

Buses are still the safest form of transport for their passengers. The automobile industry has helped to revise the ECE regulations and to incorporate them into EC legislation. It was possible for the most part to adopt the regulations applicable in the Federal Republic for power-operated and automatic passenger doors. Further EC directives for buses will incorporate regulations governing the strength of seats and seat anchorages and the fire behaviour of materials used in the passenger compartment. The German Vehicle Code also states that bus passengers can only be transported lying down if they are adequately protected by restraining devices.

Changes to road traffic legislation involved changes to individual provisions of the Vehicle Code and adaption of national regulations to EC directives and ECE regulations. Particularly worthy of mention are the change in the maximum permissible length of semi-trailers to 16.5 m, changes in certain axle loads and laden weights, fitting of certain vehicles with lateral protectors including obligatory retrofitting of vehicles already on the road, an obligation on the part of other vehicles to fit wide-angle rear-view mirrors and additional lamp mirrors and to increase the minimum tyre tread to 1.6 mm.

Accident Statistics

An examination of accident trends must make a distinction between the area of the Federal Republic before 3 October 1990 and that of the five new federal states.

In the Federal Republic as it existed prior to this date the number of road traffic accidents over the period 1988 to 1990 remained virtually unchanged at around 2 million. This must be seen against an increase in vehicle travel of 8%.

The number of road fatalities has fallen by more than a half since 1970 while the number of vehicles on the road has increased from 18 to 37 million over the same period and vehicle travel by 97%.

The number of fatalities attributable to road accidents in the Federal Republic (excluding the new federal states and Berlin (East)) came to approx. 8,200 in 1988 and roughly 8,000 in 1989. The total of approx. 7,900 fatalities in 1990 represents the lowest figure since 1953. The number of passenger car occupants killed of roughly 4,500 in 1990 was about as high as it had been in 1988. The corresponding figure for 1989 was around 4,350. The renewed increase is probably attributable to the opening up of the inner-German border.

Accident trends in the five new federal states need to be examined separately after German unification in October 1990. Some 1,600 fatalities were registered on this territory in 1988 and around 1,800 in 1989. This figure for 1990 climbed to approx. 3,150. Compared with the year before (roughly 600 passenger car occupant fatalities), the number of car occupants killed almost increased threefold in 1990. There are many reasons for the rise in fatalities in the new federal states: an enormous increase in mobility, a large growth in the number of (what were by former standards) high-power vehicles on the road, a substantial increase in the number of inexperienced drivers, particularly younger-generation drivers, the change in social values and the removal of intensive police traffic monitoring, inadequate traffic infrastructure (in terms of both structural and safety aspects), etc.

Accident Research

The activities of the Federal Government, the automobile industry and motor insurance companies are once again prominent in the field of accident research. The efforts and advice to improve rear signalling, particularly as regards increased conspicuousness of braking signals, have been continued. Important aspects currently under discussion include increasing the light intensity, prohibiting combined tail and brake lights, a possible minimum distance of 100 mm between the two signal lighting areas and the fitting of a third central brake light. A braking prewarning system is currently being discussed which will give an earlier warning of a braking vehicle.

Headlight systems have seen continuous improvement over recent years. Systems employing electric discharge lamps are in the process of being tested.

Additional lateral turn indicators to protect cyclists when heavy vehicles are turning off are to be employed for both new and existing vehicles with a maximum design speed exceeding 32 km/h and a length of more than 6 m. The Federal Government is endeavouring to bring about a uniform solution throughout the EC.

As regards governmental accident research, a number of projects have been performed in close cooperation between government agencies, the automobile industry and other research bodies.

At-the-scene accident investigations have been continued using the modified random sampling method described at the last conference. Special analyses of these data have been performed e.g. for assessing the effectiveness of head rests, for designing a pedestrian-friendly vehicle front, for analyzing injuries to vehicle occupants wearing seat belts and for assessing the effectiveness of individual sets of measures envisaged in the PROMETHEUS Programme.

The Federal Ministry of Research and Technology (BMFT) continues to lend support to research and development projects designed at improving passive and active safety.

The EUREKA project PROMETHEUS continues to form a pivotal point of the promotional activity. PROMETHEUS is concentrating its efforts on developing intelligent systems to assist drivers. In addition to such aspects as environmental considerations and the reduction of transport costs, the primary goal is to achieve an increase in active safety.

The necessary studies are being performed in the main using the PRO-GEN scientific subprogramme. A PRO-GEN safety group has been set up to satisfy the high demands placed on safety in the PROMETHEUS project. Primary areas of activity to date have included the drafting of a safety check list and studies into the influence which the PROMETHEUS functions have on safety. Reports on these topics will be presented in the technical sessions.

Trials of the ALI-Scout route guidance and information system (project named: "LISB—Leit und Informationssystem Berlin") under real traffic conditions in Berlin ended in March 1991. These trials were intended primarily to demonstrate the technical feasibility and operability of the system, its acceptance by drivers, the benefits for traffic technology and its cost-effectiveness.

The effects of route guidance recommendations on local and non-local drivers are also being dealt with. This is intended to ensure that indicators inside the vehicle in no way result in any reduction in the level of safety.

As regards the safety aspects of transporting hazardous goods, the successful completion of the development work and trial testing of the TOPAS safety tanker truck has seen a consistent continuation of the BMFT's promotional policy in the form of the THESEUS project (Tankfahrzeug mit hochst erreichbarer Sicherheit durch experimentelle Unfallsimulation = Tanker truck with maximum safety attained through experimental accident simulation). The results of TOPAS were reported in detail at the last ESV Conference.

A primary aim of THESEUS is to examine the safety of the tanker truck in its entirety, its individual components and safety devices, the types of accident it is involved in and the other road users it is involved in accidents with. For the first time, systematic and reproducible studies will analyze the safety standard of different vehicle designs and concepts and enable these to be evaluated. The trials revolve around systematic and reproducible crash tests between tanker trucks and other trucks. This is an area about which there is still little known worldwide.

The results of the studies will make a vital contribution to increasing the safety of transporting hazardous goods by road, and in particular to providing new information on the requirements on such vehicles which are essential in safety terms and advisable from an economic standpoint. The project may also be able to demonstrate the safety benefits of special design structures. Further details of this project and its current status will be given in one of the technical sessions.

The safety of today's coaches has been analyzed in the SMARAKD project (Sicherheitsmassnahmen am Reisebus an kritischen Details - Safety measures relating to critical details of coaches). The study, which has now been concluded, made a detailed examination of all factors influencing the safety of buses. By performing detailed, uniform analysis and evaluation of various accident surveys, it has been possible to make a contribution to the development of new and improved safety concepts for coaches.

The Federal Ministry of Transport has continued its extensive research work in all fields. The Federal Highway Research Institute (BASt) is playing a major part in this work.

The ECE and EC have drafted a test method which is designed at protecting the occupants of passenger cars in the event of a lateral collision. This test method, which employs a full-scale vehicle test, has been the subject of numerous reports. Efforts are currently under way to determine whether the composite test method, which is proposed by industry and takes the form of a computer-aided laboratory test, is equivalent to the integrated impact test.

The Federal Highway Research Institute is participating in crash tests as defined by American Standard 214 in order to determine whether the EUROSID dummy is an equivalent alternative to the SID dummy for use in the lateral impact test. The EEVC is presenting three reports on this subject in the technical seminars at this conference.

As reported at the last ESV Conference, the EC has supported a research project for developing a test method for pedestrian protection. Within this international project, the Federal Highway Research Institute was assigned the task of analyzing contact between the head and the front hood. Since the biomechanical basis for drawing up a test method was insufficient, appropriate tests were initiated which had the specific goal of resolving this problem and which will be used for future test series with a hydraulic impact device. A separate report will be given at this conference on the expanded proposal.

The studies to determine the influence of corrosion on the changed behavior during impact have been continued. The structural behaviour is currently being examined using vehicle types which are 5 to 6 years old and which have undergone modern series anti-corrosion treatment.

In conjunction with the automobile industry and the Technical Inspection Agency Rhineland (TUV Rhineland), the Federal Highway Research Institute has, for the time being, completed its work on a draft EC directive to protect belted occupants of passenger cars on impact with the steering wheel. Values of 80g/3ms and a maximum acceleration of 120 g were taken as criteria for assessing a rigid head impacter. These values are also contained in a proposal for changing the ECE regulation No. 12. This work is to be continued as soon as future efforts are undertaken to develop a method involving a deformable impacter in which pressure per unit of area appears a suitable criterion.

A thorough examination has begun to determine the influence of the impact speed on the dummy loads in a frontal impact. Small, mid-size and large cars are being examined at five different impact speeds ranging from 30 to 55 km/h. The influence of this speed tends to increase as a linear - rather than a quadratic - function of the dummy load. The results will be reported at this conference.

Although purchasers can refer to easily understandable criteria for most requirements, e.g. cost-effectiveness, which cars have to meet, this is not yet the case with safety aspects. A research project into assessing the passive safety of vehicles has now been completed and an initial proposal made for an appropriate method of procedure. A characteristic feature of this work is the linkage between an intensive accident analysis and the biomechanical interpretation of the physical values measured in the experiment.

Characteristic tests have been conducted for the planned further development of ECE regulation No. 22 (protective helmets). None of the nine helmet types tested satisfied all aspects of the current testing conditions at a speed of 35 km/h. Attainable limit conditions for the applicable limit values are given at impact speeds of up to 30 km/h. Further research work extends to drafting a test method for the helmet chin guard. Work is currently being conducted on a national DIN standard for the purpose of testing protective clothing for motorcyclists. The CEN (Comite Europeen de Normalisation) is also drafting a regulation for testing helmets for cyclists.

The Federal Highway Research Institute has conducted studies into the behaviour of wheel-chairs in braked means of transportation. These studies have revealed that wheel-chairs tilt over or slide at deceleration levels exceeding approximately 2m/s2. Proposals for improving restraint systems for wheel-chairs and wheel-chair users travelling in transport systems for the disabled have been drawn up on the basis of impact tests. A number of questions are yet to be resolved in order to ensure the safe transport of disabled persons in modern low-level buses, e.g. the most appropriate positioning in the bus (either in forward or rearward facing position). These buses are currently being analyzed under normal conditions of operation to obtain data on longitudinal and transverse decelerations.

I will now look at only a small selection of research activities which have been initiated specifically for the further development of existing rules and regulations.

A project to draft the requirements which motorcycle brakes with anti-blocking systems have to satisfy, particularly as regards braking on curves, has now been concluded. The information obtained will be used in a further-reaching project to draft the theoretical and dynamic principles required for safe motorcycle braking on curves.

In order to improve the requirements for direct and indirect visibility from passenger cars, a study has been conducted into the minimum light transmission capacity of windows in vehicles. One important conclusion drawn from this study is that windscreens in future should be tested after installation and, once installed, must satisfy the minimum requirements as regards light transmission capacity.

A study has been initiated to further concretise the requirements for bus passenger protection. This study is intended to develop criteria which the seats in modern coaches have to satisfy in their role as restraint systems.

The experiments into the passive safety of road equipment have been continued and extended at the Federal Highway Research Institute's crash test facility. These experiments have included the testing and approval of marker posts on the basis of the conditions set out in the "Technical Terms of Delivery" as well as the testing of guiding and slide barriers when impacted by passenger cars at speeds of 80 km/h.

The interplay of members of the public, communication systems, organised rescue services and hospitals and clinics is often crucial in determining the success or failure of efforts to rescue accident victims. Studies have shown that laymen can often save lives and provide the preconditions essential for effective action by the professional rescue services. Rapid reporting of the accident is crucial in this regard. Nevertheless, it still takes an average of 5 - 8 minutes until an accident is reported and a further 8 minutes or so until a rescue vehicle arrives at the scene of the accident - the average rescue time for road traffic accidents is therefore around 15 minutes. Accident victims are now being treated more and more frequently by an emergency doctor at the scene of the accident before being taken to a suitable clinic for further treatment. This means that even persons with serious injuries which would otherwise prove fatal now still have a chance of survival. This rescue chain can be further improved by greater involvement on the part of laymen. Our studies revealed that no assistance was provided by members of the public at every third accident, even though this was both necessary and possible. The rescue service can also be made more efficient through specific efforts to improve communication, personnel training and coordination with clinics and hospitals. Scientific bases must be provided for further development work of this type.

The German motor insurance companies began a new phase of their accident research work in 1990. All German insurance companies notified the HUK Association of accidents involving personal injury within the framework of third party motor insurance. Consequently, data from a total of well over 100,000 accidents are now available for special analyses in the future. These figures cover one in every four accident fatalities recorded in 1990. The following fields of study are planned in order of priority: front, lateral and tail-end collisions in terms of frequency and serious injury, field studies into the effect of new technical systems (e.g. airbag) and measures designed for the protection of drivers and the other parties involved.

The usually accepted international criteria are employed for the evaluation work. A Simplified Injury Scale has been devised by a group of medical advisers on the basis of the Abbreviated Injury Scale revised in 1990 (AIS 90). This scale combines the advantages offered by an exact description of injuries based on AIS 90 with simplified application for large-population studies.

One area of particular interest in the HUK accident evaluations currently taking place is that of young drivers and the problem of their higher-than-average involvement in accidents. 40% of accidents involving serious/fatal injury are caused by drivers up to the age of 25. Young men have a particularly high risk rate.

Polls conducted as part of the "Young Drivers Campaign" clearly demonstrated that a very distinct differentiation must be made with new drivers as regards risk types and life-style. A direct correlation with accident frequency does not appear feasible, however.

The German motor insurance companies are promoting safety programmes. In conjunction with the German Road Safety Council (DVR) a model has been developed for voluntary further training of new drivers which has been given the name "Young Drivers Drive Safely". Some 2,000 new drivers will take part in a model experiment in 1991. The Federal Highway Research Institute will conduct the evaluation study.

Following several years' analysis work, a representative database has been compiled from 2,000 accidents involving "trucks 3.5 t and above". The database includes collisions with other vehicles as well as with pedestrians and two-wheelers.

Fitting underride protection to the front of trucks can be expected to yield a substantial reduction of around 10 to 20% in the number of serious injuries suffered in all passenger car and truck collisions. Preliminary work conducted within the framework of the "Economic Commission for Europe" (ECE) has already commenced on a new ECE regulation. The requirements which underride protection must meet will be tested in a research project conducted by the German motor insurance companies.

An area of primary concern for the motor insurance companies is the protection afforded to child passengers. Material has been gathered on 1,200 child accident victims. Comparative studies revealed that unprotected children are seven times more likely to suffer serious/fatal injury than protected children. The age group up to around 2 years was found to bear a particularly high level of risk. The biomechanical criteria of small children require still more intensive research.

A HUK project conducted in conjunction with the ADAC (German Automobile Club) performed a comparison between the behaviour of child protection systems in real accidents and crash tests. The tests revealed that rearward facing systems for small children carry the lowest loads. The tests also revealed, however, that using only adult belts to secure children's seats often results in a very pronounced relative movement between the child's seat and the vehicle, a fact which involves an additional risk of injury. Both the protection afforded to children by restraint systems and the actual fitting of the system in the vehicle must be optimised.

An extensive poll of 2,000 parents on "Problems with child protection systems" revealed that the children are often heavier or lighter than the stipulated ECE weight groups. This was particularly true of Group I. Almost 50% of the parents questioned stated that their children did not like using child protection systems. This also explains why 84% of the persons questioned wanted to see improvements made to the current systems.

The majority of parents would like to see higher quality seat material, easier installation and removal, improved instructions for use which are permanently affixed to the protection system, and locks which children themselves are unable to open.

The use of child seats in the front passenger seat is being examined in accident surveys conducted by the German motor insurance companies. The fact that such systems are easier to use is countered by disadvantages relating to possible intrusions in the event of frontal collisions and problems where vehicles are fitted with front seat passenger airbags. Close cooperation with the manufacturers is required in this area to find suitable solutions.

The German automobile industry has continued its efforts to improve vehicle safety. Its annual report "Auto 89/90" once again gives top priority to the protection of occupants of passenger cars. Most passenger cars today have adjustable upper belt anchorages for the front seats. A number of vehicles are already fitted with belt systems which are anchored in the seat itself. Air cushion systems integrated into the steering wheel are gaining in popularity and similar systems for the front seat passenger are anticipated.

In the field of traffic jurisdiction, there are repeated calls for accident data recorders to be fitted in all vehicles. Given the current state of technology, units are available which store the travel speed and other data relating, for example, to brakes or turn indicators, for a period of around 60 seconds. The Federal Government and the automobile industry believe that the problems involved in introducing units of this type are less technical in nature than legal and organizational.

Endeavours by the automobile industry to improve vehicle safety naturally also apply for commercial vehicles. Efforts are therefore being supported to revise the provisions governing dimensions and weights of vehicle combinations in order to ensure that the length of the driver's cab meets all ergonomic and safety requirements. Seat belts and anchorages are envisaged for all seats in the truck. Consultations on design requirements and testing of speed limiters for trucks are in the final stages.

A new generation of brake systems, known as "electronic brake systems," is currently being developed for heavy commercial vehicles. Whereas existing brake systems control the braking pressure pneumatically, these new systems control it by electrical or electronic signals. Although these new systems will not be available on the market until a few years' time, experts in the automobile industry and governmental agencies are already busy defining technical requirements such as the electronic signal transmission structure.

Since the start of the year, the automobile industry has been offering all new drivers free safety training when they buy a new vehicle.

An "Automobile Advertising Monitoring Group" has been in existence since 1988. By continuously assessing automobile advertising, it has made a valuable contribution to reducing possible areas of conflict between product advertising and road safety.

The Federal Republic's status reports for previous conferences have also outlined the extensive measures the Government has adopted to reduce environmental loading by motor vehicles. I will not enter into a discussion of these activities at this point, particularly since the current conference is interested primarily in safety aspects and most other participating countries are restricting themselves to such.

Since the last conference was held in Sweden in 1989, numerous research projects into vehicle safety have been concluded and numerous other themes have been taken up. The results which have been achieved will be presented at this conference and we will be following and discussing them with interest and attention. The generous exchange of experience and continued cooperation in research and development work will remain of inestimable value in the future.

Japan

Noritoshi Horigome
Ministry of Transport

First, a summary of the current state of traffic accidents in Japan is given. The number of automobiles owned in Japan totaled approximately 60 million units as of March 1991, meaning that there is one automobile for every two Japanese people. The automobile is, therefore, an indispensable commodity without which the livelihood, economic and social activities of the Japanese people could not be maintained.

With the progress of this motorization, the number of traffic deaths, totaled 11,227 in 1990, a 1.3% increase over 1989 and traffic fatalities have remained above the 10,000 line for three years in a row, from 1988 to 1990.

A remarkable feature of recent accidents is an increase in the deaths of vehicle occupants, and these fatalities accounted for 40% of the total traffic accident death toll in 1990. Also, the number of fatal accidents at night-time driving accounted for 57% of the total fatal accidents.

The most probable causes of these factors are a sharp rise in the number of aged drivers, a drop in the seat belt use rate (to some 70% from a high of 95% reached shortly after the enforcement of the Compulsory Seat Belt Usage Law in 1986), and a shift of people's lifestyles to a night-oriented pattern.

Next is a brief explanation of the fundamental Traffic Safety Program of the Japanese government. To cope with the increase in traffic accidents, in March 1991 the Japanese government drew up the 5th fundamental Traffic Safety Program providing traffic safety policies for the coming five years. The Program is aimed at a reduction of traffic fatalities to below 10,000 per year by 1995 through an active promotion of traffic safety measures.

The main safety measures outlined under the Program are: the improvement of traffic safety facilities, the promotion of traffic safety education, the enforcement of effective traffic safety guidance and control, the upgrading of rescue operating systems and first-aid system, and the expansion of research and development in the field of traffic safety. Also, two other high-priority measures are comprehensive investigative studies on traffic accidents and securing the safety of motor vehicles.

With regard to the promotion of safety measures related to automobile in the future, the following five subjects will be explained. These subjects are:

(1) A promotion of comprehensive investigative studies on traffic accidents
(2) A expansion and strengthening of the Automobile Safety Standards
(3) A promotion of technological development
(4) A promotion of research
(5) An international harmonization of automobile standards.

Beginning with Subject 1, in order to take truly effective measures to prevent traffic-accidents, it is indispensable to grasp what actually happens in traffic accidents accurately, and to undertake investigative study and analysis of the causes of accidents from the respective stand points of the driver, motor vehicles and road construction.

However, the comprehensive studies and analyses of traffic accidents in Japan have not been fully sufficient so far. Therefore, the government plans to establish a comprehensive traffic accident research and data analysis institute in the near future through a collaboration of the government and private sectors. The major activities of this institute will be:

(1) To construct a data base integrating the various data on traffic accidents, a nd perform statistical (macro) analyses of traffic accidents, using these data.
(2) To perform individual case (micro) analyses of accidents occurring in certain local areas.

With regard to subject 2, the expansion and strengthening of the Safety Regulations will be explained. In August 1990, the Safety Regulations were revised to make it mandatory to install antilock brake systems (ABS) on large tractors, large trailers carrying dangerous goods, and large buses running on highways.

Also, large trucks will be required install large-sized reflecting plates on the rear in order to increase the visibility of the vehicle and thus prevent large truck rear-end collisions. Further, large trucks will be required install improved rear underrun protective devices, to reduce the damage incurred in large truck rear-end collisions. These measure are scheduled to take effect in June 1992.

The Japanese government in October 1990 requested the Council for Transport Technology to undertake a study on future Technical Standards to ensure vehicle safety, and the Council is now discussing this matter and expected to make recommendations by the end of March 1992.

Recently, the five types of fatalities listed below have increased.

(1) Accidents involving motor vehicle occupants
(2) Accidents during night-time driving
(3) Accidents on highways driving
(4) Rear-end collisions with trucks
(5) Accidents involving young or aged drivers.

Therefore, the Council for Transport Technology is discussing safety measures to cope with these kinds of accidents.

In addition to these countermeasures, the Council for Transport Technology is also discussing safety measures in relation to the increasing use of electronics in automobiles.

Subject 3 pertains to the promotion of technological developments. In addition to the expansion and strengthening of safety standards, it is also essential to promote technological development in order to improve the safety of automobiles.

The government has been engaged in a five-year study since fiscal year 1991 in the hope of developing by early in the next century, practical Advanced Safety Vehicles (ASV), as we call it, which are automobiles made more intelligent by exploiting the latest electronic control technologies.

The specific technologies examined in this study are how to perform automatic braking and automatic steering by means of onboard sensors for detecting traffic and road surface conditions in the vicinity of the vehicle, a transmission processing and equipment and so forth so that the vehicle itself can perform the most optimum safety operations; all aimed at avoiding accidents, and minimizing injuries due to collisions.

The fourth subject is that of Japan's promotion of automobile safety research. Currently the following studies are underway by the government and the private sector:

(1) The lighting of the braking lamp when the retarder equipped on large-sized trucks and buses is in operation.
(2) Improvements of safety in frontal collisions for passenger cars.
(3) The protection of occupants in lateral collisions for passenger cars.
(4) The improvement of the conspicuousness of lighting and signalling devices.
(5) Research into accident-avoiding systems for automobiles.
(6) Research and development of specialized taxi-use vehicles.

Some of these studies will be presented by Japanese automobile manufactures at this conference, and it is hoped that the participants in the conference will actively exchange opinions on these fields.

The fifth subject matter is the international harmonization of automobile standards. Since automobiles are an international commodity distributed worldwide, it is necessary to harmonize the automobile standards in each country as much as possible, taking into consideration the respective traffic conditions of each country.

Accordingly, Japan, along with the other major automobile producing countries, has been participating actively in the United Nations ECE/WP29, which is playing a central role in international harmonization activities of automobile standards. Also, in 1987 Japan established JASIC, the Japan Automobile Standards Internationalization Center, to support the harmonization activities of the Japanese government. Japan expects that the activities for the international harmonization at the stage of the ECE/WP29 is promoted further.

Finally, as you are all aware, it is widely recognized that we today face not only safety problems, but also global environment issues. In particular, the issues of reducing CO2 emissions and improving the safety of automobiles may be contradictory, as safety devices will tend to increase the weight of the automobile. Therefore, how to harmonize these contradictory requirements is an important topic which will be imposed on us in the future.

Italy

Franco Zacchilli
Ministero dei Trasporti

Status report not available.

Canada

S. Christopher Wilson
Transport Canada

Introduction

It is once again my great pleasure to present the Canadian status report on progress in the area of automotive safety. Before starting, however, I would like to take this opportunity to thank the French government, the United States government, and the French Automobile Manufacturers for making this conference possible.

Canadian Accident Environment

I am pleased to report that we have seen the continuation of the downward trend in the annual fatality rate noted in the last two Canadian progress reports. In 1990, a total of 3,961 traffic fatalities occurred on Canadian roads and streets. This translates into a fatality rate of 2.3 per 10,000 registered motor vehicles, the lowest rate ever recorded in Canada and represents over a 60 percent decline in the fatality rate since the early seventies. The 1990 fatality total also represents the first time since 1962 that the fatality count in Canada dropped below 4000.

We believe the increased use of seat belts has played an important part in this downward fatality. This is reflected in the vehicle occupant fatality total which,in 1990, is ten percent lower than that in 1989. The national seat belt use rate of drivers has been monitored closely in direct observational surveys conducted annually by Transport Canada. Through the latter half of the nineteen seventies and the early eighties, the time period over which most of the dramatic decrease in traffic fatalities occurred, the seat belt use rate among drivers increased from under 15 percent to over 50 percent. Substantial further progress in increasing the seat belt rate has been made in recent years. The most recent survey, conducted in June of 1991, showed a national seat belt use rate among drivers of just over 85 percent, the highest rate recorded to date. In 1990, Ministers representing all provinces, the territories and the federal government endorsed the National Occupant Restraint Programme, which seeks to attain a 95 percent use rate of seat belts by 1995. This goal, very clearly, is now within reach.

Undoubtedly, another contributing factor has been the reduction in alcohol related fatalities. In the past decade, there has been a 28 percent reduction in the proportion of fatally-injured drivers-who were impaired.

Regulatory Developments

Regulatory priorities in Canada are sensitive to the global nature of the automotive industry and the importance of improved international trade unencumbered by artificial barriers. We hope that our regulatory initiatives retain the high level of compatibility with foreign standards that historically existed while, at the same time, respond to the needs and priorities of Canadians.

In this context, the past two years have seen a number of changes to Canada Motor Vehicle Safety Standards. For the most part, these changes were very similar to those introduced in the United States. Two changes unique to Canada were also introduced. The first of these was the introduction of requirements addressing occupant restraint systems designed for use by the disabled. The second involves an alternative set of injury criteria addressing frontal crash protection requirements. These new criteria are based on the responses measured with Hybrid III crash test dummy in a 48 km/h frontal barrier crash test. These new requirements will be outlined in a separate technical presentation at this conference.

Crashworthiness Research

In the vehicle crashworthiness area, our more recent research efforts addressing frontal crash protection have focussed on gaining a better understanding of the response of the human chest when loaded by a seat belt and how accurately these responses are replicated by contemporary frontal crash test dummies such as the Hybrid III. We recently participated in a cooperative research programme with both INRETS in France and the U.S. National Highway Traffic Safety Administration to gather comparative chest deflection data using human cadavers and the Hydrid III dummy. The cadaver testing portion of this programme was completed in France. The test apparatus used in this programme has now been returned to Canada where it will be used to gain additional thoracic response data, this time with live human volunteers. In addition, as part of a separate cooperative programme with NHTSA, we have just recently completed a large number of frontal barrier crash tests using a Hybrid III fitted with a special instrumentation package which allows the general deformation pattern of the chest to be monitored.

The proportion of new passenger cars fitted with "supplementary" air bag systems has increased greatly in Canada in recent years. This trend is expected to continue. The field effectiveness of such combination systems and the accompanying usage rate of seat belts in these vehicles is being monitored closely by the Department. We recently initiated a combined field accident data analysis and crash testing research programme which seeks to quantify the effectiveness of air bag systems, when used in combination with manual three-point seat belts. As part of this programme two offset head-on vehicle-to-vehicle collisions were completed in which air bag fitted passenger vehicles were impacted by much stiffer and heavier pickup trucks. The findings will be discussed in the separate technical presentation which I made reference to earlier.

In recent years much of our research effort has been directed to the issue of side impact protection with particular attention being given to the best means by which such protection can be defined and regulated. We have been following, with great interest, the various regulatory proposals and initiatives taken both in Europe and in the U.S. To assist the Department in its own deliberations over what course of action Canada should take, a combined field accident analysis and vehicle crash testing programme was initiated in 1988. The crash testing portion of this programme examined, in the context of the Canadian situation, the relative merits of the various testing procedures and test devices either under consideration or adopted in the U.S. and Europe to regulate side impact protection. To date, close to 30 full-scale vehicle crash tests have been completed as part of this programme.

From the testing completed to date, it is very clear that vehicle performance rankings based on the proposed European testing procedure can be expected to differ greatly from those obtained following the U.S. testing protocol. These differences can be attributed primarily to differences in the design of the two moving barriers and their alignment rather than to differences in the designs of the European and U.S. test dummies. Of the two barriers, the U.S. barrier and testing protocol produced damage patterns which showed much closer agreement with those observed in staged vehicle-to-vehicle collisions conducted in our programme. The final portion of our test programme will focus on the sensitivity of test results to dummy design and other related considerations such as the position of the dummy's arm.

Crash Avoidance

The past years have seen a number of regulatory initiatives addressing crash avoidance, particularly in the area of vehicle lighting. Two of the more significant of these pertained to increasing the conspicuity of vehicles. The first of these was the requirement for a centre high-mounted stop lamp. The second and more recent is the requirement for a daytime running light system. Fitment of the latter became mandatory in Canada as of November 30, 1989, and in the context of North America, represents a uniquely Canadian requirement.

Both of these requirements are currently the subject of evaluation studies. As yet sufficient field accident data have not been compiled to allow definitive statements regarding what impact either of these standards have had on accident rates. In the case of the centre high-mounted stop lamp requirement, the preliminary findings are encouraging, although they show benefits which appear to be well short of those predicted in pilot studies. They suggest reductions in target accidents of between 7 and 14 percent, depending on class of accident and the control group used as the basis of the effectiveness estimate. In the case of the daytime running light requirement our current efforts are directed largely at monitoring the use of driving lights in the daytime, on quantifying both the added vehicle production costs directly attributable to this regulation as well as the added costs due to increased fuel consumption and bulb replacement, and examining other related issues such as driver behaviour adaptation. The more formal field accident analysis portion of the evaluation programme will likely not be completed until 1994. However, I expect to be in a position to share some preliminary findings with you at the next ESV conference.

Heavy vehicle safety continues to be of concern, with approximately 10 percent of traffic fatalities involving such vehicles. We are involved actively in joint research efforts, both with industry and NHTSA, on anti-lock braking requirements and on improved visibility of large vehicles. Research is also progressing on the safety implications associated with in-vehicle displays and other technological advances in road-vehicle-driver communication.

School Bus Safety

Finally, it is perhaps appropriate to direct my closing remarks to a class of vehicle which, by virtually any standard, is the safest in operation in Canada. Most days, tens of thousands of children across Canada are transported daily to and from school in large yellow school buses. Notwithstanding their outstanding safety record, the safety of these vehicles continues to be a topic of considerable interest, and sometimes, emotional debate. This is readily understandable given the precious nature of the cargo they transport. Recognizing the need to provide to interested parties more comprehensive information on this special class of vehicle, the Directorate recently completed a background paper which summarizes information available on school bus accident studies, on safety standards, and on our demonstration programme of different bus seat and seat belt combinations, including rearward facing seats. This report has been distributed to provincial and territorial governments, school boards, safety organizations and interested members of the public. We are reviewing and responding to the comments received.

I thank you for your attention and look forward to listening to the upcoming technical presentations at this conference.

The Netherlands

Gerard Meekel
Ministry of Transportation and Public Works

Introduction

Holland: A unique country with its own special characteristics.

It is a very "small" country, with:

- 15 million inhabitants on 33,724 sq. km. The density varies from 150 to more than 1100 inhabitants per square kilometer, with an average of 444 inhabitants per sq. km.;
- a large number of vehicles—6 million;
- a relatively high number of heavy goods vehicles—444,000;
- an important function/part in the international transport of goods; and
- a highly mobile population.

But it is a very "big" bicycle country—over 14 million.

Despite our relative prosperity and level of technical development, we suffer from enormous transport and traffic problems.

A. Firstly, road traffic is increasing rapidly. Every day the accessibility of our economic centres is further endangered. If nothing is done about this problem, we will soon be facing a total traffic-block. This poses a threat to both national and international transport. Without a change in policy, road traffic will increase by 70% by the year 2010. The western part of our country would be simply a crazy-paving of cars. THE MOBILITY PROBLEM WOULD BE SOLVED!?

Some indicative figures: Road traffic increased by 12% in the period between 1986 and 1989; on the main roads this figure is even higher—20%. The economic and social damage as a consequence of the traffic jam today has increased to the amount of one billion guilders per year, and will rise to four billion in the year 2010 if policies are not changed.

B. Secondly, traffic and transport have negative effects on the environment. Not only is pollution as a consequence of gaseous emissions and noise emission our concern, but the consequences of the infrastructure on the natural environment must also be reckoned with.

C. Thirdly, fatalities and injuries on our roads appear to have stabilised at an unacceptably high level. Each year is a disaster—over 1,400 people are killed and another 50,000 are injured. But this happens gradually. If this were to occur in one single accident, the whole Dutch nation would be devastated. It happened in 1953: the break in the sea-dykes and the subsequent flood claimed 1,800 lives. As a result, during the course of the following 35 years the "Delta-Plan" project was carried out at a cost of 15 billion guilders.

Some indicative figures: After a period of declining accident rates, 1989 saw an increase of around 10% in the number of road deaths and injuries. This put the figures back up to their 1986 level. In 1989 the total number of both fatalities and injuries among cyclists increased by 20% in relation to the 1988 figures. The cost of road-"hazards" is estimated at six billion guilders per year.

Road Casualty Figures (1990)

	Deaths	Seriously Injured	Other Injuries
Automobiles	702	5,115	13,401
Trucks	53	407	1,316
Buses	2	21	1,316
Motorcycles	72	749	215
Mopeds	98	2,619	9,463
Cycles	304	3,277	9,574
Pedestrians	144	1,364	2,653
Others	1	28	81
Total	**1,376**	**13,580**	**38,380**

Policy

General

At the end of 1988 the minister of transport in the Netherlands published her Transport Structure Plan, the SVV, outlining concrete goals and the instruments which should be used to achieve them. The latest update contains thorough analyses of the problems facing the transport sector over the next few years, both nationally and internationally—and of these, safety is of major importance. Above all, it deals with all aspects of *tomorrow's* transport system. The goal: a sustainable society—defined as "society which meets the present generation's needs without jeopardizing future generations' ability to meet theirs." The implication is that we must build a transport system which does not shift the burden of environmental problems onto future generations. This will necessitate bold political choices.

Two problem areas have been identified which should be dealt with in the near future in order to create tomorrow's traffic and transport system:

1. Environment and amenities of life, and
2. Accessibility.

Today's generation must have the courage to take the necessary measures. We have a collective responsibility: we must face it together.

Road Safety

This subject is dealt with in detail in the already-existing Dutch MPV "Long Term Policy for Road Safety." It consists of an in-depth programme within the aim of producing a Sustainable Traffic System. This MPV is aligned with the SVV as far as goal-setting is concerned. The road-safety goal-setting formulated in both SVV and MPV reads:

- by 1995, the number of deaths shall be decreased by 15% and the number of injured by 10%, relative to 1986;
- by 2010 these figures should be 50% and 40% respectively.

The 1,529 deaths and 50,081 injured were registered in 1986. It will be very difficult to attain the goals. However, if today's policy is enhanced, theoretically speaking it is still possible. The Dutch government has therefore "sharpened" the present MPV-policy. The enhanced policy is based on two main items:

1. "spearheads," being:
    - drinking and driving,
    - safety aids,
    - speed,
    - dangerous locations,

    and two recently introduced items:
    - heavy traffic, and
    - cyclists.
2. "the policy of encouragement," aimed at stimulating and supporting the efforts of local councils, Provinces, trade and industry, and road users themselves. All parties involved must be made aware of the full extent of the problem.

In order to give you some idea of the Dutch approach to road-safety, I would like to present information on the following:

- the cyclists' project, the Cycle Master Plan and
- the heavy traffic project.

Before going into detail, I would like to point out that there is a major difference between the two projects. Both deal with the issue of road-safety. However, in the heavy traffic project the safety aspects of the vehicle and those in relation to its surroundings are taken into account, whereas in the Cycle Master Plan safety aspects as a consequence of encouraging the use of bicycles are dealt with as well.

Cycle Master Plan

Situation

In view of today's problems, and tomorrow's Sustainable Traffic Plan, the use of the bicycle is to be encouraged, but without the attendant rise in traffic accidents.

In order to be able to formulate an efficient long-term policy we need to analyse the bicycle as a means of transport.

The Pros

The bicycle:

- is very suitable for short distances;
- is suitable for getting to and from public transport;
- requires relatively cheap infrastructural measures;
- is non-polluting, silent, and has minimal impact on the environment;
- requires little space when either on the road or parked;
- is now accepted as a means of transport in its own right—its image is improving;
- is a reliable means of transport as far as time of arrival is concerned. You won't end up in a traffic jam;
- is healthy and relaxing;
- is a cheap means of transport, especially in the light of increasing prices of motor vehicles and public transport;
- is an individual means of transport with positive aspects, e.g. door-to-door transport.

The Cons

- Cyclists run a relatively high risk of being involved in an accident.
- The social safety aspect of cycle routes is not always too good, especially when badly lit, overgrown with bushes, etc.
- The quality of the cycle routes is frequently poor.
- Lack of cycle-sheds, which leads to a very high number of bicycles being stolen.
- Lack of good provisions for combined use of bicycle and public transport;
- Cyclists are subjected to weather conditions—although according to the Royal Netherlands Meteorological Institute there is rainfall only 6% of the time.

Strategy

The Cycle Master Plan is designed with both mobility-management and safety-goals in mind, within the framework of SVV. All aspects relevant to the increased use of the bicycle and a good road safety system are taken into account. In order to create a bicycle-friendly environment the Minister of Transport has formulated several strategies, e.g.:

- Physical planning policy should work towards concentration of living, working, shopping, and recreational amenities, in order to reduce the distances between these activities.
- Infrastructural policy should focus on safe and comfortable routes, especially for bicycles, including specific arrangements, e.g. parking boxes.
- Through a programme of information and instruction, there shall be a general policy of encouragement towards a more frequent use of the bicycle, and wherever applicable, in combination with public transport.

The Cycle Master Plan will deal with all aspects which come under the jurisdiction of the Minister of Transport by means of a project divided into themes, and goal settings formulated where applicable.

The themes are:

- infrastructure,
- mobility,
- safety,
- anti-theft provisions and parking,
- promotion, and
- bicycle + public transport + companies.

The aspects dealt with under the heading of "safety" are:

1. classification of safety for cyclists and moped riders;
2. advice for safe cycle infrastructures;
3. further development of the concept of the self-contained commercial-residential-recreational suburb;
4. mopeds;
5. education for cyclists in cycle traffic;
6. a post-academic course on "safe infrastructure for cyclists";
7. symposium on "safe and polite traffic, also for cyclists";
8. accidents involving cycles on public highways; and
9. bicycle safety and crash-worthiness.

Bicycle Safety and Crash-Worthiness

One of the activities which can be employed to improve road safety in general is the stimulation of the use of bicycles. At present the cyclist runs a very high risk of injury, which means high numbers and relatively severe injuries. So, simply stimulating use would merely increase the number of traffic casualties. The government therefore first inaugurated a programme to explore the possibilities of increasing the safety of the cyclist.

This programme is divided into three parts:

- the cyclist,
- the bicycle, and
- the surroundings (infrastructure and other road users).

Within each part the role of the three actors—the government, the manufacturers, and the consumers/road users—may be identified.

The Cyclist

Dutch medical data for 1990 and 1991 has been examined. The objective was to gain more information concerning the extent and type of injuries amongst cyclists. Among the results of this study were two conclusions:

- The cyclist very often sustains injuries to the head as the result of the accident (approx. 50% of the accidents).
- With respect to long-term effects of injuries, the extremities of the body need extra protection.

Under discussion at the moment is how this protection can best be provided—by prescribing protective clothing and/or helmets, and/or by reconstruction of the surroundings.

The Bicycle

In 1991 the government started a research programme to improve the safety and comfort of the bicycle. The first stage concerns the arrangement of those aspects of the bicycle which have an influence on its safety. The next stage will be to formulate and develop test procedures for all types of bicycles, specifying the minimum requirements for a safe bicycle. The last stage is a future-orientated project—ignoring the current form of the bicycle, and with regard to such features as comfort, safety and speed, what should be the form of the bicycle of the future?

The Surroundings

This part of the programme is divided into two main areas: one concerning the infrastructure and the other concerning the other road users.

Because the major interest of this conference is in the vehicles, we shall concentrate further on the other road users. The most frequent opponent of the bicycle is the private car, and one of the most frequent types of accident is where the front of the car strikes the side of the bicycle. Through analysis of mathematical simulations and accident reports, combined with the relevant medical data concerned (stage 1), we are trying to obtain input for new mathematical simulations of collisions between cyclists and private cars. Through this we are trying to gain greater knowledge of the kinematics of the cyclist during the accident. The objective is to learn which parts of the car play an important role in the injury-producing process during the accident.

Later we hope to get more information about the possibilities of creating a "soft nose" front for private cars. In this programme the results of the EEVC project concerning pedestrians are taken into account.

For the third stage of this project we are trying to stimulate the industry to participate in the progamme. The objective is to perform one (or if possible several) full-scale collision experiments using adjusted models of existing cars. Using this approach we shall try to stimulate the car industry to produce cars with built-in safety—not only for the passengers, but also for the other road users.

Anticipated results should contain suggestions for:

- optimized car front-ends,
- optimized bicycle forms - safe and comfortable, and
- optimized crash-protection for cyclists.

The government programme concerning the improvement of the safety of cyclists is expected to be completed by December 1994.

Heavy Traffic

Situation

This project must also be regarded within the framework of SVV. We start with the reality of a certain need for transportation, and a related mobility. The existing national and international infrastructures affect not only the level of mobility, but also the means of transport, whether by road, rail, water or air. By virtue of their construction, heavy trucks are both unsafe and aggressive. In view of this, choices must be made concerning the acceptability of heavy vehicles on the roads. They are, in fact, incompatible with other road users.

A favourable tendency towards combined-mode transportation an already be seen, but first of all the infrastructure and logistics need to be re-organised and developed into a more integrated system which makes more even and efficient use of the existing transportation networks. It must be borne in mind, however, that re-organising these aspects may lead to limiting conditions or consequences for road safety. In the meantime we must improve heavy truck safety. However, we realise that not much attention has been given to this category in comparison with other categories. We are somewhat behind as far as our knowledge of heavy truck safety is concerned.

Strategy

Since the safety aspects of heavy traffic have so far been under-exposed in relation to other categories of road users we must first catch up. The Heavy Traffic Project has been divided into two phases. There are no goal settings at this stage, due to lack of sufficient relevant information.

Phase 1. Scheduled for completion in November 1992, this consists of firstly, improvement of the present situation by:

- incorporating safety-related aspects in projects which already exist as a consequence of SVV;
- application of existing instruments and measures in order to improve road safety as far as heavy trucks are concerned, especially through technically-related aspects.

Secondly, with a view to a policy of encouragement:

- formulating a research and development programme in order to be able to formulate future measures;
- creating support as a first step towards implementation of specific measures on a long-term basis;
- developing future strategy; and
- active international participation with the aim of developing international legislation on aspects of road safety.

Phase 2. Scheduled for completion in June 1993, this consists of:

- implementation of results from Phase 1;

- evaluation and, where applicable, adaptation of the project;
- research and development of new measures;
- formulating the long-term policy.

Research and development programmes will be formulated, based on the quantitative and qualitative analyses of the unsafe aspects of Heavy Traffic.

Finally, a total evaluation of this project is scheduled, and the long-term policy will be established.

Heavy Truck Safety

In view of the emphasis on truck safety a research and development programme was commissioned in 1991. The aim is to establish a good basis for R&D in this area. The programme deals with both passive and active safety of heavy goods vehicles and contains vehicle-, occupant-, and environment-related topics. With respect to passive safety, the research focusses on front-underrun protection in frontal collisions with private cars. Practical solutions are studied in co-operation with manufacturers. An EEVC ad-hoc group is also studying this subject. With respect to active safety, the possibilities of several criteria and test-methods for the assessment of the stability and control of heavy vehicles are being evaluated. Another project focusses on the calculation of the dynamic stability of articulated trucks. We foresee that this first step will be followed by further research on active and passive truck-safety topics over the coming years.

Conclusion

A lot of problems, discussions, several reports, other opinions, striking interests, incompatible priorities and financial aspects, etc., have resulted in SVV, and consequently many projects have already started or will shortly start.

The Dutch Minister of Transport was challenged nationally. Additionally, as a result of the report "Our Common Future," we felt challenged by the *world*. So the policy was again argued and enhanced, and SVV-II was created. A great deal of work remains to be done in the near future. You need to challenge in order to be challenged. You need to be challenged in order to challenge.

So now we want to challenge the world, and we are focussing on YOU AND YOUR KNOWLEDGE. Thank you for your kind attention.

Sweden

Lennart Fremling
Ministry of Transport

Introduction

I take pleasure in reporting that since the 1989 Experimental Safety Conference in Gothenburg, there has been progress towards improved safety of vehicle occupants, motorcyclists and other road users. We hope this trend will be lasting, although one important explanation to the positive trend of reduced casualties last year can be influenced by a somewhat decreased travel indicated by the petrol consumption, that last year was 5 per cent lower than during 1989.

The number of fatalities in road traffic accidents in 1990 was 772 which is a decrease of 15 per cent compared to 1989 which had the highest figure since 1979.

The fatality risk in Sweden is among the lowest in the world. The number of fatalities per a population of 100,000 last year was 9.0 and per 100 million vehicle kilometres 1.25.

A major goal in the Road Safety Office's effort to reduce the number of traffic fatalities and injuries has been to increase the use of occupant restraints. We have seat belt use laws covering both front and rear seats of passenger cars. The use of safety belt use laws covering both front and rear seats of passenger cars. The use of safety belts has steadily increased from 80 per cent to 85 per cent in front seat and from 10 per cent to 70 per cent in rear seat over the last decade. Now, we have monitored a certain decrease of safety belt use. In the mid 80's we launched several information and promotional programs supporting the passage of law of mandatory use in rear seat, 1 July 1986. The belt use improved. We now believe that the lack of programs designed to build public support for belt use during the last years, when we were nearly satisfied with the use rate achieved, has contributed to the falling use rate. Therefore there is a need to restart activities to upgrade the existing belt use.

Organized under the Ministry of Transport the National Road Safety Office is the central administrative authority for matters related to safety on the roads. The Swedish parliament set a target in 1982 to reduce on a continual basis the number of people killed and injured. It is obvious that we have not succeeded to attain this major goal. The numbers have only been reduced for children and motorcyclists during the period 1982 - 1990.

In December 1990 the government appointed an expert group to give proposals on how to organize the traffic safety sector in the future, to more effectively reduce the consequences of vehicular transportation. The investigation committee forwarded their proposals in September this year. The proposal is aiming at reducing the number of organizations dealing with road safety and to mandate local administrations to take over the responsibility for road safety measures in their own areas.

Drivers Licensing

The development of the driver training schemes has continued. New schemes have been introduced for all types of driver training. Shortly, there will be new theoretical tests for all categories of driving licenses, and already new tests for category A and B licenses have been introduced as we reported at the last conference. As a result we can see an improvement of the driver training in driving schools.

The training of driving school instructors is of very short duration, in fact the theoretical education is only 20 weeks. To create opportunities for an improved driver training it is necessary to improve and extend the training of the instructors. We are considering an instructor education at university level. The length of the education is planned to be two years.

New drivers are a high-risk group in traffic. One of the main reasons for the high risk is the lack of experience. Therefore, we are considering learner driving from the age of 16. We have in this case been inspired by a similar scheme already introduced in France. Training in a driving school will be compulsory before starting the learner driving. The extent of the compulsory part has not yet been decided.

Elderly drivers are another high-risk group in traffic. A research and development programme has been initiated in order to evaluate this problem. We are especially interested in dementia and its consequences upon driving skills. Furthermore we have started a training programme on a theoretical basis for a group of elderly drivers. The aim is to find out whether a training programme can contribute to an even larger risk reduction among elderly drivers.

Finally we have continued our efforts to reduce drunken driving. The legal blood alcohol content limit was reduced to 0.02% in 1990. This year we have introduced a special test for drivers sentenced for drunken driving with a blood alcohol content of at least 0.15%. When applying for a new driving permit a medical certificate about the fitness to drive has to be enclosed. This certificate shall be based on a certain time of observation as well as laboratory tests. When a person is granted a driving permit, a follow-up within a period of eighteen months is then compulsory.

Research

The need to improve the passive safety of cars in lateral collisions has been recognized during recent years both in the United States and in Europe. Side impacts account for more than 20% of all accidents and with a risk of serious injuries of 35%, this is higher than for frontal collisions.

The main injury causing parameters in side impacts are, firstly the door inner velocity at the time of impact with the occupant and secondly the degree of car body lateral deformation.

The occupant protection in side impacts can be improved by e.g. reinforcement of the car body and the door to reduce the door inner velocity as well as the car body deformation, padding and airbag at the inside of the door to reduce chest, head/neck and pelvis loading.

The present status is that a joint Swedish study has been undertaken to find out the injury patterns and injury risks for different types of cars and for different impact directions, with the main results that head, chest and abdomen/pelvis are mainly exposed to life-threatening injuries while the neck and legs mainly receive injuries with risk of permanent disabilities.

A simplified method has been developed and validated in fullscale tests, in order to be used in research and development of side impact protective systems. The test method comprises a reinforced door, mounted to a test sled and with a dummy sitting on a seat at right angle to the crash track. The door approaches the dummy at a constant speed and is then decelerated with a linear function applied. With this method different dummy parameters have been studied for a reference door and for two different door designs. Both designs have shown good improvements especially the one with polyethylene foam and an airbag. The choice of padding material has been evaluated by mathematical simulations.

The present status of these two projects will be reported at this conference.

In parallel with this mechanical test procedure a mathematical method based on MADYMO has been developed. A two dimensional side impact dummy has been developed, which now is validated against the side impact dummy (BIOSID). Most parts of the body are well correlated to the BIOSID. With this mathematical simulation method the mechanical tests are reproduced.

Rear end impact injuries to the neck have been an increasing problem during the past decades in Sweden. Rear end car collisions cause the so called whiplash injuries. These injuries, often disabling, will be seen even in very low impact velocities.

The injury mechanisms are not properly known today. We do not have adequate knowledge to develop an optimal seat with head-rest for minimizing the risk for whiplash injuries.

Both basic and applied research is going on to find out the injury mechanisms and the principles for an improved seatback/headrest design.

After development of methods for applying both static and transient dynamic loads to the spine, research has been undertaken to study biomechanical, biological and patho-anatomical effects of the spine under different loading conditions. Different biological and morphological parameters have shown to influence the mechanical response of the spine, especially the bone mineral content in the vertebrae has shown to be a good predictor of ultimate strength of spinal segments.

A method has been developed by Chalmers University to study the flow and pressure gradients in the spinal canal during the whiplash movement. With this method, studies are now undertaken to investigate the gradients, which could be the possible mechanisms to the probable nerve tissue effects.

A method to study the nerve tissue function caused by different loading conditions, especially transient has been developed and is now going to be used in the attempts to find the injury mechanisms of whiplash injuries.

Based on the current knowledge a rear impact dummy has been developed by Chalmers University to be used in the development of better headrests and seatbacks. The dummy is based on the Hybrid III but with a completely new neck and spine and work is at the moment going on to validate the new dummy.

Heavy Truck Safety

The number of trucks on our roads is increasing. Truck-trailer combinations weigh 30 or 40 times as much as the cars and take far greater distances to stop, pass, turn and accelerate. Most big truck crashes involve passenger cars and when these crashes happen it is almost always the people in the cars who suffer most. The odds of surviving an impact with a heavy truck have been steadily diminishing. There is no doubt that we are in need of investigations exploring the feasibility of incorporating cost-effective design modifications to trucks.

To demonstrate the heavy truck braking problem, the Nordic countries in 1987 conducted a joint project and evaluated 400 heavy truck-trailer combinations for in-service braking capabilities. Results from the braking tests revealed poor general braking performance due to lack of maintenance and adjustment and far-from-optimal brake load distribution within the truck-trailer combination. For example over 50 percent of the combinations were not able to meet acceptable deceleration criteria. This means that hazardous cargo is being transported under less-than-safe conditions in spite of fairly sophisticated annual heavy truck testing schemes.

These results call for development of brake systems that better match brake force distribution to braking demand. We are in great need of a successful introduction of antilock systems and the European Community has already taken the lead.

After the general ban on the use of asbestos from 1988, industry was faced with a big task to restore the safe brake properties in the heavy vehicles. A part of the heavy truck braking problem was an in-service problem when replacing brake linings. The aftermarket supply of linings was unregulated and often incompatible lining/drum combinations were found. An international standard for replacement linings is needed. As an intermediate measure we have established a Swedish Standard for replacement linings. This standard is legally applied from January 1992. We are now expecting a gradual improvement in this area.

It is equally important that we also continue to improve the occupational safety in trucks.

In Sweden dynamic testing of heavy truck cabs has been mandatory since 1961. The testing methods have been slightly revised in 1979 and 1981. Thus the reinforced truck cabs have saved many lives through the years.

Child Safety in Cars

Among children and young persons road accidents are the most frequent single cause of death. The safety of children has therefore been a matter of great concern in Sweden for many years.

The problem of protecting children in cars arises immediately after the birth of the child. We have therefore a nation wide system of lending parents suitable restraints for newborn babies for a period of 9 months. We believe this is an effective way of promoting the need for life-long protection in vehicles.

We find it encouraging that the Swedish experience of rearward facing child restraint systems, now in use for over 20 years, reduces the risk of injury by 90-95%. These seats are used for children up to an age of 3 years and are usually mounted in the front seat passenger position leaning against the dashboard. This excellent protection is parallelled only by a similar experience in the U.S.

Thus the widespread use of child restraints in Sweden especially the *rearward* facing designs, has proved to be very efficient and is now the best available protective system.

It seems only reasonable that we should have the possibility of easy access to properly fitted protective systems for both adults and children in the family car. A new initiative from the industry to respond to the public demand and also to prevent misuse of child restraints is to integrate them into normal car seats.

These integrated child restraints, which are designed and available for several age groups, can in fact introduce a greater risk when used in the forward position for smaller children who are normally at present using rearward facing designs in Sweden. This development can create a problem for small children and has therefore to be monitored with great care.

Another problem is that a passenger airbag obviously can be dangerous in combination with a rearward facing child restraint. Some dynamic tests have been performed with different combinations of child seats and dashboard designs. These tests show that the dummy accelerations will reach very high levels and that some child seats even can disintegrate. A paper will be presented during this conference in Session 9 showing some of the results received and possible remedies to the problem will be discussed.

Head-on collisions occur most frequently at an angle of approximately 10-30 degrees to the longitudinal axis of the vehicle. However, child restraints are only tested in zero degree direction. For forward facing designs a much higher forward displacement of the dummy is recorded for oblique impacts than for the zero degree direction. This knowledge calls for a revision of the ECE-Regulation 44.

The protection in side impacts is limited. In Session 3, a paper will be presented discussing the injury mechanism in side impacts, and a test method is proposed for use together with child restraints in ECE mass group 1.

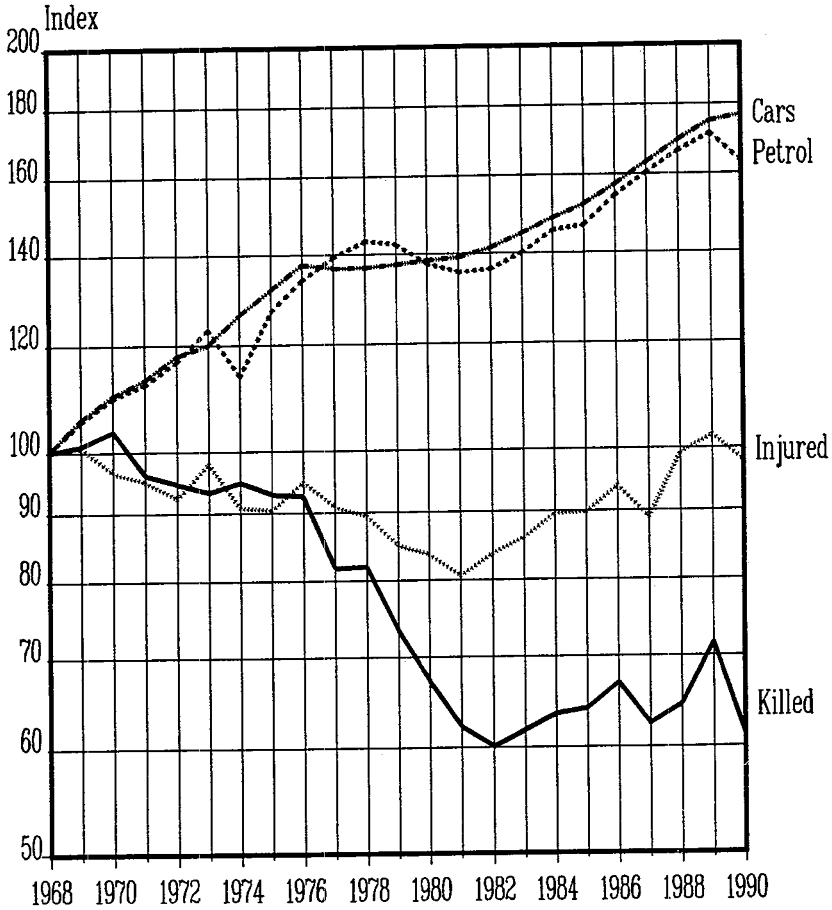
Vehicle Lighting

Signalling is a very important factor in primary safety. The prevention of rear-end accidents in particular is largely dependent on the swift receipt and interpretation of information by the following driver. Such information is transmitted principally by rear signal lamps on the vehicle and the signalling functions of rear lights are becoming steadily more complex. Especially position is used to code or to draw attention to information. In the US high mounted stop lamps have shown to have an excellent effect. For this reason we wanted to introduce this safety feature by legislative means in 1988. Unfortunately ongoing European harmonization in the vehicle sector persuaded us to withdraw this proposal. In the meantime we have welcomed the initiatives of manufacturers who are introducing such safety features ahead of any legal requirements.

Thus a number of car models have been equipped with high mounted stop lamps during recent years. A field study has shown that the high mounted stop lamps are at least 10% effective in reducing rear end collisions in Sweden. Fully applied the annual benefits for the lamp from reduced property damage are estimated at 60 million SEK. The insurance companies jointly have now launched a campaign to persuade car owners to equip their cars with high mounted stop lamps.

In order to increase conspicuity of heavy and long vehicles, Sweden is applying the ECE Regulation No. 70 (rear marking plates) for trucks, tractors, trailers and semi-trailers with a weight exceeding 3.5 tons.

Sweden, in 1973, introduced a national requirement for side marker lamps on trucks exceeding 6 m and all trailers, to make these vehicles more visible for the side. Now ECE has decided on a Regulation for side marker lamps, with requirements similar to ours. This draft regulation has gathered wide support in Europe.



Killed and Injured in Road Traffic Accidents, Cars in Use and Petrol Deliveries 1968-1990 (Index 1968 = 100)

United States

George L. Parker

Highway Traffic Safety Administration
National Highway Traffic Safety Administration

The first International Technical Conference on Experimental Safety Vehicles (ESVs) was held in Paris, France, 20 years ago. Since the first Conference, dramatic changes in automotive safety have occurred worldwide due in part to the collaborative safety technology efforts brought about by these conferences. Many of the experimental safety devices developed under the original program are standard equipment on motor vehicles built today. Through these and other conferences dealing with motor vehicle safety, we have been able to increase, on an international level, the importance of motor vehicle safety.

The commitment to motor vehicle safety in the United States is as strong today as it was in 1971 when NHTSA's Chief Scientist, Dr. Robert Brenner, announced to the audience the "best wishes of President Nixon for a successful meeting." Today, President George Bush is equally concerned with transportation issues, and, in February 1990, he issued a National Transportation Policy (NTP). The President, through this national policy, has made a commitment to the American public to continue to "cut the death rate and reduce the traffic death toll below the current level through the next decade, even in the face of increasing travel."

This transportation policy has been fully supported by the U.S. Department of Transportation and has brought transportation issues to an even higher level of awareness nationwide. One of the major themes of the NTP is to "Ensure that the Transportation System Supports Public Safety and National Security." Naturally, this encompasses all modes of transportation, however, a major challenge rests with the National Highway Traffic Safety Administration (NHTSA) to reduce the more than 44,000 deaths and 4.8 million motor vehicle related injuries which occur annually on U.S. highways.

The National Highway Traffic Safety Administration has planned a vigorous Research and Development program to support the President's NTP goals and to meet the demands of future transportation safety. Currently, motor vehicle fatalities account for more than 90 percent of the transportation fatalities, and are the leading cause of injury in the United States. As part of an overall program, we have developed a 5 year R&D plan which addresses all aspects of motor vehicle safety. The program plan deals with the problems of today, such as enhanced data collection activities and vehicle crash avoidance and crashworthiness issues. We have also examined the issues that may be of concern in the next century. NHTSA has begun actions to help ensure that the needs of the older driver population will be met, that advanced technology from Intelligent Vehicle/Highway Systems (IVHS) programs will be fully used to improve crash avoidance and will be a benefit rather than a hindrance to drivers. We have also initiated programs with university centers to help ensure the science of motor vehicle safety continues into the next decade.

In addition to its R&D plan, NHTSA has developed an Agency Priority Plan which describes aggressive programs to address traffic safety. These programs and activities include reducing the length of time to issue rulemaking actions; developing programs for State and community implementation which will increase safety belt usage to 70 percent by the end of 1992, increase proper child restraint usage, and reduce the number of drug and alcohol related crashes. NHTSA is also strengthening its 1987 collaborative pilot project with the Centers for Disease Control in the areas of data collection linkages and biomechanics. The Centers for Disease Control program is still growing, having just held its Third Injury In America Conference which was co-sponsored by NHTSA. The theme for this year's Conference focused on a National Agenda for Injury Control, which includes motor vehicle safety issues for the year 2000.

Crash Environment

Since 1971 the fatality rate has been dropping in the U.S. Fatalities per 100 million vehicle miles travelled were 4.5 in 1971 and had declined to 2.1 in 1990. Other fatality rates have also declined. The rate per 100,000 population dropped from 25.40 to 17.90; and the fatality rate per 100,000 registered vehicles declined from 45.17 to 23.08. This year, we estimate that 44,000 people will die, another 523,000 will be hospitalized, and 4.8 million will be injured but not hospitalized as a direct result of motor vehicle crashes. Based on a May 1991 Federal Highway Administration report, the average lifetime cost per person injured by a motor vehicle in the U.S. is $21,000. The average cost per fatality in the U.S. is $652,500, for a serious injury (AIS 3-5) the cost is estimated at $106,600 and for a minor injury the cost is estimated at $7,727. All of these estimated costs include property damage.

Passenger car fatalities are still the largest proportion of U.S. fatalities—54 percent for 1990 followed by light trucks and vans at 19.3 percent. Nonoccupant fatalities accounted for 16.7 percent, and motorcyclists represented 7.3 percent of the fatalities. The number of deaths in each of these categories was down compared to 1989.

How much progress have we made in the United States over the last 20 years? It is projected that if we had remained at the 1971 fatality rate level, 96,600 people would have died on the U.S. highways in 1990.

We have made tremendous progress over the last 20 years, but we still have a long way to go.

While we continue with our R&D efforts, our rulemaking activities and our state and community programs directed towards reducing motor vehicle fatalities and injuries, we must also look toward the challenges the next century may bring and be prepared to meet the requirements of intelligent vehicle/highway safety systems, and the needs of an older driving population.

Crash Data Collection and Analysis

The National Highway Traffic Safety Administration's National Center for Statistics and Analysis develops and uses large scale automated data bases to support problem identification, program planning, and program evaluation. We have made several important changes to our data collection sources which we believe will be of benefit not only to our Agency, but also to the entire highway safety research community, nationally and internationally.

Our crash data system is composed of several components serving varying needs. Our Fatal Accident Reporting System (FARS) is a census of all fatal crashes occurring on public roads in the U.S. Our National Accident Sampling System (NASS) is a yearly collection of data from a statistically representative sample of crashes occurring in the U.S. This system is composed of a Crashworthiness Data System and a General Estimates System. These two primary crash data systems, FARS and NASS, are complemented by State crash data systems compiled from police accidents reports for a number of States.

NHTSA's Fatal Accident Report System (FARS) is a system which provides basic information on all highway traffic crashes in the U.S. in which one or more people die of injuries within 30 days of the crash. This automated data base system has been in operation for the past 16 years and contains detailed information (over 100 data elements on each fatal crash) on approximately 800,000 fatalities. In 1991, 15 additional data elements were added to the FARS collection to focus on crash avoidance maneuvers, heavy trucks and their cargo, and occupant ejection path. We are also continuing the 1987 initiative to link FARS data with information from death certificates and our collaboration with the Federal Highway Administration to expand its Trucks in Fatal Accidents (TIFA) file. The TIFA file contains information extracted from the FARS files and FHWA's motor carrier accident files. FHWA's motor carrier data files contain detailed information on regulated carriers such as the characteristics of medium/heavy trucks involved in fatal crashes, cargos carried, configuration of the trucks, and the characteristics of drivers operating them. These efforts provide us and the entire highway safety research community with valuable insight into the factors influencing injury severity, the crash involvement of heavy trucks, and other critical areas in fatal traffic crashes.

Our National Accident Sampling System (NASS) provides information from investigations of a statistical sample of police reported crashes at all levels of injury severity. NASS is composed of two data files, the Crashworthiness Data System (CDS) which contains detailed information on approximately 7,000 crashes each year and the General Estimates System (GES) in which crash information is extracted from a sample of about 46,000 police accident reports annually. In 1990, a 6-month NHTSA-wide review of the Agency's crashworthiness data needs concluded that "representative national estimates" were essential to the Agency's research and regulatory programs and that the CDS sampling plan should be modified to increase the likelihood of selecting crashes that resulted in serious injury. Because it has been shown that a person who is actually hospitalized is more likely to have a serious (AIS 3+) injury than one who is not hospitalized, the CDS sampling methodology will be modified in 1992 to identify such crashes. This revision is expected to yield about 20 percent more serious injury cases. Work also is in progress to convert the CDS to the AIS 90 injury coding and to add other available and useful trauma data to the data files. The General Estimates System provides data necessary for the Agency to produce accurate estimates of the magnitude and general trends in highway safety. In 1989, the GES sampling plan was modified slightly to increase the annual sample of heavy truck crashes to about 7,000.

NHTSA's State Data Systems Program provides a data base consisting of all police reported crashes. This data base allows for a wide variety of highway safety issues to be assessed. Collectively, the 50 United States spend over 500 million dollars each year collecting information about the crashes that occur on the Nation's highways. There are over 13 million police reported crashes annually. A major effort to enhance the analytic utility of police reported accident data was initiated in 1990. The objective of this program is to create national uniformity in the variables that are essential to the use of police reported accident data for highway safety analyses. This can be achieved by adding a limited number of critical automated data reporting elements (CADRE) to those the States already collect. A final list of CADRE items will be published in the Federal Register this fall, and we are working with the States to ensure the adoption of these new data elements in all States. In addition, we have expanded our use of State accident files as a source of data, and currently have on hand data from 28 States. These data cover several years of crash experience and have been a valuable source of information for crash avoidance, crashworthiness, and highway safety analyses.

Another data collection activity that we have placed a high emphasis on is linking crash data files to hospital records, trauma center records, and emergency services system records, better known as trauma files. We believe the trauma data are a potentially important source of information for quantifying the relationship between crash characteristics, motor vehicle design features, and the injury consequences of motor vehicle crashes. At present, however, obstacles to linking these data with police accident reports remain and experience in utilizing these data to address many highway safety issues is limited. An initial investigation of these issues is being examined in a joint protect with the State of Virginia to study injury mechanisms in motorcycle crashes. This project will provide the experience needed to assess the extent to which trauma data can support highway safety analytic requirements. This project will also assist in developing a model trauma data system and assessing the status of trauma data systems nationally.

Major analytic activities undertaken by the Agency since the last ESV Conference include: an analysis of occupant head injury protection, relative injury/fatality risks for front and rear seat child occupants, an investigation of door latch and hinge failure, an analysis of the characteristics of heavy truck crashes, a study of the relationship between measures of static and dynamic vehicle stability and light duty vehicle rollover propensity; and an investigation of the relationship between passenger car weight and fatality and injury likelihood. We are presently estimating that from 1983 through 1990, almost 25,000 lives have been saved by the use of safety belts; from 1982 through 1990, over 1,500 children's lives have been saved by the use of child restraints; and from 1982 through 1990, over 4,700 lives have been saved from the use of motorcycle helmets. We estimate that lives saved from 21 year old minimum drinking age laws currently average approximately 1,000 per year, with over 11,000 lives saved since 1975.

Motor Vehicle Safety Research Advisory Committee

In May of 1987, the Motor Vehicle Safety Research Advisory Committee (MVSRAC) was established to foster increased communication with researchers working in industry and academia. The Committee has served as a forum for the consideration and communication of current and planned research projects of both NHTSA and other organizations.

The Committee has provided the Agency with information leading to a better understanding of motor vehicle safety research needs in the areas of rollover crash prevention and protection, biomechanics of injury, crash data analysis, heavy truck safety, and the use of "Information Age" technologies to improve motor vehicle safety. Subcommittees have been established to examine specific research topics in greater technical detail.

Crash Avoidance Research

Crash avoidance research continues to provide the basis for reducing the number of crashes and/or their severity through changes to the vehicle to improve the vehicle's performance or the match between the driver and the vehicle.

Intelligent Vehicle Highway Systems

A major new initiative in Crash Avoidance research since the last ESV Conference is the Intelligent Vehicle/Highway Systems (IVHS) program. Recent developments in the fields of electronics, artificial intelligence, and communications provide the basis for designing and producing the smart sensors, computers, and control systems needed to facilitate and augment driver and vehicle performance. In-depth crash investigation studies in the United have consistently shown that human error is a major contributory factor in most crashes. Advanced technology provides the potential to help drivers better sense impending danger, sense and alert drivers of lapses in their judgement or skill, aid them in performing the driving task, and, ultimately, compensate for some of their errors.

NHTSA's efforts in IVHS have two major thrusts. First, NHTSA is embarking on an extensive program to define specific crash avoidance situations and conditions, to develop performance specifications for promising IVHS applications that could improve the crash avoidance capabilities of drivers and vehicles in these situations, and to evaluate the performance, reliability, and costs associated with developed products and systems. Second, NHTSA is working with other DOT agencies and other participants to assess the safety impact of other IVH systems which are being developed primarily for their mobility or congestion relief benefits.

The keystone of the NHTSA performance specification research will be multidisciplinary programs for countermeasures that help prevent crashes or help reduce the severity of a crash. The programs will require the integration of a number of facets. An initial step will be a review of collision data files such as the National Accident Sampling System (NASS), the General Estimates System (GES), the Crash Avoidance Research Data file (CARDfile) and individual State databases as a means of defining problems in a quantitative way. This review will be coupled with preliminary estimates of benefits that might accrue to the implementation of various countermeasures. This study is already underway and is expected to be completed by mid-1992. The initial problem definition step will be followed by individual programs to develop performance specifications for countermeasures for high priority problem areas. These individual programs will include development of specifications for the performance of the driver/vehicle interface as well as the performance of such hardware features as sensors, data processing equipment, and software and communication links. A key question that will be addressed in each program is "What is the best way to elicit a necessary collision avoidance action from a driver"? It is expected that initial work will focus on rear-end collisions, collisions associated with lane-changes, collisions that involve leaving the road, and intersection collisions. These programs will be initiated this year and will be integrated with human factors projects that are already in place. Current human factors projects include an assessment of driver workload, studies of the human factors considerations for in-vehicle crash avoidance warning signals, and development of a capability for vehicle-based driver performance monitoring.

In the second area, the current emphasis is on congestion relief systems that provide route guidance and navigation information to drivers. An underlying hypothesis of these systems is that drivers with such a system will be able to navigate better than drivers who do not. If this is true, drivers should have a more worry-free and safer driving experience because they would be routed around congestion and delay-causing incidents, and should, therefore, spend less time being lost or confused about their location. The counter hypothesis is that drivers might need to devote so much time and attention to obtaining the necessary information that safety could degrade. Thus, these systems may have a measurable impact on safety, either positive or negative, depending on their design and operation. These two sides of the safety question will be addressed as part of the system evaluation.

NHTSA is currently working with other partners (General Motors, the American Automobile Association, the Federal Highway Administration, the State of Florida, and the City of Orlando) to evaluate the performance of the TravTek system. TravTek (short for Travel Technology) is an advanced motorist information demonstration project which will provide navigation assistance, real-time traffic information, route selection, and other information to tourists and other travelers in Orlando, Florida, for a period of 1 year starting January 1, 1992. A key element of the TravTek program is inclusion of a plan to evaluate trip/network efficiency, congestion avoidance, time savings, system reliability, and safety. NHTSA expects to continue to work cooperatively with its sister administrations within the Department of Transportation to assess the safety impact of future field operational tests.

Human Factors

Since the last Conference our human factors program has included:

- Work was completed describing the functional and performance specifications for passive retro-reflective marking systems that could be added to heavy truck trailers to make them more conspicuous to other drivers at night.
- Two studies were completed to evaluate the performance requirements needed for daytime running lights (DRL). One study examined the upper intensity limits needed to control glare from DRL in rearview mirrors, and the other involved collecting data on minimum intensity levels needed to enhance vehicle conspicuity under daytime ambient light levels.
- Research was continued on developing headlight system illumination requirements based on driver visibility needs and glare limits. We examined the ability of existing object detection models to predict driver capabilities and are developing a computer-based analysis procedure to derive illumination requirements for a headlight systems.
- Because of concerns about the number of children struck by school buses, research was undertaken to determine human factors requirements for crossview convex mirrors.
- A study was completed of the various human factors issues associated with foot pedal configurations. This research was in response to concerns about "sudden acceleration" crashes that may have been caused by drivers hitting the accelerator instead of the brake.

In addition, over the past year, the Agency implemented a comprehensive human factors research program to support the expanding effort to develop Intelligent Vehicle/Highway Systems. The goal of the Agency's human factors program is to ensure that the IVH systems are suitably matched to the capabilities and limitations of the drivers who must use the devices. An extensive series of studies are planned to quantify critical driver sensory, perceptual, and motor capabilities, and to define and measure relevant mental and decision making capabilities and their interactive role in driving safety. The initial Agency initiative includes:

- A project to determine how best to present/display crash avoidance warning signals to drivers in ways that will ensure they understand them quickly and respond appropriately. A key issue to be addressed is whether standardized system function characteristics and display formats for each system are needed/appropriate to avoid driver confusion. Also, in situations where multiple systems are employed, hierarchies will be developed describing which systems should take precedence over others, so that competing signals are not simultaneously presented to drivers.
- A project to determine if real-time measurements of drivers' driving performance can be made and assessed as a basis for developing an in-vehicle monitor that could warn drivers of transient lapses in a driver's performance.
- A project to develop measurement techniques for assessing the extra workload imposed on drivers by

additional displays, warning signals, or other aids that are equipped on vehicles ostensibly to help drivers better navigate or control their vehicle.

- A project to develop standardized methods of measuring and evaluating the visual content and informational value of the direct and indirect visual fields of view out of a vehicle that are afforded drivers.

National Advanced Driving Simulator

NHTSA is assessing the merits of constructing a National Advanced Driving Simulator (NADS) to support a national research program to achieve improvements in the transportation system through reduced crash rates, improved vehicle design, increased roadway efficiency, and expanded mobility for special populations such as elderly and handicapped drivers. Realistic high fidelity simulation would provide researchers with the ability to: (1) examine hazardous situations in great detail that cannot be evaluated in field test conditions because of the possible safety hazard to test subjects, (2) exactly replicate conditions for a large number of subjects thereby enabling a genuine assessment of the role of human factors in traffic safety, (3) acquire for the first time accurate measures of human response and control during critical crash situations, and (4) exercise precise experimental control of environmental conditions (ice, snow, fog, etc.), vehicle characteristics, and human characteristics. Research projects would focus on the complex interactions among the vehicle, the driver, and the highway environment by means of multi-variate experiments that involve operator-in-the-loop driver performance during critical driving situations.

The technical feasibility and conceptual design study of the NADS has been completed. No technical barriers were identified in this analysis.

Two NHTSA-sponsored studies have been completed to identify the research needs of potential user groups, such as automobile and truck manufacturers, vehicle component suppliers, traffic safety engineers, highway designers, public health officials, human factors researchers, and motor vehicle administrators. These data will be used as the basis for developing detailed functional design specifications for the simulator facility. In addition, the Transportation Research Board conducted an independent assessment of user needs.

The National Science Foundation (NSF) provided assistance to the U.S. Department of Transportation in conducting a national competition among major transportation research universities to identify the qualified educational institution to host the NADS. NSF has provided the results of its efforts to the Department.

Heavy Vehicle Research

Heavy truck safety continues to draw a great deal of publicity and attention in the U.S. Heavy truck crashes are not unduly frequent, but are often spectacular. They frequently result in fatalities, usually to occupants of other vehicles involved in collisions with trucks, and often lengthy traffic tie-ups result. Current vehicle-related research programs intended to reduce heavy truck crash and injury rates are focused on brake system performance, handling and stability, crashworthiness/aggressivity reduction, and human factors.

Five different tractor antilock systems have been evaluated on the test track in a range of braking and steering maneuvers. As a result of this effort, we have a much better understanding of the relationship between cost/complexity and performance. The 2-year, in-service field evaluation of 200 antilock brake-equipped heavy truck tractors has been completed. Seventeen fleets, the seven major U.S. heavy truck manufacturers, and the five suppliers of antilock brake systems, cooperated in this test involving vehicles based in six cold weather climate cities. Maintenance records, data from a special on-board instrumentation system, and feedback from drivers and mechanics were used to judge the reliability, durability, and maintainability of the systems. In 1990, the program was expanded to include the evaluation of antilock systems on 50 trailers.

The Heavy Truck Subcommittee of the Motor Vehicle Safety Research Advisory Committee has been very active, forming two task groups, one on antilock brake test procedure development, the other on tire traction performance measurement. The antilock brake test procedures task force successfully conducted a series of round-robin tests at several different industry and government test sites focusing on the issue of test surface variability.

The tire research task force presented a plan for an industry/government cooperative research program, which the Agency is in the process of implementing. The first phase of the program involves developing standardized methods of measuring and reporting truck tire traction performance. The second phase will involve testing a wide of range of tires with the test procedure to develop a catalogue of data characterizing the range of performance available from current tire designs.

Light Vehicle Rollover Research

Utility vehicles and light pickup trucks continue to make up an increasing share of the U.S. car market. At the same time, crash data studies conducted by NHTSA and others show that these vehicles demonstrate an over involvement in rollover crashes. The crash data also shows that rollover crashes produce higher levels of fatalities and injuries. NHTSA has completed an extensive research program to investigate the causes and possible solutions to light vehicle rollover crashes. As a part of this research effort, an extensive rollover crash database was constructed and validated with respect to such things as vehicle make/model identification, crash factor definitions, and data coding. A full scale vehicle test program was conducted to reveal the vehicle factors influencing rollover and to generate vehicle dynamics data for validating a vehicle handling simulation being used to study vehicle rollover. In addition, a statistical analysis of these results was performed to assess or establish correlations between rollover rates and vehicle characteristics such as wheelbase and center of gravity location. Continuing rollover research at NHTSA will involve primarily additional statistical analysis of our rollover database to further define the magnitude of the contributions of vehicle, driver, and environmental factors to vehicle rollover causation.

Crashworthiness Research

NHTSA's Crashworthiness research program currently focuses on three major crash modes for the protection of occupants of passenger cars, trucks, and vans: frontal, side impact, and rollover. The fundamental knowledge necessary for crashworthiness advances is obtained through our biomechanics research efforts. NHTSA's crashworthiness programs have successfully applied this scientific approach to achieve major advances in motor vehicle safety such as air bag automatic crash protection systems. Crashworthiness advances presently being developed will further advance the state-of-the-art in vehicle design crash protection. The end result will be the development and application of cost-effective motor vehicle safety technologies that prevent injuries and save lives.

Crash Data Files

NHTSA is using the National Accident Sampling System (NASS) and Fatal Accident Reporting Systems (FARS) crash data files to support the problem determination phase of its crashworthiness research projects. The NASS data contain very extensive detailed information regarding each available case. For the various research projects, these data are being reviewed to identify the number and types of injuries, the mechanisms causing the injuries, and the associated crash conditions, and vehicle parameters.

Also, NHTSA is continuing to utilize the crash data files from individual States to supplement the FARS and NASS crash files. The Crashworthiness State Database (CWSD) currently consisting of three States, Pennsylvania, Texas, and Indiana, has been developed to particularly support the crashworthiness programs of the Agency. These particular States were selected because of the detailed information contained on make/model designation, body regions injured, injury source, and other important crashworthiness parameters.

Frontal Crash Protection

With the implementation of Federal Motor Vehicle Safety Standard (FMVSS) No. 208, which requires automatic occupant protection in frontal collisions, continuing research is focusing on identifying the remaining safety problems for restrained occupants. While the lives and injuries which will be saved by this standard are substantial, it is estimated that, even after full implementation of this standard, frontal impacts will account for approximately 10,900 passenger car and light truck fatalities per year. Research has been initiated to investigate concepts to mitigate this safety problem including the evaluation of advanced automatic restraints, improved structural integrity, and improved energy absorbing interiors. Crash data, full scale crash testing, and analytical modeling are providing NHTSA insight into the magnitude of the problem and specific injury mechanisms.

Crash environments being investigated include higher speed impacts and offset impacts which can result in high levels of intrusion. Improvements to interior components such as the steering assembly, instrument panel, and pillars are continuing to be tested, especially as to their ability to reduce head injuries.

Side Impact Research

The Agency's research program for the last several years culminated in the issuance of a Final Rule amending FMVSS No. 214 in October 1990. In this amendment, a dynamic test procedure has been specified for passenger cars to augment the static test procedure written to provide side door strength. The new dynamic test procedure establishes minimum requirements for thoracic and pelvic protection for near-side occupants in side impact crashes. Research has been completed that demonstrates the specified protection levels can be achieved by structural modifications and/or the addition of side door padding. Even though the near term side thorax and pelvic impact research has been concluded, work has been continuing in both the analytical and testing area. We have developed a mathematical model for simulating passenger car side crashes. This model has been extensively used in parametric studies and countermeasure evaluation. We are extending this model to simulate light truck crashes.

Light truck testing was initiated in 1988. We are currently using the amended FMVSS No. 214 dynamic test procedure to continue side impact testing of light trucks and vans in order to develop baseline data on these vehicles. Particularly, we are focusing on light trucks and vans (LTVs) in which the seated height of the occupant is similar to that of passenger cars.

Even with the upgrade of FMVSS No. 214 to address the thoracic and pelvic injuries, head injury remains as a major contributor to the fatal harm experienced in side crashes. Unfortunately, even survival of a head injury is frequently debilitating. NHTSA disability studies show that 50 percent of the medium term cognitive impairment is due to contact with the A-pillar and roof rails.

Our upper interior head protection research program seeks to improve head protection in occupant head impacts with the upper interiors of passenger vehicles. The upper interior is defined to be the side roof rails, the front header rails, and the A/B-pillars. Since the last conference, the research program has achieved several important milestones. As a result of this program, an updated analysis of the U.S. crash data was done and we now estimate that, in 1989, head impacts with the upper interior claimed the lives of an estimated 4,000 persons and left another 9,300 occupants with serious head injury. The program has developed a promising component level head impact test procedure which has been extensively validated in sled tests. Most recently, the program has completed a characterization of head injury potential across a sample of the U.S. passenger car and LTV fleet. We have found that head impact injury potential is a strong function vehicle design, and protection varies widely from vehicle to vehicle. Minivans and vans appear to have designs which yield severe responses. However, padding the upper interior was found to be a feasible and exceptionally effective method of reducing head injury potential.

Ejection Reduction Program

Approximately 9,300 people are killed each year on U.S. highways as a result of ejection from passenger cars and light trucks. Of these, about 3,300 are ejected through the side doors. NHTSA has conducted studies of crash-involved vehicles where door latch failures may have occurred in order to understand the failure mechanisms in crashes. A number of tests have been conducted to determine the ultimate strength of latches on various makes and models of vehicles using procedures in the current door latch safety standard. To date, there has been no strong correlation found between openings and the measured latch strength. New test procedures are being developed to mimic the combined longitudinal and lateral loadings the door latch was observed to have experienced in a recent review of crashes involving door openings. This combined loading provides a more realistic representation of the latch failures seen in the real world crash experience.

Rollover Research

Our research in crashworthiness rollover protection has emphasized a refined definition of the problem, the development of improved test devices, and analytical techniques. Experimental testing has continued to concentrate on the crashworthiness of LTVs in a controlled rollover event. These were recently conducted on small pickup trucks to assess the structural integrity of the vehicles. We have initiated finite element modeling of the roof structure to explore possible design changes which would improve the roof structure performance and to determine its effect on restrained occupant injury. We have also continued to improve our rollover simulation capability by improvements to the Articulated Total Body (ATB) occupant simulator. Advanced restraint system concepts are being explored with the ATB model.

Biomechanics Research

The primary pursuits in the area of biomechanics continue to be efforts in impact injury research directed toward increasing our understanding of injury mechanisms, development and application of unique instrumentation necessary to capture and characterize the mechanical conditions of injury that conventional instrumentation cannot measure, application of finite element modeling technology toward detailed structural modeling of the human, and the efforts to translate this knowledge into physical test devices that will enhance our ability to assess and ameliorate the hazards of the automotive crash.

Impact injury research activities are now being pursued at three NHTSA-sponsored Impact Injury Research Centers: the University of Virginia, the Medical College of Wisconsin, and the University of Heidelberg. These centers have now fully implemented the NHTSA-developed deformation measuring methodology which can determine the cross-sectional geometry of the thorax during impact events and are investigating the performance of various safety systems in frontal impacts. The greater detail of the actual deformations of the thorax during impact provided by this instrumentation promises to give greater insight into the injury mechanisms at work in frontal impacts, which, in turn, should provide more definitive means and methods of evaluating accurately the safety of vehicles in the future.

Efforts to apply the finite element technology to the detailed modeling of anatomical structures are continuing. In addition to ongoing efforts to develop detailed anatomical models of the brain/skull and the complete upper torso, development of a cervical spine model has also been undertaken. These models, when fully developed, will be capable of simulating, for the variety of automotive crashes, both the impact response and the type, location, and severity of any expected injuries.

We have completed the design, development and construction of the first prototype of NHTSA's advanced test dummy thorax. This design has achieved greater thoracic anatomical similarity than current dummies by extending the lower rib cage and improving the shoulder, spine, and clavicle structure. It possesses more realistic regional stiffness characteristics to insure proper interaction with safety belts and air bags and has improved impact response fidelity while reducing temperature sensitivity and material dependence. An initial design evaluation effort will start shortly, and we hope to involve as many interested organizations as possible. Efforts also continue on the development of an advance neck which will present the head to possible impact points with a more correct attitude and velocity, as well as mimic observed human responses more accurately than current neck systems do.

Highway Safety Research

NHTSA's behavioral research program continues to concentrate on alcohol and drug impaired driving and occupant protection. In addition, we have developed a research plan on ways to improve the safety and mobility of older drivers and pedestrians in response to the rapid expansion of this segment of our population.

Alcohol and Drug Safety Research

During the last decade, our alcohol research program has developed, tested, and evaluated specific countermeasure techniques and strategies such as eye gaze nystagmus, license suspension, and combined enforcement and publicity programs. Many of these techniques were found to be effective and are used in States and communities around the nation.

Our current alcohol research emphasizes four areas:

- Norms Development. We are identifying changes that have to be made in attitudes, knowledge, motivations, etc., to gain wider acceptance of ANTI-DWI standards of behavior; as well as studying ways of inducing these changes.
- Youth. We are investigating and evaluating the effects of strategies such as special sanctions for youth who drive after consuming alcohol and programs to support the 21 minimum drinking age.
- Deterrence. We are studying the effects of specific sanctions for driving while intoxicated, including vehicle and license plate impoundment and insurance sanctions.
- Community Traffic Safety Programs. We are developing methods to support alcohol and other traffic safety programs at the community level.

Our drug research seeks basic knowledge on the influence of drugs in traffic safety. We are assessing the incidence and role of drugs in fatal traffic crashes and are measuring the effects of different doses of specific drugs in a driving simulator and in on-the-road driving.

Safety Belt Use Research

The first safety belt use law in the United States became effective in the State of New York in December 1984. At the time, belt use (as measured by our survey of passenger car drivers in 19 U.S. cities) was 15 percent. At the May 1987 ESV meeting, we reported that 24 States and the District of Columbia had passed belt-use laws and belt use had reached 42 percent. Our report at the 1989 meeting noted laws in 33 States and the District of Columbia and belt use at 47 percent. We are pleased to report continued passage of State belt-use laws: we now have laws in 41 States and the District of Columbia. Earlier this year, NHTSA embarked on a program, in partnership with the States, to increase safety belt use to 70 percent by the end of 1992 through a combination of public information and belt law enforcement. Our 19-city survey results now show belt use at 54 percent, but use determined from State surveys is 59 percent.

NHTSA's current research on occupant protection spans several areas: (1) completing demonstrations of integrating safety-seat and belt-law enforcement and public information into regular police activities; (2) identifying characteristics of population subgroups involved in fatal crashes in order to develop more effective strategies for reaching these groups with better-defined messages; (3) developing program strategies for identified target groups such as part-time users and parents of young children. We continue to monitor belt use trends and provide assistance to in designing, conducting, and analyzing belt observation surveys.

Motorcycle helmet use is now required for all motorcyclists in 24 States and the District of Columbia. Motorcycle driver helmet use observed in the 19-city survey shows that, in cities covered by State helmet-use laws, nearly all drivers are helmeted. In cities not covered by laws, however, fewer than 50 percent of drivers wear helmets.

Older Drivers and Pedestrians

Our older driver and pedestrian research is aimed at reducing crash risks without unduly restricting personal mobility. We have examined existing State licensing requirements and procedures that apply specifically to older drivers, especially testing requirements based on advanced age alone, and the use of restricted licenses for drivers with marginal qualifications. Working with the American Association of Motor Vehicle Administrators, we have contributed to the development of model licensing regulations for older drivers. We have completed development of information programs for older pedestrians and are studying the concept of creating safety zones around housing areas for our older citizens.

We are currently analyzing data obtained from a cooperative study with the National Institute on Aging relating health status, driving practices, and crash experience of older persons. Our long-term research is directed toward developing methods for detecting problem older drivers and providing guidance for physicians, occupational therapists, family members, and licensing officials in assisting older drivers make appropriate decisions about driving.

Rulemaking

Since our last meeting in Sweden, NHTSA's rulemaking activities have resulted in 26 regulations or proposed regulations. Eighteen of these were in the area of crashworthiness, while eight were related to crash avoidance. Some of the more noteworthy actions were the extension of the passenger car Occupant Crash Protection standard (FMVSS 208) to light trucks, the amendment to FMVSS 214 (Side Impact Strength) to include dynamic performance tests requirements in addition to static test requirements for passenger cars. Standard 214 was later amended for extension to light trucks. The following represents the actions taken by NHTSA since May of 1989.

Crashworthiness:

- On June 14, 1989, a Final Rule was published adding the requirement to FMVSS No. 208, "Occupant Crash Protection," that lap/shoulder belts be installed at all forward-facing rear outboard seating positions in passenger cars. The purpose of the rulemaking was to provide more crash protection to rear seat occupants that than that of the previously required lap belts. The effective date was December 11, 1989.
- On September 25, 1989, a Final Rule was published extending FMVSS No. 202, "Head Restraints," to light trucks. The purpose of the rulemaking was to reduce the frequency and severity of neck injuries in light trucks. The effective date was September 1, 1991.
- On November 2, 1989, a Final Rule was published extending the rear seat lap/shoulder requirement of FMVSS No. 208, "Occupant Crash Protection," to light trucks. The purpose of the rulemaking was to create more effective crash protection for rear seat occupants in light trucks. The effective date was September 1, 1991.
- On December 21, 1989, a Notice of Proposed Rulemaking (NPRM) was published establishing performance requirements for automatic locking retractors in seat belt systems, in FMVSS No. 208, "Occupant Crash Protection," for trucks, buses, and multipurpose passenger vehicles over 10,000 pounds gross vehicle weight rating (GVWR). The purpose for the rulemaking was to make these seat belt systems more comfortable, and thus increase the usage. The effective date was May 28, 1991.
- On July 26, 1990, a Final Rule was published amending the Agency's specifications for the 3-year-old child test dummy used to test child restraint systems. Specifications are provided for a new head with a higher natural frequency response and for two different types of accelerometers which may be used. The effective date was May 28, 1991.
- On October 30, 1990, a Final Rule was published amending FMVSS No. 214, "Side Impact Strength," to include dynamic performance test requirements, in addition to static test requirements, for passenger cars. The effective date was November 29, 1990.
- On January 29, 1991, a Final Rule was published amending FMVSS No. 208, "Occupant Crash Protection," so that manufacturers would have the option to use the automatic safety belt warning systems in passenger cars equipped with manual belts. The warning system for cars equipped with manual belts is not as stringent as the one for automatic belts. The effective date was January 29, 1991.
- On March 15, 1991, a NPRM was published proposing to enhance the objectivity and applicability of school bus joint strength requirements and test procedures in FMVSS No. 221, "School Bus Body Joint Strength." Its purpose is to clarify and expand procedures for testing the strength of school bus body joints.
- On March 15, 1991, a NPRM was published proposing to increase the minimum emergency exit space, based on the capacity of the bus, in FMVSS No. 217, "Bus Window Retention and Release." The proposal would also require school buses to provide improved access to side emergency doors.
- On April 16, 1991, a Final Rule was published amending FMVSS No. 208, "Occupant Crash Protection," and No. 209, "Seat Belt Assemblies," to eliminate the static testing requirements for safety belts that are dynamically tested. This has been amended because the dynamic test more accurately reflects the occupant protection in a crash. The effective date was April 16, 1991.
- On June 6, 1991, a Final Rule was published amending FMVSS No. 201, "Occupant Protection in Interior Impact," to alter the requirements concerning the instrument panel for vehicles with passenger-side air bags. The purpose of the rulemaking is to encourage greater availability of such air bags. The effective date was July 8, 1991.
- On February 19, 1991, a NPRM was published proposing to modify FMVSS No. 213, "Child Restraint Systems," to require manufacturers of child safety seats to provide a postage paid registration form to first purchasers of the seats.
- On March 21, 1991, a Final Rule was published extending the front-seat automatic crash protection requirement of FMVSS No. 208, "Occupant Crash Protection," to light trucks. The rule will be phased in during the model years 1995-1997 and will be fully effective in the model year 1998.
- On April 16, 1991, a Final Rule was published extending FMVSS No. 216, "Roof Crush Resistance," to light trucks of 6000 pounds or less GVWR. The purpose of the rulemaking is to resist intrusions in the roof by providing crush resistance. The effective date is September 1, 1993.
- On June 10, 1991, a Final Rule was published extending FMVSS No. 214, "Side Door Strength," to light trucks. The purpose of the rulemaking is to resist intrusions in side doors by providing crush resistance. The effective date is September 1, 1993.
- On July 17, 1991, a notice was published announcing the publication by NHTSA of a planning document that discusses planned research and possible upgrades to FMVSS No. 213, "Child Restraint Systems."

- On August 12, 1991, a NPRM was published proposing modifications to the seat adjustment requirements of FMVSS No. 213, "Child Restraints Systems."
- On August 12, 1991, a NPRM was published proposing adding a newborn infant test dummy to part 572. The issue of using the dummy in FMVSS 213 testing will be explored in future rulemaking.

Crash Avoidance:

- On June 29, 1989, a Final Rule was published amending FMVSS No. 108, "Lamps, Reflective Devices, and Associated Equipment," to include an additional type of standardized replaceable light source to be used in replaceable bulb headlamps on motor vehicles. The effective date was July 31, 1989.
- On April 9, 1990, a Final Rule was published amending FMVSS No. 108, "Lamps, Reflective Devices, and Associated Equipment," to include an additional type of standardized replaceable light source to be used in replaceable bulb for headlamp systems on motor vehicles. The effective date was May 9, 1990.
- On March 26, 1991, a Final Rule was published which replaced the existing FMVSS No. 102, "Transmission Shift Lever Sequence, Starter Interlock, and Transmission Braking Effect," requirement that there must be permanent display of gear position information for automatic transmission vehicles which do not have a gear shift lever park position. This Final Rule requires display of gear position information only when the ignition is in a position capable of operation. The effective date for the deletion of the old requirement was April 25, 1991. The effective date for the amendment was September 23, 1991.
- On April 10, 1991, a Final Rule was published extending the center high-mounted stop lamps requirement of FMVSS No. 108, "Lamps, Reflective Devices, and Associated Equipment," to light trucks with a GVWR of less than 10,000 pounds. The rule is optional as of September 1, 1992, and mandatory as of September 1, 1993.
- On April 19, 1991, a Supplemental NPRM (SNPRM) was published proposing that FMVSS No. 108, "Lamps, Reflective Devices, and Associated Equipment," be amended to allow the physical combination (but not the optical combination) of the center high-mounted stop lamp with cargo bed lamps on vehicles other than passenger cars.
- On May 2, 1991, a NPRM was published proposing that FMVSS 111, "Rearview Mirrors," be amended to increase the field-of-view around school buses. This could be accomplished either by direct view or by mirrors.
- On May 3, 1991, a Final Rule was published establishing a new safety standard requiring new school buses to be equipped with a stop signal arm. The intended effect of this rule is to reduce the risk to pedestrians near stopped school buses. The effective date is September 1, 1992.
- On May 3, 1991, a NPRM was published proposing two alternative amendments to the requirements of FMVSS No. 121, "Air Brake Systems," concerning electrical power systems. The first alternative is that trailer antilock systems would be required to be powered by a separate electrical circuit, with the stop lamp circuit being used as a source of backup power. Under the second alternative, the Agency would rescind the existing requirement that trailer antilock systems be powered from the stop lamp circuit. The reason this rulemaking is being undertaken is that the Agency is concerned that requiring antilock systems to be powered from the stop lamp circuit inhibits some state-of-art trailer antilock systems.

International Harmonization

Finally, in closing, it is appropriate to restate NHTSA's ongoing commitment to fostering worldwide harmonization of motor vehicle safety standards to the maximum extent practicable. This policy is, of course, governed by applicable U.S. laws and procedural requirements, and by our overriding concern that the current level of motor vehicle safety in the United not be degraded.

Efforts toward greater harmonization have been concentrated in the areas of brakes, lighting systems, and side impact protection for passenger car occupants. Also, during the past few years, we have also become more involved in fostering institutional changes to facilitate worldwide harmonization. The following address progress in each of these areas since the 12th ESV Conference.

Brakes

The effort to harmonize brake standards for passenger cars on a worldwide basis began in the early 1980's. At the last ESV Conference, we reported that the issues of a test procedure for measuring adhesion utilization might be resolved by the use of a simple wheel lock sequence test as a screening test with the use of torque wheels as backup. We further indicated that such a test procedure was being evaluated and the results would be discussed in informal sessions of the Meeting of Experts on Brakes and Running Gear (GRRF) of the Economic Commission for Europe (UN/ECE).

The results of those discussions and the review of comments to the previous Supplemental Notice of Proposed Rulemaking (SNPRM) led the Agency to further revise and refine the test procedures and performance requirements and to publish a new SNPRM in July, 1991. It is our tentative conclusion that this new SNPRM will achieve the goals of harmonization while being fully consistent with the requirements of our legislation. The comment period, originally set to end on October 31, 1991, has been extended to January 10, 1992, to provide for the consideration of additional test data to be submitted.

Lighting Systems

At the last ESV Conference we reported on the status of several proposals that had been made to the ECE for further harmonization of lighting standards. At that time, proposals concerning the permitted maximum intensity of yellow rear turn signals and of stoplamps and the amendment of appropriate ECE Regulations to permit the approval of certain replaceable headlamp bulbs had progressed, but were yet to reach fruition.

Given the agreement by the Working Party on the Construction of Vehicles (WP29) that harmonized standards need not be identical standards, but standard that provide corridors of overlapping performance or windows of compliance, agreement was reached on permitting higher intensity levels for yellow rear turn signals and stoplamps in response to U.S. actions concerning the minimum intensity levels. The appropriate ECE regulations have been amended to permit the U.S. HB-3 and HB-4 bulbs while FMVSS 108 has been amended to permit the HB-2 bulb (a closer-tolerance European H-4 bulb). Also, we have been petitioned to amend FMVSS No. 108 to permit the European H-7 replaceable headlamp bulb. The petition is under consideration and a decision concerning rulemaking will be made early next year.

Our proposals concerning center high-mounted stoplamps is still under active consideration within the Meeting of Experts on Lighting and Light-Signalling (GRE). We have reached agreement on the harmonization of vertical installation requirements for lighting systems, and work on harmonization of horizontal installation requirements and harmonized low beam photometric continues. The ECE has adopted a new regulation on optional side marker lamps that sets intensity and color regulations that are not in total agreement with those we would have preferred but which nevertheless will enable compliance by a wide range of vehicle designs.

Side Impact Protection

NHTSA's final rule on upgrading FMVSS No. 214, "Side Door Strength," was issued in October, 1990. The amendment establishes chest and pelvic injury criteria to be used in full-scale crash tests. In its notice, NHTSA addressed the question of harmonization with Europe and noted the differences in the movable barrier (the U.S. barrier being heavier and representative of passenger cars and light trucks likely to be the striking vehicles in the U.S.) and the availability of the EUROSID (side impact dummy) at that time, and the uncertainty, also at that time, as to whether Europe would adopt requirements based on a full scale dynamic crash test. The Agency noted further that as Europe continued to develop its standard and test procedures, it would consider whether further rulemaking is appropriate.

Progress on development of alternative side impact dummies, the EUROSID being one of them, is prompting the Agency to issue an advanced notice of proposed rulemaking on the subject in the very near future.

Institutional Matters

Finally, the United States has been very active in the process of reviewing and revising the "1958 Agreement Concerning the Adoption of Uniform Conditions of Approval and Reciprocal Recognition of Approval for Motor Vehicle Equipment and Parts." The Agreement provides the process by which ECE Regulations are adopted and amended. The current review is aimed at providing a process that is reflective of the world situation in the automotive sector and which will serve the goals of automotive safety and improved environment for the coming years.

France

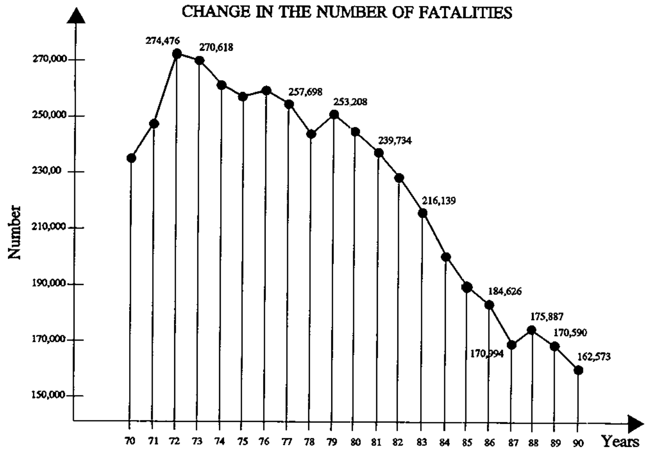
George Dobias
Institut National de Recherche sur les Transports et leur Sécurité

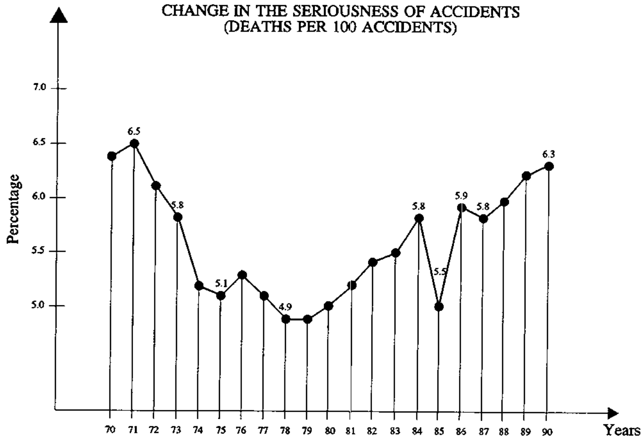
Since 1989, the picture of road safety in France has slightly improved, despite a significant increase of road traffic, especially for inter-urban travel. However, a slowing down in this trend has been noticeable since the end of 1990.

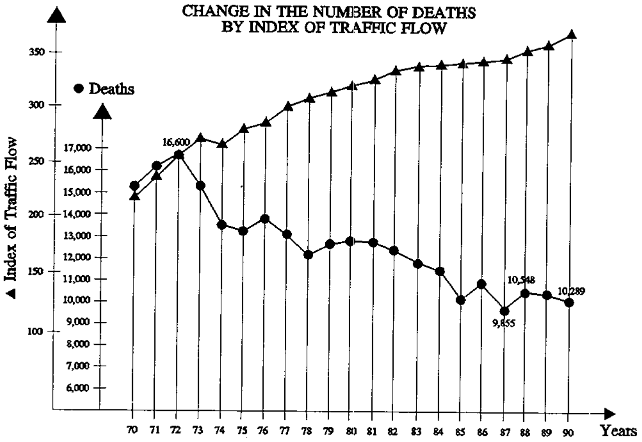
While the number of accidents as well as the number of injured people decreased during this period, the number of deaths was reduced by only a small amount; thus risk exposure goes on decreasing while accident severity measured by the ratio: number of deaths/number of accidents goes on increasing. This negative evaluation appears related to the behaviour of younger drivers driving sporty and powerful cars, to the increase in the number of motorbikes and likely in the number of heavy goods vehicles.

The following diagrams illustrate this evaluation which is not specific to France.

The progress brought in national and local road safety policies, whether they deal with the driver, the vehicle,







the infrastructure or the traffic conditions explain the stated improvements.

- With regard to the driver, training conditions have been renewed on the basis of the National Training Program devised by INRETS following a request by the Ministry of Transport. Application programs have been built and driving school teachers are now being trained. The originality of this program lies within the introduction of some training on car use conditions as well as on possible risk situations the future driver might have to face.

  Simultaneously, the anticipated learning of the driving from the age of 16, with the presence of an experienced driver aboard the vehicle, was extended to the whole French territory. First results seem very promising and the younger drivers, training in this way, have 4 to 5 times less accidents than others.

  At last, the point demerit will be introduced starting from June 1992, with an initial capital of 6 points which, for each recorded offense, will be diminished by a number of points depending on the severity of offense. It will be possible to replenish one's points capital by undergoing a specific training. Such training is now being experimented.
- Regarding the vehicle, the most important measure is the introduction, from January 1, 1992, of a periodical technical inspection, in accordance with the usual practice in other European countries. Seat belt use for rear passengers was also made mandatory on December 1, 1990. The effects of such a measure remain to be evaluated.
- The improvement of road infrastructures has mainly dealt with:
  - the extension of the network of motorways, infrastructures providing the highest level of safety, with a new master plan aiming at adding 4,000 km to the existing network;
  - the continuation of the treatment of accident black spots, with a markedly increased budget for the fiscal year 1991;
  - many actions within cities aimed at opposing physical limitations to traffic speed.
- The main measure regarding road traffic was to lower the usual speed limit within cities from 60 to 50 kmph. Some roads may be posted at 70 kmph and others at less than 50 kmph (especially in residential neighborhoods) through a Mayor's decision.

The State has been going on with its policy of incentives towards local authorities through the promotion of various programs such as road safety plans at the "department" level or "Villes plus sures" (Safer Cities).

In the research and development field, France participated in various EEC or European programs. For example, DRIVE 1 and DRIVE 2 aimed at promoting the use of telematics and information technologies in order to enhance travel safety and efficiency. Various field trails dealing with corridor traffic control (CORRIDORS) or urban network traffic control (POLIS) should be conducted in France within the DRIVE 2 framework. French car makers are involved in the EUREAK, PROMETHEUS and CARMINAT projects, the goal of which is to develop equipment for the road-vehicle/vehicle-vehicle communications and for road guidance.

The French Government decided on October 23, 1991, to launch a research and development program called "Vehicules et securite routiere" (Vehicles and Road Safety). This program, jointly sponsored by car-makers and INRETS, is pursuing several objectives:

- better knowledge of accidents and recent trends with an important research program around accidentology;
- better prevention of accidents, through the development of new driving aids;
- better protection of car occupants while considering the structural aggressivity of opponent vehicles and exploring new means of protection for collisions occurring at higher speeds.

This work will concern both passenger cars and heavy goods vehicles and should lead to the production of experimental vehicles, which is in line with the very philosophy of the ESV conferences. One component of the program will be made up of socio-economic research aimed at the results assessment with regard to the needs and stakes, at checking public acceptance of driving aids, and at promoting a closer partnership between all the parties involved in road safety.

Consequently, the program is aimed at the development of:

- detectors of loss of alertness, devices for stopping against an obstacle, warning devices on elements crucial for safety;
- priority ranking of warning systems;
- systems to actively manage vehicle's behaviour and road/vehicle interaction (simultaneous management of braking, steering, suspension functions balance in critical situations).

Research is to be carried on:

- improving visual perception of environment and signing;
- alerting the driver by continuous monitoring of vehicle functions;
- improvement of vehicle dynamic behaviour;
- data transmission between roadside equipment and the vehicle;
- the effect of traffic on vehicle interactions.

The research program is to focus on road user and car occupant protection, dealing mainly with the following points:

- reduction in severity of frontal impacts against a fixed obstacle and of lateral and frontal impacts between vehicles;
- to improve safety in crashes, i.e., optimization of energy absorption of seat structures and higher performance of seat/restraint device systems;
- road user and car occupant protection in impacts with heavy goods vehicles;
- design of restraint devices for children of various ages;
- improvement of vehicle dynamic behaviour by a better design of chassis structure (modelling, testing), braking and steering;
- reducing the aggressivity of heavy vehicles;
- design of driving and monitoring aids: real time dynamic monitoring (stability and trajectory, vigilance detectors) with priority for motorcoaches and vehicles carrying hazardous cargo.

Another component of this program is the development of a range of driving simulators to be used in cars and heavy vehicle drivers' training, which will take advantage of the achievements of the large driving simulator being built jointly by PSA, RENAULT and INRETS.

Lastly, in March 1991, a Forum of European Road Safety Research Institutes (FERSI) was established to promote a joint scientifical approach of road safety related issues.

Section 3
Technical Sessions

Technical Session 1
Crash Investigation and Data Analysis

Chairperson: Fred Wegman, The Netherlands

S1-O-02

Advanced Accident Data Collection—Description and Potentials of a Comprehensive Data Collection System

Kamren B, v Koch M, Kullgren A, Lie A, Nygren A, Tingvall C
Folksam Research, Chalmers University of Technology

Abstract

The most important input for development and evaluation of crash protection is real life accidents data. The data is however time consuming to collect and the output is in relation to what can be measured in laboratory testing, primitive. Important parameters are often collected by untrained people as secondary task in the rescue work at the accident scene. The precision and accuracy of the data can therefore often be questioned and the possibilities to draw conclutions are often limited. By using modern technology, such as photogrammetric measurements of exterior and interior of the vehicle deformations, cheap crash pulse recorders (CPR), and by training workshop and rescue personal, the possibility to collect high quality accident data can be dramatically increased. In this presentation, such a comprehensive system is described, in terms of potentials and possible output, as well as a theoretical background for increasing precision of collected data.

Background

Real life accidents is the leading source for priorities in accident research, legislation and vehicle construction. Methods used to gather and analyze information from accidents will therefore be of great importance. One field of certain interest is the measurent of accident severity. There are mainly three fields where this is essential.

A. Estimate of the accident severity distribution.
B. Estimates of the relation between accident severity and injuries (risk, mechanism, severity, etc.)
C. Estimates of a protective measure in a vehicle by a controlled study.

Today, the accident severity is assessed by accident reconstruction or by indirect statistical methods (paired comparisons, (1)).

Accident reconstruction used for analysis of occupant protection is always a result of a retrospective method. Accident severity is assessed by measuring adequate parameters on the vehicle in order to calculate the energy absorbed. The accident severity is often given in change of velocity (ΔV), although this is sometimes related to either barrier velocity or energy equivalent or sometimes change of velocity during impact (2), (3).

The data required for accident reconstruction are different types of measurement on vehicles and sometimes from the accident spot. In most cases some generalized constants are required. The precision of the assessment of accident severity is therefore not only a matter of the methods used and the generalizations of constants in the models used, but also a matter of the measurements taken from the vehicles involved.

In accident research including accident reconstruction, there will always be error terms also in the independent variables, that is the accident severity. This is, however, overlooked thus causing some serious problems. In this paper, the error in the accident severity term is discussed in relation to some simple examples, and a model for more advanced data collection and methods is shown. The aim of the paper is to show how better methods can affect the results of future data collection. The aim of the paper is also to show how better methods can be cheaper than otherwise used methods.

Accuracy of estimation

In order to demonstrate the influence of measurement errors, a simple regression model was used for a simple simulated data set where the relation between accident severity and some measurement of injury or damage to the vehicle was studied. The model used is a simple linear model, but a log-linear or logit approach with a dichotomized dependent variable could have been studied instead, with the same conclusions possible to draw.

In the simulated data set, the measurement variable was given an error of 0, 10, 20 and 30% standard deviation for each value of Y. The number of observations was 60, with ten cases for each Y. In table 1 the data set as a diagramme is given and in table 2 the outcome is shown. It can be seen that the regression coefficient is strongly affected and where the error was 30%, the coefficient is reduced by more than 50%. It can also be seen that the standard deviation of the regression coefficient is increased to a large extent. In a more realistic data set, with more cases in low speed and less cases in high severity, the loss of precision would have even more effects on the parameter estimates.

Table 1. Schematic relation between accident severity (X) and injury risk (Y) and a linear equation describing the relation

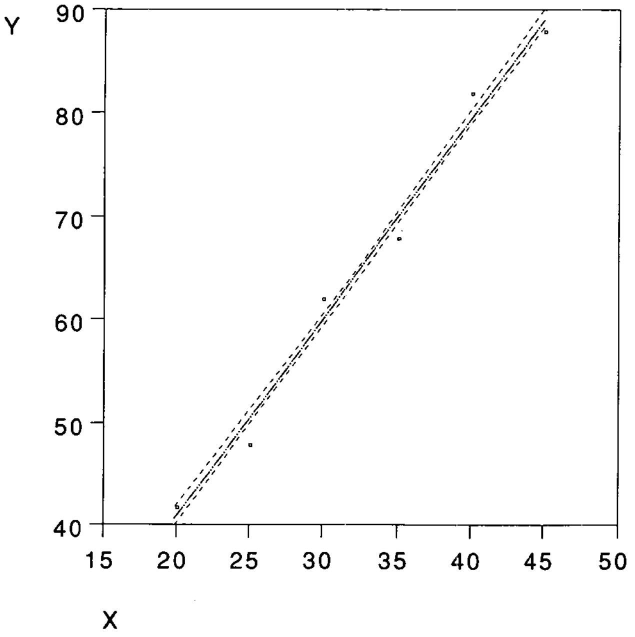


Table 2. Regression coefficients (a for intercept and b for slope) and amount of variance explained (R^2) by a simple linear model Y = a + bX where X is subject to measurement errors of 0, 10, 20 and 30%

parameter	0% error	10% error	20% error	30% error
a	2.23	10.6	26.3	38.8
b	1.93	1.67	1.19	0.81
t(b)	65.7	18.5	9.5	6.4
R^2	0.98	0.85	0.61	0.41

The phenomenon presented in table 2 is well known from the statistical litterature and the change of the regression coefficient is sometimes given as

$$B=\frac{B}{(1+E)}\quad \textit{where,}$$

$$E=\frac{s_{e^2}}{s_{x^2}}$$

that is, the regression coefficient and the calculated relationship is affected by the measurement error.

The possibility to draw conclusions is also affected as the relation between what can be detected and the measurement error is highly affected.

An another related problem is misclassification of variables. In the following example, the belt use among car occupants is misclassified to different amount. In table 3, the "true" data is given with the estimated belt effectiveness of 50% given by the formula;

$Effect = 1 - r(b) / r(u)$, where

r(b) and r(u) are the estimated risk of injury for belted and unbelted occupants respectively.

Table 3. Calculated belt effectiveness with different amount of misclassification

Level of misclassification	Belt effectiveness
0%	50%
10%	42%
20%	33%
30%	24%

It can be seen in table 3, that a random misclassification of 30% leads to a calculated belt effectiveness that is reduced by more than 50%. Already a misclassification level of 10% is of great importance. This has got two important implications. Firstly, the estimation of the effectiveness is reduced even when the sample size increases and secondly, the number of observations that must be collected to show that the seat belt is effective at all must be increased.

Advanced accident data collection

The elements of advanced data collection is to increase the accuracy of the collected data dramatically in order to produce better estimates and with fewer observations. There are mainly three areas where this is described; estimation of crash severity, measurement of vehicle deformation and assessment of injuries including use of restraints and contact areas.

Photogrammetrical measurement

In order to measure exterior and interior vehicle deformations with high accuracy and minimize the systematic error, a photogrammetrical measurement system was developed (4).

The photogrammetrical system is based on specially adapted small format cameras and a special software for threedimensional measurements.

Using the special camera a standard set of 24 photographs are taken covering both the exterior and the interior of the car. Before taking the photographs, the car is prepared with scaling rods on the roof and some adhesive stickers. The fieldwork is normally done in less than 15 minutes.

Data processing is done in a centralized workshop where a small group of people evaluate the measurements. The photos of importance are mounted on a digitizing tablet connected to a standard personal computer and the points of interest are measured and their threedimensional coordinates are calculated. The work station is seen in fig 1.

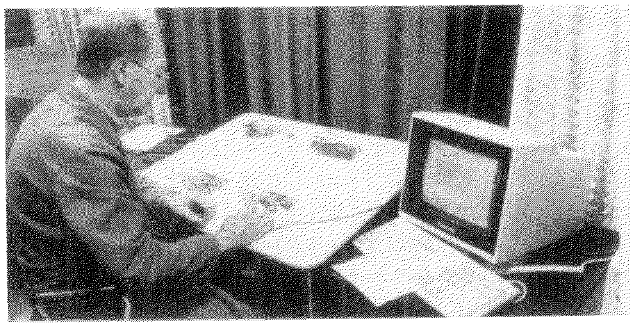


Figure 1. Workstation for the Photogrammetical System

A set of standard points are available for the car models measured. These previously known undeformed points are used to orient the measurements into a specific coordinate system. These points are also used for deformation vector calculation.

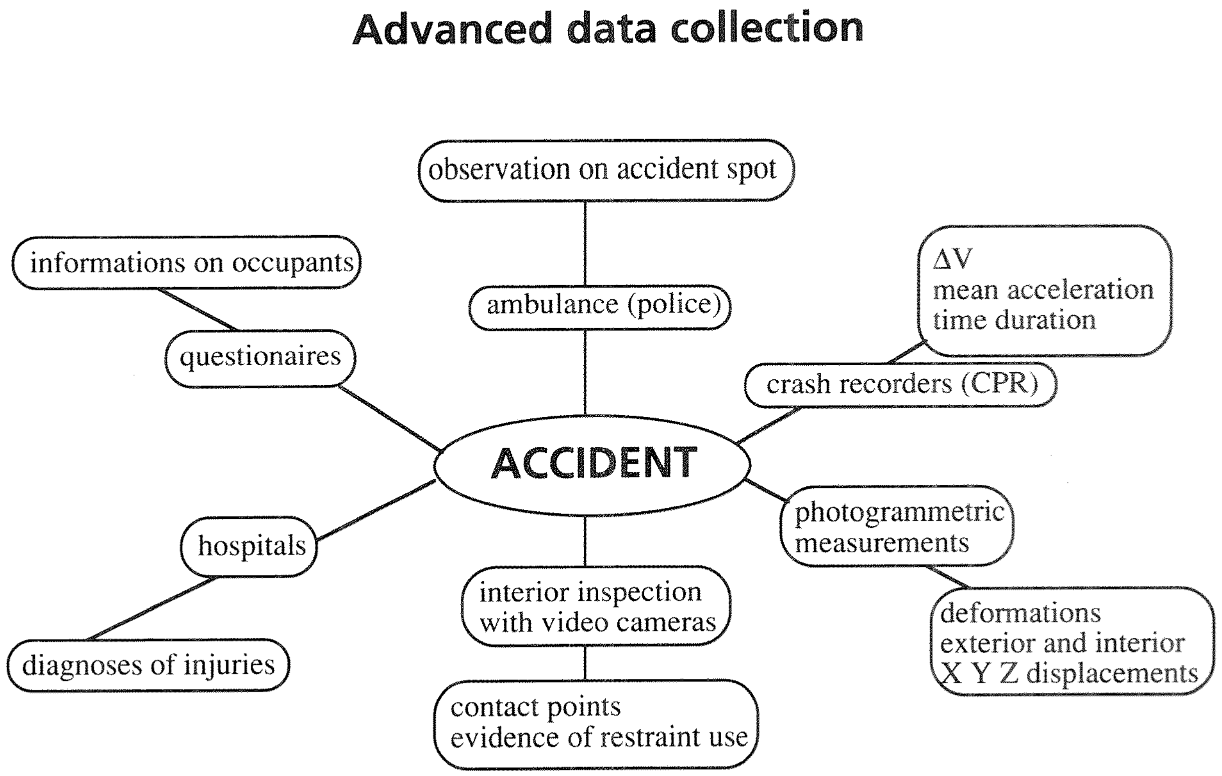
The measurements are presented as deformation vectors for standard points. All other measurements are presented coordinates in the car specific coordinate system. The output is shown in fig 2.

The accuracy in the system in every single pair of photographs is approx 5 mm and after transformations the global accuracy is better than 15 mm in space.

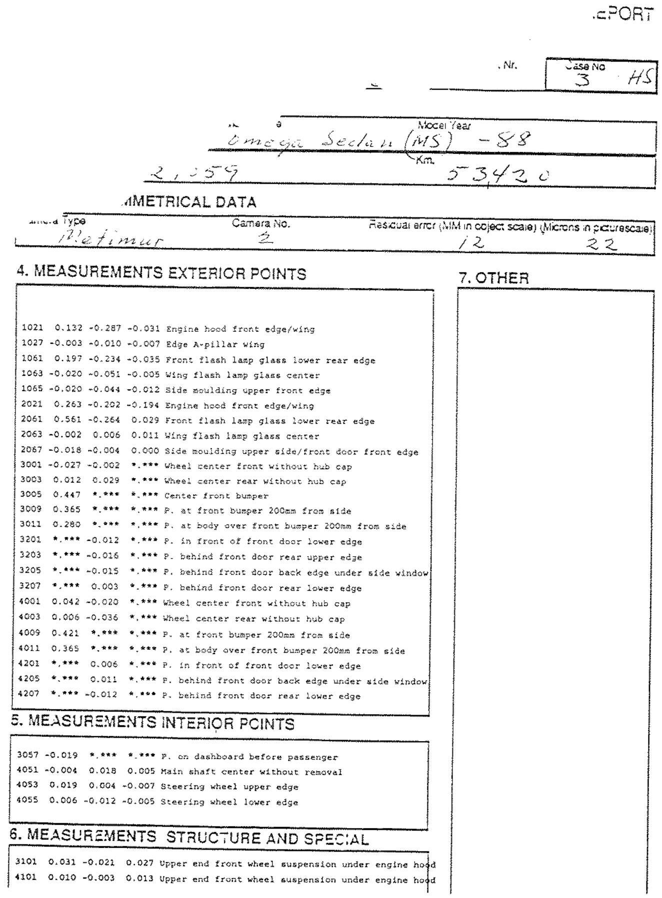
CPR - Crash Pulse Recorder

The measurement of the crash severity is made by an in vehicle recorder with the main purpose of making ΔV estimations of impacts (5). It is a very simple one dimensional accelerometer which can register the acceleration time history, though with a lower precision and a lower sampling frequency than an accelerometer for laboratory use.

The CPR, fig 3 is based on a spring mass system where the displacement of the mass in an impact is measured. The registration of the displacements of the mass is done on a photographic film by light emitting diods (LED) driven by a crystal oscillator circuit with a frequency of 1000 Hz. The circuit has its own power supply. The circuit is activated by a micro switch when the mass starts to move in a crash.



After an impact the registrations on the photographic film, fig 4, is measured and the CPR is calibrated to get adequate parameters measured. The accuracy of the CPR is mostly linked to production quality and quality of the measurement equipment for the photographic film. The overall accuracy of ΔV estimations will be better than 5%.



EPORT

Nr.

Case No 3 HS

Model Year

Omega Sedan (MS) -88

Km.

2,059

53420

METRICAL DATA

Type Metimur

Camera No. 2

Residual error (MM in object scale) (Microns in picturescale) 12 22

4. MEASUREMENTS EXTERIOR POINTS

```
1021  0.132 -0.287 -0.031 Engine hood front edge/wing
1027 -0.003 -0.010 -0.007 Edge A-pillar wing
1061  0.197 -0.234 -0.035 Front flash lamp glass lower rear edge
1063 -0.020 -0.051 -0.005 Wing flash lamp glass center
1065 -0.020 -0.044 -0.012 Side moulding upper front edge
2021  0.263 -0.202 -0.194 Engine hood front edge/wing
2061  0.561 -0.264  0.029 Front flash lamp glass lower rear edge
2063 -0.002  0.006  0.011 Wing flash lamp glass center
2067 -0.018 -0.004  0.000 Side moulding upper side/front door front edge
3001 -0.027 -0.002  *.*** Wheel center front without hub cap
3003  0.012  0.029  *.*** Wheel center rear without hub cap
3005  0.447  *.***  *.*** Center front bumper
3009  0.365  *.***  *.*** P. at front bumper 200mm from side
3011  0.280  *.***  *.*** P. at body over front bumper 200mm from side
3201  *.*** -0.012  *.*** P. in front of front door lower edge
3203  *.*** -0.016  *.*** P. behind front door rear upper edge
3205  *.*** -0.015  *.*** P. behind front door back edge under side window
3207  *.***  0.003  *.*** P. behind front door rear lower edge
4001  0.042 -0.020  *.*** Wheel center front without hub cap
4003  0.006 -0.036  *.*** Wheel center rear without hub cap
4009  0.421  *.***  *.*** P. at front bumper 200mm from side
4011  0.365  *.***  *.*** P. at body over front bumper 200mm from side
4201  *.***  0.006  *.*** P. in front of front door lower edge
4205  *.***  0.011  *.*** P. behind front door back edge under side window
4207  *.*** -0.012  *.*** P. behind front door rear lower edge
```

5. MEASUREMENTS INTERIOR POINTS

```
3057 -0.019  *.***  *.*** P. on dashboard before passenger
4051 -0.004  0.018  0.005 Main shaft center without removal
4053  0.019  0.004 -0.007 Steering wheel upper edge
4055  0.006 -0.012 -0.005 Steering wheel lower edge
```

6. MEASUREMENTS STRUCTURE AND SPECIAL

```
3101  0.031 -0.021  0.027 Upper end front wheel suspension under engine hood
4101  0.010 -0.003  0.013 Upper end front wheel suspension under engine hood
```

7. OTHER

Figure 2. Output from the Photogrammetical Measurement System

Interior inspection

In order to get a more objective picture of the interior of the vehicle, the interior inspection should be done after all other information has been gathered and by an expert team. This can be done by using a videocamera and where the film is analyzed afterwards together with measurements of deformation and accident severity.

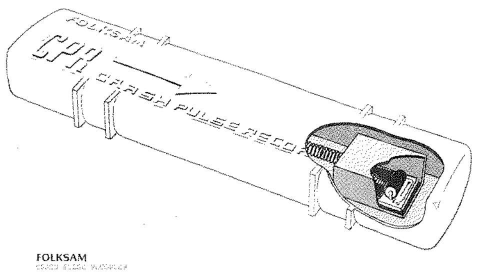


Figure 3. CPR

Observations on the accident spot can be picked up by interviewing the ambulance team.

Discussion

In this paper the measurement error in the reconstruction of real life accidents is addressed. This is an area where most studies related to the relation between a measurement variable and an outcome resulting from this parameter does not take any error into account.

In this paper, some simplified examples of measurement errors are shown together with the effects on the outcome of estimates. Even fairly small errors leads to estimates that are significantly affected, normally reduced. This means that protective measures can be overlooked even if they are effective and even if a large sample of accidents is used (6). In cases where there are measurement errors the number of observations will not eliminate the influence. This is an extremely important fact, well known in statistical analysis but more or less forgotten in quantitative accident research. It is easily realized, that there are plenty of results from studies that are heavily biased and relationships between variables that are wrongly stated to be weak. It is believed that especially the relation between accident severity and injury risk is biased

The reliability of the data is not the only important issue in accident reconstruction. Also the validity must be addressed. In this paper, ways to measure also other parameters than just deformation of vehicles is described. The possibilities to measure with more advanced methods will lead to questions raised about what are the most adequate parameters to use in reconstruction.

The reliability of assessment of change of velocity is bases on several parameters when using reconstructive

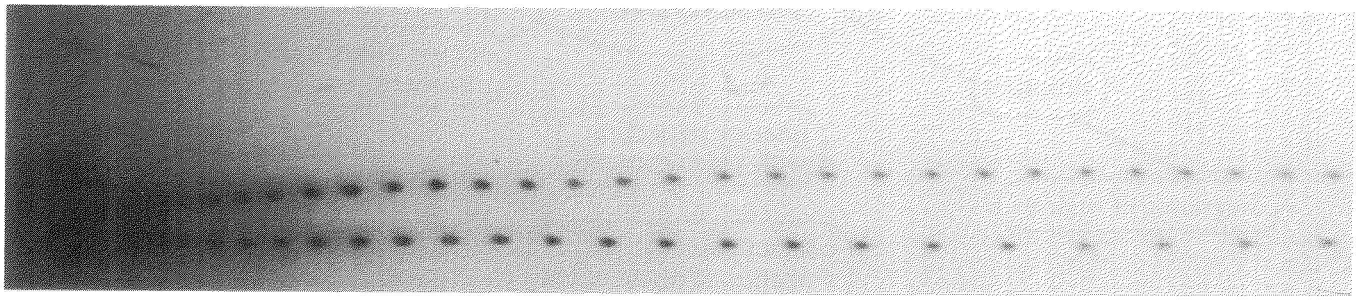


Figure 4. Displacement Registration of the CPR on a Photographic Film

methods. In a study of the CRASH-3 method, the mean error was 13.8-17.8 % but the objects studied were fairly simple. In other materials the error may well be larger, also including possible systematic errors.

The term advanced data collection is addressed to an approach where the measurement errors are minimized to a level where they do not lead to interference with estimates and where the number of observed accidents is minimized. Instead of studying a large population, a subset of vehicles are studied in more detail. If these vehicles are prepared with on-board measurement devices, and if the crashed vehicles are all studied with advanced technique, a population of approx 10 000 vehicles will produce a number of accidents in one year that will give a high precision in i.e., injury risk for occupants.

An on board recorder can give a level of precision that can be used for advanced data collection if it is simple and cheap. In this paper such a recorder is presented. The described recorder can be used for frontal collisions and give a good estimate of the change of velocity as well as the time and mean deceleration, without using measurements of the static deformation of the vehicle. This is of great importance, as the the deformations of the car will be a function of the change of velocity and not vice versa as it is in reconstruction using deformation measurements. Still, deformations of the vehicle outside and inside is of interest,and a method for increasing measurent reliability is presented. In this technique, using photogrammetry, the measurements can be done afterwards and by experts thus minimizing both systematical, random and intraobserver errors. In a study of the reliability of exterior measurements, the error was at least 5 times larger than when using photogrammetry.

In the data collection used today, most vehicle data is gathered by individual members of a team, and at one moment. In the technique presented in this paper, the data consists of materials not possible to destroy by incorrect judgement by the data collectors. Instead, the data collection and the data processing is separated and where it is an important part of the concept to use experts when processing the data collected. Restraint use judged by using several sources such as interior vehicle inspection (belt tongue and joints, anchourages, webbing etc.), interview with occupants and ambulance teams.

In the future, fast and precise statements of the performance of new safety systems and constructions are strongly needed. The methods used today cannot serve this purpose sufficiently and a change in the scientific methods is essential. It therefore seems to be more realistic to use small populations of vehicles studied where the fleet has been prepared and where an organization that can minimize errors is developed.

References

1. Gustafsson H, Hägg A, Krafft M, Kullgren A, Malmstedt B, Nygren Å, Tingvall C, Folksam Car Model Safety Rating 1989-90.
2. F Hartemann, J Y Foret-Bruno, C Henry, G Faverjon, C Got, A Patel, J C Coltat, The characteristics of frontal impacts in real world accidents, In: proceedings of the ESV-conference 1987; 424-431.
3. D Otte, Comparison and realism of crash simulation tests and real accident situations for the biomechanical movements in car collisions, Proceedings of the STAPP car crash conference, 902329, 1990.
4. Lie A, Tingvall C, Johansson S, Johansson S-O, Photogrammetric measurements of damaged vehicles in road traffic accidents, In: proceedings of the ESV conference 1989.
5. Aldman B, Kullgren A, Lie A, Tingvall C, Folksam Research and Chalmers University of Technology, Dep of injury prevention. Crash Pulse Recorder (CPR) - Development and evaluation of a cheap device for measuring crash pulse and delta-V in real life accidents, Accepted for publication in the proceedings of the ESV conference 1991.
6. Malliaris A C, Digges K, Crash protection offered by safety belts. In: proceedings of the ESV conference 1987; 242-252.

S1-O-03

Data Linkages in Real Crash Analysis: A Key to Progress in Road Safety

Urs Maag[1]
Denise Desjardins
Claire Laberge-Nadeau
Universite de Montreal

Abstract

Government agencies and insurance companies collect and record on computer files enormous amounts of data on road accidents. The collection of this data serves mainly for administrative purposes and only occasionally for research. The objective of this paper is to argue and to show that useful research projects can be carried out relatively cheaply, using basically administrative data, if linkage of files and linkage with other sources is possible.

In Quebec where there is compulsory government car insurance, except for material damages, there is a

---

[1] Until the end of May 1992, Section de mathématiques, Université de Genéve.

particularly favourable situation making possible the creation of complete and rich databases organized by individual records. This article shows the research potential of such databases on the example of two studies, one on the effects of age and experience in accidents with injuries, the second on medical conditions and drivers' records. It is also pointed out that the researchers have to assume a great responsibility in order that the privacy of individuals is maintained very strictly, i.e. data about an individual must be kept confidential, and the files should not carry any identity of individuals, only numbers.

Introduction

Since accidents are relatively rare events, usually between 5 and 10% of permit holders are involved in an accident in any given year, large databases are needed to study trends, associations between variables, rates for subgroups, etc. Furthermore such data sets should be available by individual and not just in an aggregate form; they should contain also the history of driving records.

Researchers often would like to be able to gather the data for their projects themselves to make sure that the right variables for an appropriate sample of the population are available. We know that in most cases this is only a dream since the cost and the time necessary to acquire such a set of observations are far in excess of the available grant money. What are the alternatives? A lot of information is present in government agencies, police reports and insurance companies. In the case of a state insurance much of this information may even be centralized. The initial problem is how to obtain, verify and collate the information held by different agencies. A second problem is how to enrich the available information in order to answer a given research question.

It will be shown that the situation in Quebec is particularly advantageous for research using government files, possibly enriched by survey data. The use of such a database must be founded on a mutual trust between the government agency and research teams. Two recent examples will serve to illustrate the tremendous possibilities available to do projects for reasonable amounts of money. The importance of a strict ethical conduct by the researchers, their assistants, students and technical collaborators is also discussed.

The Quebec Situation

State insurance against car accidents exists in Quebec since the fall of 1978. Material damages to cars and property are excluded because they are covered by private insurance. The state insurance is now administered by the Societe d'assurance automobile du Quebec (SAAQ), previously known as the Regie d'assurance automobile du Quebec (RAAQ). Over the years, the SAAQ was given the responsibility of gathering and administering the official data in the Province of Quebec on driving permits, car registrations, demerit points, infractions, suspensions, police accident reports, insurance claims, medical reports pertaining to such claims and corresponding payments. Almost all the data is on computer files which the SAAQ uses for its annual reports and for projects carried out by its internal research group. Parts of these files are available to researchers in anonymized form. The quality of the data is generally as good as the original source as shown through verifications carried out by members of our team. Data about payments will be most trustworthy because accounts get audited. Since all these files are controlled by the same agency, it is relatively easy to link them and to create sub files containing specific variables and subgroups of the population. Thus a very large and rich database is available for research. To exploit even parts of the base, a research team needs a powerful computer and a knowledgeable analyst.

The data are of course not public. Access is only granted for specific projects and to people that meet with the approval of the SAAQ. Only relevant variables are released and identifiers are always removed.

A further and often necessary step is the addition of data either obtained through a survey or from another source such as an insurance company (material damages). In such cases the merger of the SAAQ file with the outside file is done by the agency who holds the key to the identifiers for the files which are deleted before the merged file is made available.

Two Examples

The effects of age and experience on accidents with injuries

This study is based entirely on the files of the SAAQ. It was made possible by some special computations done for our team by the agency. The two areas looked at were: a) age at first licensing, and b) accident rates as a function of age and experience.

The minimal legal age to obtain a driving permit is 16 years which is lower than in most European countries where it is 18 years. Over the period from 1971 to 1985, the acquisition of driving permits by 16 year old has increased steadily form 6% to 42% for men and from 2% to 27% for women. By age 18, about 75% of the men have a driving permit. The attributes "lack of experience" and "young" are thus confounded when looking at global accident statistics.

The second part of the study attempts to shed some light on the separate effects of age and of experience. Each driver involved in a car crash resulting in injuries was categorized by sex, age and by driving experience. The age variable was grouped by years from 16 to 24, then the groups 25-34, 35-44, and 45 or more. The experience variable was dichotomized into "one year or less" and "more than one year." Young drivers, i.e. below 25 years, were the principal target group. No exposure variable was available, which must be taken into account when interpreting the results. For example, young women drive on the average far less than young men. There are large variations in risk exposure between the young person who occasionally drives the family car and the person who uses an automobile to drive regularly to and from work.

Here are the main results: a) Accident rates for women are very much smaller than those for men; b) From age 16 to 24, accident rates decrease approximately linearly with age (for men and women); c) There is hardly any difference between experienced (more than one year) and new drivers. This means that a driver who acquired a permit at age 16 is not a better driver, in terms of average accident rates, at age 21 than the one who acquired the permit at age 19 or 20. However, the young 16 year old licensee has a good chance of being involved in an accident during those five years (see Bourbeau et al., 1991).

The question which thus confronts the population in general, and the politicians in particular, is: Should the licensing age be raised in Quebec from 16 to 18, the minimal age required in most European countries?

Medical conditions and drivers' records

The SAAQ requested a comparative study (permit holders with a medical condition versus healthy ones) of the effects of certain medical and ophthalmological conditions on road safety in terms of accident rates, demerit points and suspensions, taking into account the distances driven. Special restrictions, based on safety considerations, apply to drivers of trucks, busses, taxis and even automobiles in the case of elderly drivers. In order to acquire exposure variables, a survey had to be carried out. A questionnaire appropriate for a telephone survey was constructed and validated, since this was the only way to obtain a sufficiently large sample at a very reasonable cost.

In this instance, the interaction between the SAAQ and the research team became quite considerable. Using the computerized files, the team was allowed to obtain the basic statistics on the drivers in a given permit class having a certain medical condition (the cases) and the ones being in good health (the controls). As a consequence, some groups of drivers had to be left aside since they contained too few individuals, for example female permit holders in the classes 1 to 4 (trucks, busses and taxis), and truck drivers above age 65.

The telephone survey based on our questionnaire was carried out towards the end of 1990 by a polling company attempting to reach 17 658 individuals. The response rate was 64.5%, even 75% when corrected for invalid telephone numbers. The file resulting from the survey was linked with the SAAQ file that contains the safety and basic medical records of the drivers, resulting in a large anonymized database ready for analysis. The first results have been presented this summer at various conferences: Joly et al. (1991a), Joly et al. (1991b), Desjardins et al. (1991), Maag et. al. (1991). Many more analyses of this very rich data set are being carried out and are planned.

File Linkage and Ethical Considerations

For the researcher it is advantageous to have as free an access as possible to the files. It is also important to be able to link various files and to add variables from other sources such as a survey or a file belonging to another agency or a company. A researcher likes to be able to create appropriate sub files, fetch an additional variable when necessary, do crosschecks, and so on. There are also advantages for the owner of the files: More information can be obtained from the files by commissioning analyses or letting a researcher carry out a project without the owner having to hire additional staff. Thus, sharing files is good economics.

The owner of the file, however, is obliged to keep the data on individuals protected. This is particularly true for government agencies. There are legal restrictions, and penalties for people who divulge data on individuals. Consequently, it is not surprising that agencies are hesitant about granting access to their files. Private companies are worried in addition about data falling into the hands of their competitors. However, there are states in the U.S.A. that give the possibility of linking data for research purposes by law or by introducing a special bill, particularly for epidemiological research.

In our view, these two opposing positions can be overcome by mutual trust and by an exemplary ethical conduct on the part of the researchers. In any way, mutual trust does not happen overnight, it has to be built up gradually. Researchers have to show competency through the production of useful results and new insights. Researchers must never reveal any individual data, and furthermore it is their duty to make sure that their assistants, students and technical collaborators live by the same principles. They also must take the necessary steps so that no unauthorized third party can gain access to the data. Today's open computer systems and network facilities demand extra care to protect files. A company or government agency can erect fairly stringent safeguards, but at considerable cost. For example the data analyst may have to work in the agency's offices and on its computer. If trust and responsibility are present, a lot can be gained.

Conclusions

Large databases that are pertinent and essential to research in traffic safety exist in government agencies, insurance companies and hospitals. Good research can be accomplished if access to these data is permitted, if the quality of the files can be verified, if different data sets can be linked, and if additional information, for example from surveys, can be added in order to construct a complete database organized by individual records. Indeed, large bases that are necessary to examine accidents (rare events) on a statistical basis can seldom be gathered for a reasonable price by individual researchers.

Such access can work under two premisses: On the one hand, an open mind and a willingness to cooperate is necessary on the part of the owners of the files, and on the other hand exemplary ethical conduct by the researchers and their teams is mandatory. Cooperation to enable linkage of files from different sources is thus a key to progress in road safety.

References

Bourbeau, R., Laberge-Nadeau, C., Maag. U. (1991), "The Effects of Age and Experience on Accidents with Injuries: Should the Licensing Age be Raised?," *Accident Analysis and Preventions* 24 (6), to appear.

Desjardins, D., Ekoe, J.-M., Ghadirian, P., Hamet, P., Laberge-Nadeau, C, Maag, U. (1991), "Demarche methodologique pour evaluer l'impact de trots conditions medicales sur la securite routiere en fonction de differentes categories de permis de conduire," Compte rendu de *Canadian Multidisciplinary Road Safety Conference VII*, 381-392, Vancouver, Canada, June 17-19.

Joly, P., Gagnon, R., Trudel, G., Joly, M.-F., Desjardins, D., Maag. U., Messier, S., Laberge-Nadeau, C. (1991a), "L'exposition au risque de conduire un vehicule routier chez les personnes agees en fonction tea normes visuelles minimales," Compte rendu de la *6e Conference sur les comportements de deplacements"*, Quebec, Canada, tome 2, 135-149, May 22-24.

Joly, P., Joly, M.-F., Desjardins, D., Messier, S., Maag. U., Ghadirian, P., Laberge-Nadeau, C. (1991 b), "Exposure for Different License Categories through a Phone Survey," *35th Annual Proceedings of the Association for the Advancement of Automotive Medecine*, Toronto, Canada, November 4-7.

Maag. U., Desjardins, D., Joly, P., Laberge-Nadeau, C. (1991), "How to Define, Estimate, and Compare Accident Rates for Strata of Drivers," Compte rendu de *Canadian Multidisciplinary Road Safety Conference VII*, 284-292, Vancouver, Canada, June 17-19.

S1-O-04

Child Casualties in Fatal Car Crashes

Harold Vallee, Marie Christine Caillieret, Gerard Faverjon, Jean Yves Le Coz, Jean Marie Heinrich, Christian Thomas
Accident Research and Biomechanics Laboratory Associated with Peugeot S.A./Renault
Jean Claude Coltat
Poissy Intercommunal Hospital Centre
Claude Got
Institute of Biomechanics and Accident Research
Alain Patel
Orthopaedic Research Institute

Abstract

The circumstances in which children aged less than 10 travelling in passenger cars are severely injured or killed are different from the circumstances in the case of adults.

Our knowledge in this field of safety is very limited at present, because it is hard to collect a large sample of severe accidents involving children.

On the basis of police reports on fatal crashes occurring in France in 1990, concerning 417 casualties aged less than 10, one quarter of whom were killed, we propose defining the characteristics of such crashes by analyzing the following parameters:

1. Child transportation conditions;
2. Crash circumstances;
3. Restraining systems.

Materials and Methods

The sample used consists of 275 fatal motorist crashes (the police reports for which were kindly made available to us by the police forces) in which at least one child aged less than 10 is involved. All the crashes analyzed occurred between the beginning of March 1990 and the end of February 1991.[1] Each of these reports contains the following information: a detailed drawing of the crash, a series of photographs (locations, vehicles involved), a brief (wear level of tyres, etc.). The report also includes: the statements of those involved and the witnesses, the medical state of the injured (only the location and nature of the injuries sustained by the deceased are unknown, for want of an autopsy) and, finally, the result of the driver alcohol tests when it is known.

The conditions required to judge as to whether or not restraining systems were used are as follows: observation of the system's presence in the vehicle by the police forces, confirmed by the statements of those involved and witnesses. We later contacted the family of the restrained children individually, via a questionnaire and even by telephone whenever necessary.

The criteria set by us for characterizing impact mechanisms and their injury consequences are as follows.

---

[1] To enable chronological comparisons we use a sample of police reports on fatal crashes occurring in the 2nd quarter of 1980 on the whole national network.

- The intrusion evaluated on photographic documents is quantified by the percentage of reduction of the free space in front of, behind, or to the right or left of each child. Thus, in frontal impact, intrusion is considered to occur when the reduction of available space is at least equal to 30% for a child seated in the front. For a child in the back seat, only those cases in which the windscreen pillar intruded as far as the centre pillar were considered as intrusion mechanisms. In side impact, the intrusion thresholds taken into account are as follows:
  - for a near-side occupant, whenever the external deformation of the side panel suggests a direct intrusion on the occupant;
  - for a far-side occupant, whenever the vehicle deformation has affected the car body axis. In rollover, intrusion is considered to occur when the roof panel penetrates close to the window baseline.
- Projection concerns all unejected children who are not victims of intrusion.

It was not possible to use the criteria that we normally adopt for technical analysis of vehicles, namely, the delta-V and mean acceleration. Of the 157 frontal impacts observed, 115 EES's were estimated and only 63 delta-Vs are calculated. Since the deformation measurements of the vehicles are not known, the acceleration is not calculated.

Child Transportation Conditions

Vehicle Occupancy. The average global occupancy rate (children and adults) of the vehicles involved in fatal crashes and having (at least) one child on board has varied little over the last ten years: it was 4 occupants in 1980 [1], and 3.7 in 1990. The same applies for the average number of children per car: 1.6 in 1980 and 1.5 in 1990. There has, however, been a sharp decline in the rate of car over-occupancy: 12% of cars contained 6 occupants or more in 1980, as against 7% in 1990 [Figure 1].

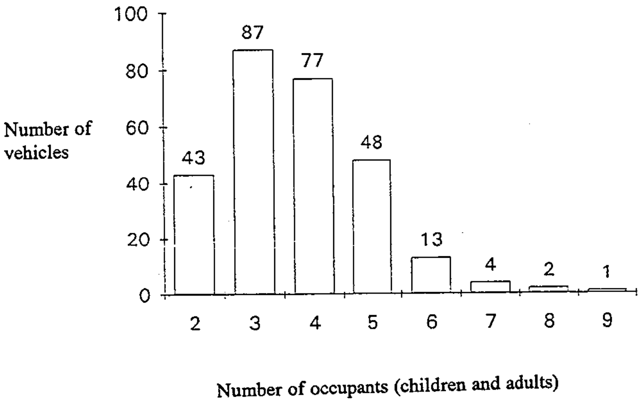


Figure 1. Occupation (adults or children) of the 275 Cars with a Child at Least

The situation most frequently encountered (60% of cases) is the presence of a single child in the vehicle. The presence of two adults in the vehicle with child(ren) is observed in 43 % of cases [Table 1]. The most frequent (children/adults) combination is 1 child and 2 adults, or close on a quarter of cars with a child.

Table 1. Occupancy (adults and children) of the 275 vehicles with children on board

		Number of children					
		1	2	3	4	5	TOTAL (vehicles)
Number of adults	1	43	24	2	1		70
	2	63	39	15		1	118
	3	36	14	4	1	1	56
	4	18	3	1			22
	5	6	1				7
	6		1	1			2
TOTAL	(vehicles)	166	82	23	2	2	275

Although the presence of a child aged less than 10 in the front seat is prohibited in France, 12 children were seated there. Of those, 7 were aged less than 5 and 2 were seated on the knees of an adult.

Of the 390 children sitting in the rear, only the positions occupied by 230 children were determined precisely. The outer positions seem to be used unequally.

Only the central rear position is seldom occupied: 18% of the children were seated there [Table 2].

Table 2. Positions Occupied by the Children According to Age

		AGE OF CHILD									
Position of child		≤1	2	3	4	5	6	7	8	9	TOTAL
Front		1	1	2	3		1		1	3	12
Rear	Left	22	6	10	4	7	12	8	13	8	90
	Centre	13	5	3	4	4	4	2	2	5	42
	Right	28	7	10	9	13	6	9	10	6	98
	Position unspecified	19	17	24	19	17	19	20	11	14	160
Position undertermined (front or rear)		1	0	5	2	1	3	2	1	0	15
TOTAL		84	36	54	41	42	45	41	38	36	417

Restraining Systems Used. Only 14% of the children were wearing a restraining system. No car bed designed according to the regulations for infants aged 1-9 months was used, while 14 very young children were transported in a cot. In the reference sample, one observes that 6 child restraining systems out of 10 are used by children aged less than 2. As for booster, they are seldom used:

4 cases [Figure 2]. The use of child seats and booster is in many cases in compliance with the stipulations for use laid down by the French regulation of 1985 (weight of the child). Only two children among the 15 users of child seats—whose weight and size are known—had a weight slightly less than the recommended weight. The general trend, however, is that most restrained children have a weight close to the minimum weight threshold required for the system used by them [Figure 3]. 19 of the 60 children aged less than 10 used exclusively the seat belt designed for adults.

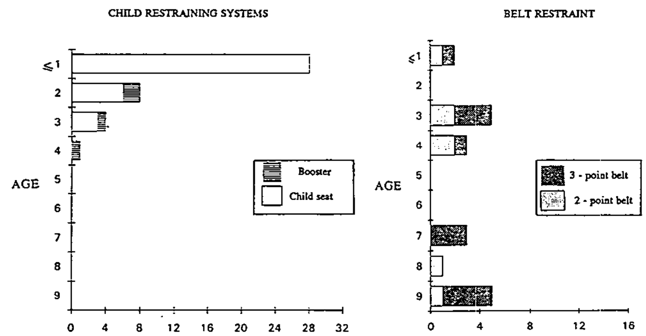


Figure 2. Type of Restraint Used According to Age of Child (N=60)

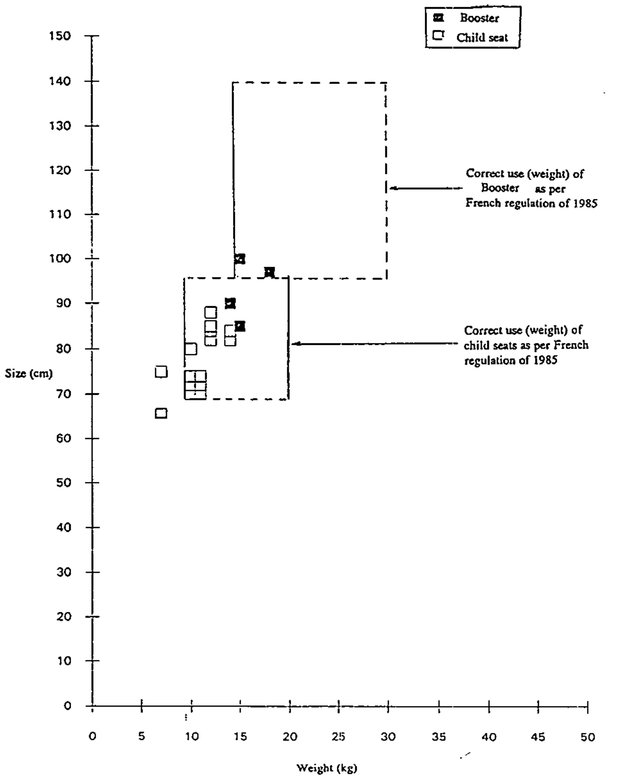


Figure 3. Size and Weight Distribution of Children According to the Specific Restraining System Used

We specify that the rate of use of child restraining systems is, in France, among the lowest of those observed at the EEC level: 89% in 1989 in Sweden [2]; from 50 to 60% in 1988 in West Germany [3]; 25% in 1987 in the United Kingdom [4].

Trip Configurations. Short trips (less than 30 km) represent 40% of all trips travelled by children.

The length of the trips does not vary with the age of the children [Table 3]. They are often the very reason for short trips (creche, school). They accompany their parents on the longest trips (week-ends, holidays).

Table 3. Length of Trip According to the Age of the Child

Length of trip (km)	AGE OF CHILD									TOTAL
	⩽1	2	3	4	5	6	7	8	9	
⩽ 30	23	11	14	12	10	13	12	16	7	118
31 - 100	10	7	9	7	6	7	6	6	4	62
101 - 500	18	4	12	10	5	10	5	10	7	81
501 - 1000	5	2	3	2	2	4	2	3	3	26
> 1000	1	1	1		2		1		2	8
Unknown	27	11	15	10	17	11	15	3	13	122
TOTAL	84	36	54	41	42	45	41	38	36	417

There is no relation in the sample analyzed between the length of the trip and the frequency of use of a restraining system by the children. It might have been thought that the risk as perceived by the parents would result in a higher rate of use of such systems on long trips, whereas it is the contrary that is observed: 21 % of the children making short trips were restrained, as against only 13% of child casualties on trips longer than 100 km [Table 4].

Table 4. Length of Trip and Use of a Restraining System

Length of trip (km)	RESTRAINING SYSTEM USED						
	Child seat	booster	2-point seat belt	3- point seat belt	Un-restrained	Unknown	TOTAL
⩽ 30	14	3		6	87	8	118
31 - 100	4			2	48	8	62
101 - 500	7		2	2	61	9	81
501 - 1000	1		3		16	6	26
> 1000					6	2	8
Unknown	11	1		4	72	34	122
TOTAL	37	4	5	10	290	67	417

The types of roads on which the fatal crashes occurred are chiefly departmental roads (44%) and national highways (41%). The motorways are weakly represented (10%), but the severity of motorway crashes is much greater for children: 41 % of the children involved in fatal collisions on the motorway are killed in them, as against 24% on national highways and 19% on departmental roads [Table 5].

Table 5. Type of Road and Global Severity for Children

Type of road	GLOBAL INJURY SEVERITY Fatalities	Severe injuries	Light injuries	Un-harmed	Severity unknown	TOTAL
Motorway	17	9	14		1	41
Freeway				1		1
National highway	41	36	66	25	2	170
Departmental road	35	34	90	20	2	181
Communal lane	5	3	6	1		15
Off public network	1	1		1		3
Unknown	4	1		1		6
TOTAL	103	84	176	49	5	417

Almost half of the children (47%) are involved in accidents on Saturday and Sunday. 48% of crashes occur between 2 p.m. and 8 p.m.

Risk Factors. In car-to-car collisions, the presumed responsibility of the driver of the vehicle in which the child (or children) were travelling is observed in one third of collisions. The frequency of positive alcohol levels above the legal rate of 0.80 g/litre of blood is close on four times higher for drivers without a child compared to drivers with a child (or children): 27% and 7% respectively in car-to-car collisions. All the differences observed with respect to both responsibility and alcohol level are statistically significant. Finally, we may add that 86% of the children were being driven by their parents.

Crash Circumstances

Crash Configuration. Car-to-car collisions are over-represented in crashes with child(ren) [Figure 4]: 46% of cases as against 27% for all crashes. Conversely, for cars with child(ren), casualties against fixed obstacles (trees, poles, walls, etc.) are half fewer than for all such crashes (with or without child on board).

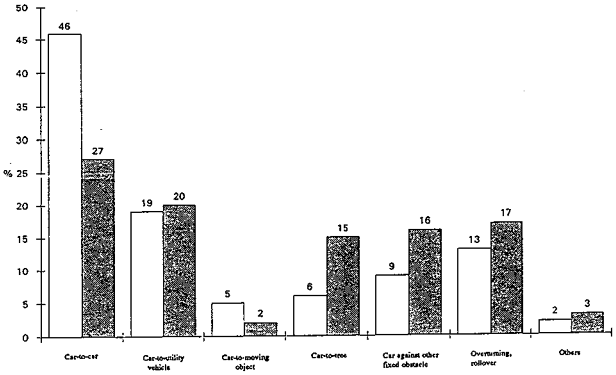


Figure 4. Breakdown of the Various Crash Configurations Involving Vehicles with Child Passengers (N=275) and Percentage of All Crashes With or Without Child Casualties

In one out of two cases, the car-to-car configurations are "head-on" and in one case out of three, "side configuration".

Type of Impact. Frontal impact is over-represented for vehicles occupied by at least one child: 57% for such cars as against 47% for all cars. Conversely, side impacts represent only 20% of impact types for cars with child(ren) as against 30% for all cars [Figure 5]. Side impacts occur chiefly against other vehicles (against cars in 43 % of cases, against utility vehicles or public means of transport in 25% of cases) and in only 18% of cases against fixed obstacles, whereas 44% of fatalities in side impact, for all cars with or without children, are involved in crashes against such obstacles.

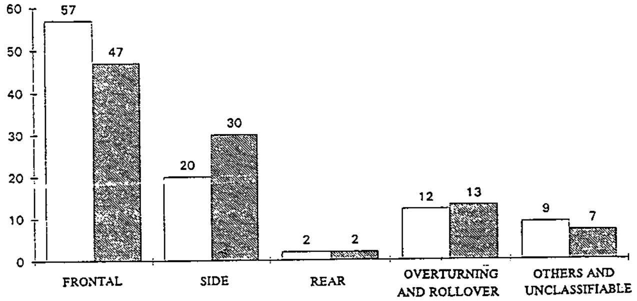


Figure 5. Breakdown of Various Types of Impact in Crashes Involving Vehicles With Child Passengers (N=275) and Percentage of All Crashes With or Without Child Casualties

Severity of Injury according to Type of Impact. The fatality rate of children involved in frontal impact is the lowest of all crash configurations: Fatality rate (F.R.) = 0.17 in frontal impact and F.R. = 0.25 for all impacts [Table 6].

Table 6. Global Injury Severity According to Type of Impact

TYPE OF IMPACT	FAT-ALI-TIES	SEVERE INJUR-IES	LIGHT INJUR-IES	UN-HARMED	SEVERITY UNKNOWN	TOTAL
FRONTAL	41	64	101	33	1	240
SIDE	34	10	29	4	2	79
REAR	5		4			9
OVERTURNING AND ROLLOVER	15	8	24	3	1	51
SIDE SWIPE			1	3		4
UNCLASSIFI-ABLE & OTHERS	8	2	17	6	1	34
TOTAL	103	84	176	49	5	417

In frontal impact, the distribution by cumulative percentages of the EES is fairly similar for child fatalities and severe injuries [Figure 6]. The violence of frontal impacts is especially high in the case of fatalities and severe injuries: 60% of them are involved in impacts of EES greater than 55 km/h.

It is in side impact that the fatality rate is highest: out of 100 child casualties, 44 are killed in this type of impact. Direct intrusion on the part of the passenger compartment occupied by the child, and ejection of the child (following an often localized impact on the front or rear structure of the car), are observed in a large proportion of side impacts.

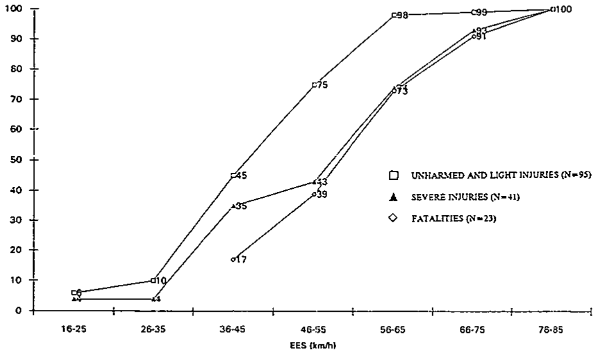


Figure 6. Distribution by Cumulative Percentage of E.E.S. According to Global Severity Injury for Children Involved in Frontal Impact

Rear impact, although not frequent, nevertheless remains severe, since in 5 cases out of 9 it resulted in the death of the child. Collisions involving a utility vehicle caused 4 of these deaths.

The high fatality rate observed in overturning and rollover is mainly attributable to ejection. Information is given further on concerning this type of impact, in the section dealing with ejection.

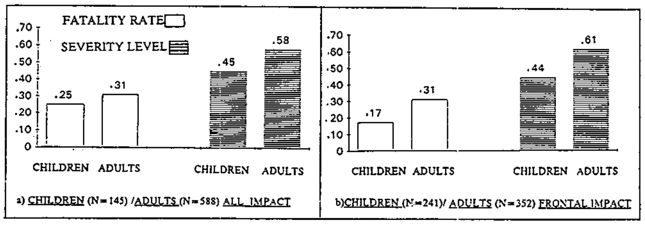
Severity of Injury according to Seating Position. Certain trends can be observed concerning the global severity of child injuries according to seating position. The lowest severity is for children located in the central rear position (F.R. = 0.21). The fatality rates observed for the outer side positions are fairly similar: 0.27 on the left and 0.32 on the right [Table 7].

Table 7. Global Injury Severity According to Position Occupied

POSITION OCCUPIED		FAT-ALI-TIES	SEVERE INJUR-IES	LIGHT INJUR-IES	UN-HARMED	SEVERITY UNKNOWN	TOTAL
FRONT POSITION		5	2	4	1		12
REAR	LEFT	24	21	34	11		90
	CENTRE	9	7	19	7		42
	RIGHT	31	20	39	8		98
POSITION UNSPECIFIED		31	34	75	16	4	160
POSITION UNKNOWN		3	-	5	6	1	15
TOTAL		103	84	260	49	5	417

The greatest severity is observed for children sitting in the front: 5 of the 12 children sitting in the front seat were killed. In two cases, the deaths are attributable to intrusion. They would undoubtedly have been prevented if the child had been sitting in any of the rear-seat positions of the vehicle. Three other children were restrained by a 3-point seat belt in the front right position. Two of them were killed by a frontal impact of moderate violence (EES of 40 km/h), while the third, aged 9, sustained only light injuries in a frontal impact estimated at EES approximately 50-55 km/h.

Comparative Severity Children/Adults. The global severity of injuries sustained by adults is higher than that observed for children [Figure 7]. The fatality rate for adults is close on one quarter higher than that for children, for all impacts; it is almost twice as high for adults in frontal impact.



a) CHILDREN (N=145) /ADULTS (N=588) ALL IMPACT

b)CHILDREN (N=241)/ ADULTS (N=352) FRONTAL IMPACT

Figure 7. Fatality Rate and Severity Level for Children and Adults

The risks incurred by children are comparatively lower than for adults, because most children are seated in the back positions where frontal intrusion is rare.

Severity of Injury by Child Age. The overall injury severity distribution [Table 8] with age is in line with what is observed in all the literature: the smallest children are the most vulnerable [5]. The highest fatality rate is for infants between birth and 12 months. One observes a fatality rate of 0.44 (Figure 8) for this age group, as against an average fatality rate of 0.25 for our entire population of children. The difference is statistically significant. For children aged between 1 and 12 months, their low tolerance to impact is not compensated for by more frequent use of specific restraining systems (28% as against 10% for all those aged less than 10). We specify that in 13 cases out of 14, the seats were positioned facing the road.

Table 8. Severity of Injuries Sustained by Children According to Age

AGE	FATALITIES	SEVERE INJURIES	LIGHT INJURIES	UNHARMED	SEVERITY UNKNOWN	TOTAL
< 12 months	23	9	14	6	1	53
13 to 23 months	10	4	9	8	-	31
2 years	7	10	18	1	-	36
3 years	10	11	25	8	-	54
4 years	11	7	18	4	1	41
5 years	10	13	14	4	1	42
6 years	8	3	26	7	1	45
7 years	7	9	20	5	-	41
8 years	5	9	21	3	-	38
9 years	12	9	11	3	1	36
TOTAL	103	84	176	49	5	417

Ejection. One out of every three children killed is a victim of ejection. The frequency of ejection in crashes is twice as high for children as the rate observed for adults: 18% and 8% respectively. There are two explanations for this:

- The very unequal rate of use of restraining systems by children and adults partly explains this finding.

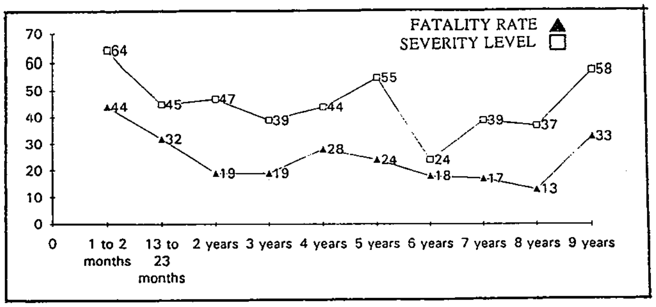


Figure 8. Fatality Rate and Severity Level for Children According to Age

- The small size of children could be a factor of more frequent ejection. The ejection rate for the youngest children (aged less than 6) is slightly higher than that for older children: 21 % and 17 % respectively for unrestrained occupants. For restrained occupants, the frequency of ejection, which is 7 % for children as against 1 % ejected for adults, may be due partly, among other causes which it is impossible for us to check, to a greater difficulty in restraining children on board cars using existing restraining systems of the seat or booster.

The proportion of ejections occurring in rollover and in side impact represents over half the cases of ejection for children [Figure 9].

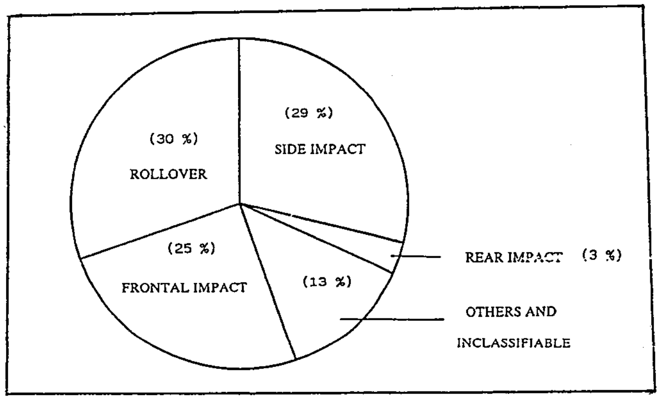


Figure 9. Breakdown of 100 Ejected Children According to Type of Impact

The fatality and severity rates give a measure of the risk incurred in the event of ejection: 0.55 and 0.75 respectively when ejection is observed as against 0.20 and 0.40 in the absence of ejection. Here again, children show greater vulnerability, since the fatality rate is doubled for ejected adults, whereas it is multiplied almost by 3 for children.

Three of the twelve children located in the front seat were ejected, as against 17% for children located in the rear positions.

Four children restrained by special systems were ejected. Analysis of these files shows that [Table 9]:

Table 9. Crash Characteristics for Restrained and Ejected Children

FILE No.	AGE	SEVERITY	POSITION	RESTRAIN-ING SYSTEM	TYPE OF IMPACT	EJECTION OF SYSTEM	SYSTEM FASTENING	COMMENTS
06 - 75	3 months	Fatal	Front right	Seat (back to road)	Overturning	No	Reel 3-point seat belt	
02 - 825	15 months	Fatal	Rear left	Seat (facing road)	Side, then car spin	No	Reel 3-point seat belt	Much play in harness, according to (woman) driver
04 - 036	3 years	Fatal	Rear left	booster	Side, then car spin	Yes	Static 3-point seat belt	Seat belt fastened, no play, according to driver
01 - 178	4 years	Fatal	Rear left	booster	Side, car spin, then rollover	Yes	Static 3-point seat belt	Seat belt fastened, no play, according to driver

- In 2 out of 4 cases, the system used was a booster Two of the 4 booster used in the sample as a whole were ejected with the child during the crash.
- No ejection of a restrained child is observed in frontal impact. On the other hand, when ejection occurs, in 3 cases out of 4 this is due to side impact followed by a vehicle spin.

Restraining Systems

Severity and Location of Injuries in Restrained Children in Frontal Impacts. The head is the location of an injury for more than half of the restrained children involved in frontal impact [Figure 10].

The other body areas most affected are the thorax (31 %), the abdomen (24%) and the neck (21 %).

Given the absence of reliable medical data for nearly all the child fatalities, we are unable to reach conclusions concerning the distribution of fatal injuries.

For severe injuries (AIS 3 to 5), abdominal injuries are preponderant, being observed in very violent impacts: EES in the range between 55 and 70 km/h. For 3 of the 4 victims aged between 7 and 9, the restraining system used was the seat belt mounted on board the vehicle without any additional booster. The last victim, aged 2, was seated in a forward facing child seat. This child was the only one of the 4 victims of severe injuries to the abdomen that suffered more severe injuries on another body area (AIS 6 to the head). There were 3 severe skull injuries (AIS 3 to 5). In these crashes, the violence of frontal impact is high (55 to 60 km/h), and is unknown in the last case, which involved extensive underriding under the front of a heavy vehicle For two of these very young victims (aged 2 and 3), decease ensued from skull injuries only.

Restraining Systems and Global Injury Severity for Children. The effectiveness of the global protection provided by the use of child restraining systems has been demonstrated by many studies [6], [7], [8]. This effectiveness is observed with respect both to the frequency of injuries and the injury severity. These results are based on studies involving the analysis of crashes of all levels of severity, which in fact means a very large proportion

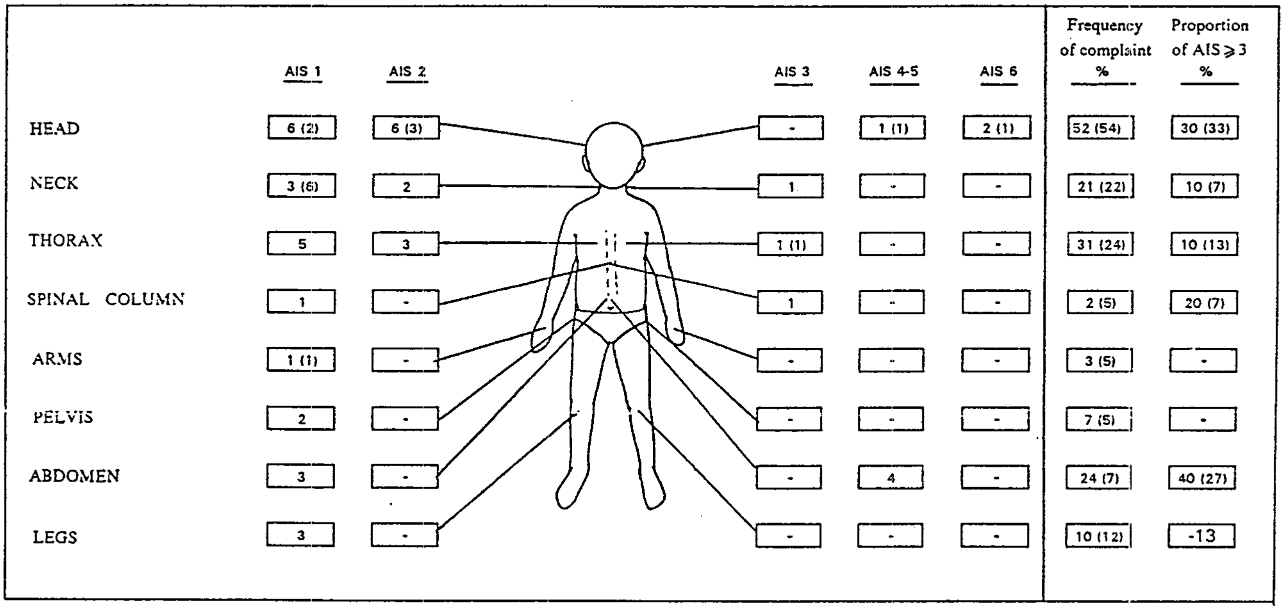


Figure 10. Frequency, Severity and Location of Injuries Sustained by Restrained Unejected Children in Frontal Impact (other impacts)

of impacts of low or moderate violence. It was interesting to check whether the effectiveness of this protection was likewise observed for the most severe crashes only.

For all impacts [Table 10], the fatality rate is situated within a 99% confidence region of 0.19 to 0.51 for restrained children, as against 0.17 to 0.30 for unrestrained children.

In frontal impact, the fatality rate is situated within a confidence region of 0.07 to 0.44 for restrained children, as against 0.06 to 0.20 for unrestrained children.

Table 10. Global Injury Severity for Children According to Age and Restraining System Used

AGE GROUP*	RESTRAINING SYSTEM	FATALITIES	SEVERE INJURIES	LIGHT INJURIES	UNHARMED	SEVERITY UNKNOWN	TOTAL
≤ 9 months	Car bed	-	-	-	-	-	-
	Child seat	2	1	1	1	-	5
	Unrestrained	12	3	7	1	-	23
10 months to 3 years	Child seat	11	6	12	3	-	32
	booster	1	-	2	-	-	3
	2-point belt	-	-	2	1	-	3
	3-point belt	2	1	-	1	-	4
	Unrestrained	16	18	36	10	-	80
4 years to 9 years	Child seat	-	-	-	-	-	-
	booster	1	-	-	-	-	1
	2-point belt	1	1	-	-	-	2
	3-point belt	3	4	3	-	-	10
	Unrestrained	39	42	83	20	3	187
Use of an unknown restraining system		15	8	30	12	2	67
TOTAL		103	84	176	49	5	.417

* according to the manufacturers' recommendations

One therefore observes no significant statistical difference whether or not a restraining system was used, both for all impacts and for frontal impact.

There are several explanations for this.

- The conditions of use of the restraining systems (fastening of seats to the vehicles, play in harness straps, etc.) are not known. We have every reason to believe that there are frequent cases in which the restraining systems are not used in accordance with the recommendations of the manufacturers. Many studies [6], [9], [10], [11] mention rates of misuse of restraining systems which are sometimes very high [12]. We also observed this ourselves for the cases already analyzed by us prior to this study.
- One quarter of the child seats used date prior to the French regulations of 1985. Of the specific systems (child seats and seat booster), only 21 % of them were in compliance with the requirements laid down by the French car makers [13].
- The influence of violence bias; in frontal impact, 25 % of restrained children are involved in impacts of EES greater than 65 km/h, as against only 7% for unrestrained children.

The comparison of global injury severities for children located in the rear of the same car, with one child restrained and the other not [Table 11], confirms the trend observed earlier. For the 19 pairs of children thus established, the situation most frequently observed is that in which the global severity for the restrained child is identical to that for the unrestrained child.

This observation does not allow us to evaluate the intrinsic effectiveness of restraining systems in the most violent crashes. This question sets the limit to what can be expected of the method used.

Estimated Potential Gains. It is difficult to evaluate the foreseeable potential gains from widespread use of child safety systems. Precise, reliable data is lacking concerning child tolerance to impact (sites and mechanisms of fatal injuries), and data is also unavailable concerning the performance of the restraining systems

Table 11. Comparison of Global Injury Severity on the Basis of a Matched Sample of Children Seated in the Rear of the Same Car (19 pairs of restrained and unrestrained children on board 15 cars)

		RESTRAINED CHILDREN				
		FATALITIES	SEVERE INJURIES	LIGHT INJURIES	UNHARMED	TOTAL
UN- RESTRAINED CHILDREN	FATALITIES	1	1	-	-	2
	SEVERE INJURIES	1	3	1	1	6
	LIGHT INJURIES	1	3	4	1	9
	UNHARMED	1	-	-	1	2
	TOTAL	4	7	5	3	19

tested in conditions similar to those of real-world crashes (type and violence of impacts, in particular).

We therefore performed, on a case by case basis, an evaluation of the potential effectiveness of a hypothetical optimized restraining system, the main characteristics of which would be as follows.

- Ejection of the system with the child or of the child from the system is no longer possible (the potential gain is therefore estimated assuming that the child is retained in the vehicle).
- The characteristics of the system used by the youngest children (aged less than 5) are such that any impact of the child against a part of the passenger compartment in frontal impact is prevented (as with a forward facing seat). The hypothesis adopted, then, is that decease is preventable in all frontal impacts in the absence of intrusion.
- The system is ineffective in all impacts in which more than 30% intrusion is observed on the position occupied by the child.

Because of the complexity of certain crashes or the absence of suitable data, we have introduced distinctions in the answers which can be obtained by case-by-case analysis. For example, we distinguish between fatalities which are certainly or probably not preventable. However, we are aware of the limitations of this approach, based on hypotheses which are at present unverifiable, which is why we prefer, instead of estimating the potential gain obtained with an optimized system, to count only those impacts in which the system would have been inoperative.

Thus, for 43% of unrestrained child fatalities, the use of an optimized restraining system would have probably (16%) or certainly (27%) changed nothing [Table 12]. The relative ineffectiveness of such a system in side impact is not surprising; 64% of the deceases observed in side impact could certainly not be prevented, due to the high intrusion levels noted in this type of impact. It is in frontal impact and rollover that an improvement in the situation can be expected, since only 25% of the deceases occurring in frontal impact could not be prevented. All fatal victims of overturning or rollover could certainly or probably be prevented.

Table 12. Estimated Potential Gains According to Type of Impact

	PREVENTABLE DEATHS					
TYPE OF IMPACT	NO		YES		UNDETER-MINED	TOTAL
	PROBABLE	CERTAIN	PROBABLE	CERTAIN		
FRONTAL	3	7	9	9	4	32
SIDE	6	10	6	3	3	28
REAR	-	3	-	1	-	4
OVERTURNING, ROLLOVER	-	-	3	9	-	12
OTHERS and UNCLASSIFIABLE	3	-	2	-	-	5
TOTAL	12	20	20	22	7	81

Conclusions

From the analysis of 275 police reports on fatal crashes occurring in France in 1990, concerning 417 child casualties aged less than 10, the following points should be noted.

- Cases of over-occupancy (more than five adults or children), which have declined greatly over the last ten years at least, now represent only 7% in vehicles with children.
- Only 14% of children aged less than 10 use a restraining system.
- 40% of the children are involved in collisions on short trips (less than 30 km).
- In car-to-car collisions, the responsibility for the crash is attributable in only one third of the cases to the driver with a child passenger. The frequency of positive alcohol levels above the legal rate is four times higher for drivers without a child compared to drivers with a child (or children).
- The proportion of car-to-car collisions is over-represented in crashes involving children: 46% as against 27% for all crashes.
- 57% of impacts are frontal.
- The violence of frontal impacts is particularly high: 60% of the EES values for cars with child(ren) are greater than 55 km/h.
- On the rear seat of the car, the central position appears the safest (fatality rate = 0.21 as against 0.27 on the left and 0.32 on the right).
- The global severity of the injuries sustained by adults is greater than that observed for children.

- The youngest children are the most vulnerable: there are 44% of fatalities for infants aged between 1 and 12 months, as against 25% for all children aged less than 10.
- One child out of three killed is the victim of ejection. The frequency of ejection of children is twice as high as that observed for adults: 17% and 8% respectively. For the children, the risk of being killed during ejection is three times greater (58% of fatalities) than the fatality rate observed in the absence of ejection (20% of fatalities).
- In frontal impact, for non-deceased restrained children:
  - The head is the location of an injury for more than half of the children;
  - or very severe injuries (AIS 3 to 5), abdominal injuries are preponderant, and are observed in victims restrained by the seat belt only.
- No statistical difference is observed in the fatality rate according to whether or not a restraining system is used. The misuse of child seats (some of which, moreover, are old or do not comply with the recommendations of French car makers) largely explains this result, which is the opposite of what is observed in other countries (Sweden and the U.S.A. in particular).
- The scope of the potential gain in terms of deceases which could be prevented by an optimized restraining system is 57% of unrestrained child fatalities. For the other unrestrained children, the violence of the impacts sustained by them is such (chiefly strong intrusion) that the use of an optimized restraining system would have changed nothing.

The global results for child restraining systems in fatal crashes may seem mediocre. However, it must be said that these results are evaluated without being able to take into account the specific conditions of use of such systems. There are strong grounds for thinking that a large number of restraining systems are not used in accordance with the recommendations laid down by the manufacturers.

That is why we feel that a substantial improvement in the child protection level must involve a better knowledge of the mechanisms of fatal injures sustained by restrained children. An increase in international exchanges of the best documented fatal crash files would help us make rapid progress in this field, where the public health is at stake.

References

1. Hartemann F., Foret Bruno Jy. et al., *"Les Accidents Mortels en 1980"* (unpublished study, Association Peugeot S.A/Renault).
2. Turbel Thomas, *"Swedish Programs for Child Protection in Cars"* (IRCOBI conference, Stockholm 1989).
3. Langwieder K., Hummel Th., *"Children in Cars: Their Injury Risks and the Influence of Child Protection Systems"* (ESV conference, Goteborg 1989).
4. Hayes H.R.M. (IRCOBI conference, Stockholm 1989).
5. Lowne R., Gloyns P., Roy P., *"The Performance of Child Restraint Systems in Side Impacts"* (T.R.R.L. May 1987 and ESV conference, Goteborg 1989).
6. Karlbrink L., Krafft M., Tingvall C. (ESV conference, Goteborg 1989).
7. Partyka S.C., *"Lives Saved by Child Safety Seats from 1982 through 1987"* (NHTSA - 1988 and ESV conference, Goteborg 1989).
8. Tingvall, *"Some Aspects of the Safety of Children as Car Passengers in Road Traffic Accidents"* (Acta Paediatrica Scandinavica magazine - 1987).
9. Dejeammes M., Biard R., Carre Jr., Cambon B., De Lavalette (INRETS magazine - France 1986).
10. Dejeammes M., Trauchessec R. ("L'enfant passager d'automobile", symposium in France 1987).
11. Petrucelli E., *"Child Restraint Misuse in the USA: Implications for Crash Protection"* (IRCOBI conference, 1989).
12. Khane C.J., *"An Evaluation of Child Passenger Safety: The Effectiveness and Benefits of Safety Seats"* (NHTSA study, report DOT HS 806 890, February 1986).

Acknowledgements

We should like to thank the Police Forces for kindly providing us with a copy of police reports on fatal crashes occurring in 1990. Without their cooperation, this study would have been impossible.

S1-O-05

Data Analysis of the Speed-Related Crash Issue

Noble Bowie
Marie Walz
National Highway Traffic Safety Administration

Abstract

Excessive speed has been recognized for decades as both a significant and complex highway safety issue. Using the most recent data available, this paper examines the size of the "speed problem" in the United States and identifies characteristics most often associated with speed-related crashes. Data from the National Accident Sampling System, the Fatal Accident Reporting System, the Crash Avoidance Research Data File, the National Crash Severity Study, and the Indiana Tri-Level Study were utilized in conducting the analysis. Information pertaining to crash avoidance, crash severity, and related crash characteristics (e.g., alcohol, vehicle type, roadway condition, etc.) were examined. Of particular interest is the use of an innovative methodology to estimate the economic impact of speed-related crashes on society.

Introduction

"Speed Kills" has been an important slogan for highway safety. While it is clearly true, it is not a very useful definition for a highway safety program. To effectively address the issue, it is imperative to know the size of the speed-related crash problem, where these crashes most often occur, why they occur, and who is most likely to be involved in such crashes. To ascertain this information, an analysis of several crash data files was conducted. This paper presents the results of that analysis. It examines the speed issue in terms of crash causation, crash severity, crash characteristics, and societal costs.

Crash Causation Data

Data from the Crash Avoidance Research Data file (CARDfile) [1], the Indiana Tri-Level study [2], and the Fatal Accident Reporting System (FARS) [3] were examined to determine the relative role of speeding in crash causation. Other than data from the Indiana Tri-Level study, the data in the problem identification/ problem size analysis are based on police-reported information, not detailed investigations. The accuracy of police-reported data is generally not as good as that provided by field investigations/crash reconstructions and this should be kept in mind when interpreting these results.

CARDfile was developed by NHTSA as an aid to problem identification and countermeasure development in the general area of crash avoidance research. It electronically combines the annual crash data files of six States into a common format. For purposes of this analysis, data from the 1986 CARDfile were utilized. The 1 986 CARDfile data contain about 1.4 million crashes involving about 2.4 million vehicles and drivers. Data from additional years of CARDfile were not included to simplify the analysis, and because previous analyses have shown that distributions obtained in a single year of data closely reflect distributions based on several years of data.

CARDfile was analyzed to determine the magnitude of the role of speed in contributing to crash causation. Table 1 compares the relative involvement of speed and other driver errors in contributing to the occurrence of crashes.

Table 1. Driver Error Involvement in Crash Causation

Crash Type	Percent of Crashes In Which Factor Was Involved*
Speed-Related**	11.6%
Right-of-Way Violation	8.7%
Following Too Closely	8.0%
Ignore Traffic Control	7.1%
Asleep/Inattention	4.1%
Improper Passing	2.4%
Failure To Signal	.9%

* Data are based on police accident reports from six States, and are not nationally representative.
** Speed-related means that in the police officer's judgment speed contributed to the cause of the crash. Up to three factors could be coded for each crash.
Source: CARDfile 1986.

As illustrated in the table, speed was found to be involved in close to 12 percent of the crashes in CARDfile. It was the most prevalent driver error-related cause contributing to crash occurrence.

A similar analysis of data from the Indiana Tri-Level study was also performed. In the Tri-Level study crashes were examined at three levels: police accident reports (level A), on-scene investigation of crashes by teams of technicians (level B), and in-depth investigations of subsets of crashes by multi-disciplinary teams (level C). Also, there were three levels of certainty that a causal factor contributed to the occurrence of a crash—definite, probable, and possible. For purposes of this analysis, only investigation levels B (2,258 cases) and C (420 cases) and certainty levels "definite" and "probable" were used.

The top crash causation factors (includes driver, environment, and vehicle related factors) were identified and rank ordered. Here, "cause" means a deficiency without which the crash would not have occurred. Each crash could have multiple causes. The factors were rank ordered by the range of their estimated involvement, considering the estimated percentage of involvement at level B definite, level B probable, level C definite, and level C probable. The highest and lowest figures for each causal factor were then used to represent its overall range of involvement (see Table 2).

Table 2. Rank Order of Causal Factors by Range of Involvement

Causal Factor	Range of Involvement (percent)
Improper Lookout	13.0 - 23.1
Excessive Speed*	7.1 - 16.9
Inattention	8.4 - 15.0
Slick Roads	3.8 - 14.1
Improper Evasive Action	4.5 - 13.0

*Excessive speed means too fast for conditions. It was not determined with reference to the prevailing speed limit.

Source: Indiana Tri-Level Study, 1979.

The table shows that "excessive speed" was the second most prevalent factor contributing to crash causation in the Tri-Level study. The mid-point of the range of involvement (7.1 - 16.9) for "excessive speed" is 12 percent which corroborates the CARDfile estimate that speed is involved in close to 12 percent of all crashes occurring in CARDfile States.

Tri-Level data were also analyzed by crash type (e.g., head-on, angle, sideswipe, rear-end, and single-vehicle). For each crash type, the top causal factors were rank ordered by their percentage of involvement. Table 3 shows where "excessive speed" ranked as a contributing factor in each of the respective crash types.

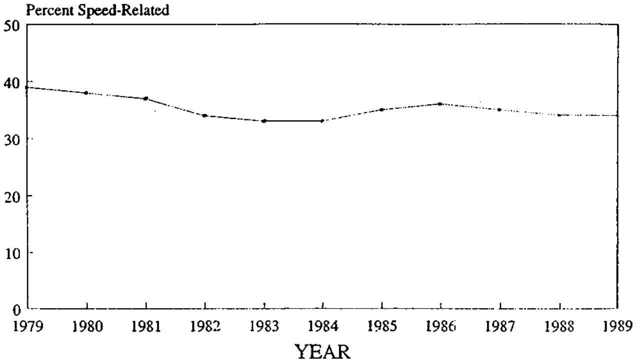
Table 3. Ranking of Excessive Speed by Crash Type

Crash Type	Ranking	Range of Involvement
Single-vehicle	# 1	22.1 - 39.3
Head-on	# 2	12.7 - 22.0
Sideswipe	# 2	10.8 - 14.9
Angle	#10	3.4 - 8.8
Rear-end	#10	2.9 - 6.6

Source: Indiana Tri-Level Study, 1979.

"Excessive speed" ranked in the top ten contributing factors for each crash type. This is especially noteworthy given there were approximately 50 factors that could be considered in each crash case. Of further significance, "excessive speed" was the first or second most prevalent cause listed for the two most severe crash types—head-on and single-vehicle crashes. This suggests that not only is "excessive speed" a leading cause of motor vehicle crashes, but it is most prevalent in the more severe crash types.

FARS data were utilized to determine the role of speed in contributing to fatal crash causation. FARS is a census of people who die within thirty days of a motor vehicle crash as a result of injuries received in the crash. The data are prepared by the States from death certificates, hospital records, police reports, and other sources and are compiled by NHTSA into a national data file. For FARS data, "speed-related" was defined as "driving too fast for conditions or in excess of the posted speed limit," and "high speed police chase." (Note that these are qualitative variables that are subject to interpretation on the part of the data coder. Quantitative variables such as travel speed and speed limits were not used because there are a substantial number of cases for which this information is unknown.) These data indicate that in 1989, approximately one-third of all fatal crashes were speed-related. This percentage has declined from a high of 39 percent in 1979. Since 1982, the proportion of speed-related crashes has basically remained stable. This is illustrated in Figure 1.



Source: Fatal Accident Reporting System.

Figure 1. Speed-Related Fatal Crashes

Crash Severity Data

The laws of physics tell us that the energy of impact delivered to vehicle occupants in a collision increases non-linearly with impact speed. Simply stated, crash severity increases (disproportionately) with vehicle speed.

To determine real-world crash experience, an analysis of data from the National Accident Sampling System (NASS) [4] and the National Crash Severity Study (NCSS) [5] was conducted. Through the use of field investigation teams, NHTSA's NASS system collects detailed data on a nationally representative sample of all police-reported crashes (the system was revised in 1987 and now consists of two components, the General Estimates System and the Crashworthiness Data System). NCSS was a NHTSA data collection program that was conducted between 1977 and 1979. Crashes were investigated in seven geographic locations across the country. Detailed information was collected on over 11,000 "tow-away" crashes.

In Table 4, the percentage of occupants sustaining Abbreviated Injury Scale (AIS) 2+ and 3+ injuries is given for various Delta V levels. AIS is a system for rating the severity of individual injuries. AIS levels range from 1 for a minor injury to 6 for an injury that is not currently survivable. Delta V is a computed estimate of the instantaneous change in velocity of the vehicle during the impact phase of the crash.

Table 4. Injury Rates by Crash Severity*, Comparison of NCSS & NASS (1982-89)

Total Delta V	AIS 2+		AIS 3+	
	NCSS	NASS	NCSS	NASS
1-10 mph	2.4%	4.5%	0.7%	1.0%
11-20 mph	9.5%	10.6%	3.5%	2.6%
21-30mph	25.3%	29.2%	13.9%	11.1%
31-40 mph	51.8%	53.4%	37.2%	27.9%
41-50 mph	70.3%	67.2%	58.3%	40.6%
Over 50 mph	64.7%	69.3%	56.9%	54.3%

*Rate equals the number of occupants at a certain Delta V level (in 10 mph increments) injured at specific AIS levels (AIS 2+ or AIS 3+) divided by the total number of occupants involved in crashes at that level of Delta V times 100. Does not include cases in which either the Delta V level or the AIS level was unknown.

Sources: NASS 1982-86, and 1988-89 (CDS). Includes only tow-away cases. There was no statistically representative NASS file in 1987. (See Appendix 1 for sample sizes and standard errors.) NCSS, 1979. Data are limited to tow-away crashes involving passenger cars and light trucks. Data are not nationally representative.

Both NCSS and NASS data show a consistent and dramatic increase in injury severity as Delta V level increases. For instance, people involved in crashes with a Delta V of 50 mph or greater are more than 50 times more likely to sustain an AIS 3+ injury than those involved in a crash with a Delta V of 10 mph or less. Clearly, the crash data are evidence that real-world crash experience follows the laws of physics.

In terms of crash severity, the most critical real-world measure is how many injuries and fatalities result from speed-related crashes. To determine this, data from the NASS General Estimates System (GES) file, FARS and CARDfile were analyzed. First, GES was referenced to obtain nationally representative estimates of the number of occupant injuries for the various police-reported injury severity levels. CARDfile, because of its large number of cases, was referenced to determine the proportion of occupant injuries for each injury severity level that is speed-related. The CARDfile percentages were then applied to the overall GES estimates and FARS data to derive the number of occupant injuries for each injury severity level that are speed-related. The FARS file was then used to obtain the total number of motor-vehicle crash fatalities, and the number that were speed-related. This is illustrated in Table 5.

Table 5. Distribution of Injuries in Speed-Related Crashes by Injury Severity Level

Injury Severity Level	Frequency*	Speed-Related**	Total
No Injury***	12,610,000	10.2%	1,286,220
Possible Injury	1,719,000	10.9%	187,371
Non-Incapacitating Injury	943,000	14.6%	137,678
Incapacitating Injury	481,000	17.1%	82,251
Fatal Injury****	45,500	34.2%	15,558

*National totals are from 1989 GES. (See Appendix 1 for sample sizes and standard errors.)

**Speed-related percentage derived from CARDfile (1984-1986).

***The estimate for non-injured people is considered to be low because some states only list injured persons.

****Fatal crash statistics are from FARS, 1989.

Based on the information in Table 5 it is estimated that in 1989, 15,558 people died in speed-related crashes and over 80,000 sustained incapacitating injuries. The injury estimates may be conservative because they do not include cases in which the occupant's injury severity level was not known. We did not attempt to include the "unknowns" because it can not be assumed that the injury severity level distribution for these cases is the same as for those cases for which the injury severity level is known. It should be recognized that many of these crashes also involved other contributing factors such as alcohol, slick roads, and driver inattention. Note also that involvement of speed as a contributing factor increases with injury severity. Only 11 percent of vehicle occupants sustaining possible injury were involved in a speed-related crash, while more than one-third of fatally injured occupants were involved in a speed-related crash.

Crash Characteristics

An analysis of the 1989 FARS file was conducted to identify the characteristics most associated with speed-related crashes. FARS data were utilized because it is a census of all fatal crashes and the level of investigation by the police for fatal crashes is generally greater than for less severe crashes. As a result, the following analysis is descriptive of fatal crash situations and may not be indicative of other crash severity levels.

Manner of Collision - Speed-related fatal crashes most often involve only a single vehicle. Almost 70 percent of all drivers involved in speed-related fatal crashes were involved in a single vehicle crash. The next highest percentages are for head-on (12 percent) and angle crashes (11 percent). For fatal crashes that were not speed-related, only 35 percent of the drivers were involved in a single vehicle crash, while 30 percent were involved in an angle crash and 23 percent were involved in a head-on crash.

Vehicle Type - FARS data indicate that among vehicle types, speed-related crashes are most frequently associated with motorcycle drivers. Over 45 percent of all motorcycle drivers involved in fatal crashes were speeding. The involvement of speed in fatal crashes for motorcycles is almost twice as much as for drivers of the next vehicle type, passenger cars and light trucks (23 percent). Speeding was found to be much less likely for drivers of medium and heavy trucks involved in fatal crashes (11 percent).

Alcohol Involvement - Alcohol involvement was found to be very prevalent in drivers involved in speed-related fatal crashes. Approximately 41 percent of all drivers under the influence of alcohol who were involved in a fatal crash were speeding or going too fast for conditions. Of all drivers involved in speed-related fatal crashes, about 56 percent were under the influence of alcohol. Conversely, of all drivers involved in fatal crashes that were not speed-related, only 24 percent were under the influence of alcohol.

Safety Belt Usage - Manual safety belt usage (lap belt or lap and shoulder belt) for drivers involved in speed-related fatal crashes was found to be only 19 percent. This compares to a usage rate of 37 percent for drivers involved in non-speed related fatal crashes. The number of cases involving automatic restraint equipped vehicles was insufficient for developing any reliable estimate.

Motorcycle Helmet Usage - Little difference was found in motorcycle helmet usage for speeders and non-speeders. Of all motorcycle drivers involved in speed-related fatal crashes, 40 percent were wearing helmets. In fatal motorcycle crashes that did not involve speed, 44 percent of the motorcycle drivers were wearing helmets.

Roadway Type - About thirty-four percent of all fatal crashes on known roadway types were speed-related. These percentages varied considerably by road type, with the percentage of those speed-related being greater in rural settings, except for "Other Principal Arterial Roads," where it was greater in urban settings. Approximately 36% of all fatal crashes on rural roads were speed-related, while only 30% were speed-related on urban roads. While rural roads account for only 40 percent of all vehicle miles travelled, they account for 61% of all speed-related fatal crashes. Finally, the highest percentage of speed-related fatal crashes among the roadway types was on "Local Roads/Streets" and "Collectors" (39 percent).

Roadway Surface Condition - About 14 percent of all fatal crashes occur on wet roads. It makes no difference whether the crash is speed-related (14 percent) or not (14 percent). Of all fatal crashes occurring on dry roads, about one-third are speed-related. The same is true for fatal crashes occurring on wet roads.

Roadway Alignment - Speed-related crashes account for only 27 percent of all fatal crashes on straight roadway sections, but constitute 54 percent of all fatal crashes occurring on curves. Approximately 40 percent of all speed-related fatal crashes occur on curves, while only 18 percent of the fatal crashes that are not speed-related crashes occur on curves.

Time of Day - While only 27 percent of all daytime fatal crashes are speed-related, 39 percent of nighttime fatal crashes involve speed. Sixty-four percent of all speed-related fatal crashes occur at night, while 50 percent of all fatal crashes not involving speed occur at night.

Sex and Age - Male drivers were more likely than female drivers to be involved in a speed-related fatal crash. About 25 percent of all male drivers involved in fatal crashes were speeding or going too fast for conditions. The percentage for female drivers involved in fatal crashes was only 16 percent. Speed-related fatal crashes were also most associated with young drivers. Further, the relative proportion of speed-related crashes was found to decrease with increasing driver age. Approximately 37 percent of all drivers aged 14-19 years involved in fatal crashes were speeding or going too fast for conditions. The percentage for drivers 70 and over involved in fatal crashes was only 7 percent. The percentages for the various age groups were as follows: 14-19 (37%), 20-29 (30%), 30-39 (22%), 40-49 (16%), 50-59 (12%), 60-69 (10%), and 70+ (7%).

Number of Vehicle Occupants - FARS data indicate that the number of vehicle occupants does not affect a person's propensity to speed. The percentage of vehicles with only one occupant was about the same for vehicles that were speeding (56%) as it was for vehicles that were not speeding (59%).

Previous Violations - An analysis of drivers with previous citations shows that in all cases, a greater percentage of drivers involved in speed-related fatal crashes had previous violations as compared to those involved in fatal crashes that were not speed-related. This is illustrated in Table 6.

Table 6. Drivers in Fatal Crashes by Previous Violations and Speed-Related Involvement

Previous Violation	Speed-Related Crashes	Non Speed-Related Crashes
Speeding Conv	34%	28%
Moving Violtn	27%	21%
DWI Convict.	12%	8%
Suspension	23%	15%

Source: FARS, 1989.

Societal Cost of Speed-Related Crashes

An innovative approach was employed to estimate the economic impact of speed-related motor vehicle crashes. This approach involves the conversion of maximum Abbreviated Injury Scale (MAIS) levels to police-reported injury severity levels, and applying societal cost estimates to the injured occupant totals for each injury severity level.

Estimates of societal cost are based on statistics considered to be the most authoritative and up-to-date by NHTSA's Office of Plans and Policy. An article by Miller, Luchter, and Brinhnan [6] provided estimates of the average societal economic loss associated with individual injuries of various maximum AIS levels. These figures are based on the sums of the following categories of economic costs: property damage, medical costs, lost productivity, emergency services, legal/courts, and other administrative costs. The Miller et al estimates are presented in Table 7.

Table 7. Societal Economic Loss Per Injury by MAIS Level

MAIS 1:	$2,860
MAIS 2:	$8,058
MAIS 3:	$19,489
MAIS 4:	$155,832
MAIS 5:	$391,314
FATAL:	$425,406

Using 1982-1986 NASS data, NHTSA's National Center for Statistics and Analysis (NCSA) converted MAIS injury levels to police-reported injury severity levels. This allows one to apply the above MAIS societal cost estimates to police reported injury severity levels. Using injury totals from NASS and the societal cost estimates in Table 7, an average cost for police-reported injury level was computed. This is provided in Table 8.

Table 8. Societal Economic Loss Per Injury (Police-Reported)

No Injury:	$260*
Possible Injury (C):	$3,104
Non-incapacitating Injury (B):	$4,656
Incapacitating Injury (A):	$20,532
Killed (K):	$409,031

*There is an injury cost because in some cases where the police officer reported no injury, subsequent information (such as the hospital report) showed the victim sustained an injury of some AIS level. Estimate does not include property damage costs.

To calculate the total economic loss to the country due to speed-related crashes, the occupant injury estimates developed under the Crash Severity section of this paper were multiplied by the corresponding societal cost figures (see Table 9).

Table 9. Estimated Societal Cost of Speed-Related Crashes (1989)

No Injury: 1,286,220 X $838*=	$1,077,852,360
C injuries: 187,371 X $3,104 =	581,599,584
B injuries: 137,678 X$4,656=	641,028,768
A injuries: 82,251 X $20,532 =	1,688,777,532
K injuries: 15,558 X $409,031 =	6,363,704,298
Total Societal Cost of Speed-Related Crashes =	$10,352,962,542

*Includes $260 in injury costs and $578 average cost per property damage only crash.

Using this approach, it is estimated that speed-related crashes cost society more than $10 billion in 1989. This is a "conservative" estimate because: (1) it does not include cases in which the injury level was not known; (2) the estimate for non-injured people is low because some states only list injured persons; and (3) the cost figures address economic loss only and do not consider the intrinsic value of life and health above and beyond economic considerations.

Summary of Data Analysis

It is always a sound practice to focus one's problem solving resources on the largest problems. The priority setting process for highway safety programs centers on the observed incidence of a given factor's involvement in contributing to the occurrence of crashes, injuries, and fatalities. The use of real-world crash data provides insight critical to the conduct of meaningful analysis and safety improvement development. As previously stated, the purpose of this analysis was to utilize current crash data files to scope the size of the "speed problem" and identify pertinent crash characteristics most often associated with speed-related crashes.

Results of this analysis clearly indicate that the speed issue warrants priority attention. Speeding/excessive speed is one of the most prevalent factors contributing to crash occurrence. It is estimated to be involved in approximately 12 percent of all police-reported crashes. The prevalence of its role appears to increase with crash severity. While only 10 percent of vehicle occupants sustaining no injury were involved in a speed-related crash, more than one-third of all fatally injured occupants were involved in a speed-related crash. In 1989, it is estimated that about 15,558 fatalities and 80,000 serious injuries occurred in speed-related crashes. The economic cost of these crashes was over $10 billion. The results also suggest that the specific aspects of the issue that should be focused upon when considering potential countermeasures include: (1) single-vehicle crashes; (2) alcohol involvement; (3) nighttime; (4) rural roads; (5) low safety belt usage; (6) motorcycles; (7) male drivers; (8) young drivers (under 30); and (9) drivers with previous traffic violations.

References

1. Crash Avoidance Research Data file (CARDfile), National Highway Traffic Safety Administration, 1984-1986.
2. "Tri-Level Study of the Causes of Traffic Accidents", Treat et. al., Prepared for the National Highway Traffic Safety Administration, May 1979.
3. Fatal Accident Reporting System (FARS), National Highway Traffic Safety Administration, 1979-1989.
4. National Accident Sampling System (NASS), National Highway Traffic Safety Administration, 1982-1986, 1988.
5. National Crash Severity Study (NCSS), National Highway Traffic Safety Administration, 1977-1979.
6. "Crash Costs and Safety Investment", Ted R. Miller, Stephen Luchter, and C. Philip Brinkman, Presented at the Association for the Advancement of Automotive Medicine Annual Meeting, September, 1988, Seattle, Washington.

Appendix 1

Sample Sizes and Standard Errors for NASS Data in Table 4

	AIS 2+		AIS 3+		
Total Delta V	Percent	Standard Error*	Percent	Standard Error*	Sample Size
1-10 mph	4.5	1.4	1.0	.95%	10,814
11-20 mph	10.6	1.9	2.6	1.1	15,364
21-30 mph	29.2	6.3	11.1	4.2	4,238
31-40 mph	53.4	14.5	27.9	18.4	1,031
41-50 mph	67.2	39.1	40.6	40.5	224
Over 50 mph	69.3	**	54.3	**	102

*The standard errors were derived from a single year, 1984. These estimates are probably larger than sample errors from all years of NASS in this analysis. Multi-year sampling error estimates are currently being developed. For more information on the sample design and estimation methodology, contact NHTSA's National Center for Statistics and Analysis.

**Sample size is insufficient to allow calculation of sampling error.

Sample Sizes and Standard Errors for NASS Data in Table 5

Injury Severity Level	Frequency	Sample Size	Standard Error
No Injury	12,610,000	N/A*	N/A*
Possible Injury	1,719,000	13,345	91,000
Non-Incapacitating Injury	943,000	11,632	56,000
Incapacitating Injury	481,000	5,718	60,000
Fatal Injury***	45,500	N/A**	N/A**

*No confidence bounds were derived for this figure because some states only list injured persons. Therefore, as noted in the paper, the estimate of non-injured occupants is considered low.

**Standard errors are not derived for FARS data because the file is a census of all fatal crashes, not a sample.

S1-O-06

Cyclists and Pedestrians in The Netherlands: Different Needs of Injury Protection?

L.T.B. van Kampen
SWOV Institute for Road Safety Research

Abstract

A series of analyses of injury data from hospitalized cyclists and pedestrians based on Dutch national hospital data has been carried out. The main purpose of the study is to establish the (different?) needs of injury protection of cyclists and pedestrians, especially those colliding with cars. Contrary to the expectation based on the use of national accident data, there appeared to be an enormous number of hospitalized cyclists resulting from non-motor vehicle collisions. Their under-representation in the national accident statistics appeared even greater than the under-representation of hospitalized cyclists and pedestrians in general.

This group of patients was analyzed as an additional third group. Conclusions regarding the specific injury patterns of the three groups, including influence of age, are drawn. Recommendations regarding the problem of underreporting and the means of protection against collision forces are given. This study forms part of a national plan regarding the stimulation of the use of bicycles in the Netherlands (CYCLE MASTERPLAN), in which plan the improvement of traffic safety of cyclists and the bicycle is explicitly aimed for. The study is carried out on behalf of the Dutch Ministry of Transport, Traffic Engineering Department (DVK).

Introduction

Bicycling in the Netherlands is as normal as walking and sleeping. Almost everyone, from the youngest to the oldest, owns a bicycle; there are some 14 million of them, compared to about 15 million people in the Netherlands. The number of cars is less than half the number of bicycles. Together they are the most common means of transportation in the Netherlands. Despite this fact car drivers and cyclists are not really on speaking terms. Their meetings in traffic are often regarded by both parties as unpleasant encounters. The number of near misses is enormous and accident statistics show a great proportion of collisions between the two groups.

The Dutch government, being very much involved in the process of controlling and guiding the traffic mobility, is trying to get car drivers out of their cars and into such modes of traffic as public transport, especially during rush hours. For short trips bicycle use is stimulated.

As has been mentioned in the Dutch Status Report, a national policy called *MASTERPLAN FIETS (CYCLE MASTERPLAN)* has recently been designed to improve all aspects of cycling and bicycles in the Netherlands. Some aspects of this enormous national effort are improvements in the field of infrastructure (even more bicycle lanes), of parking facilities and of anti-theft improvement. Other parts of this Masterplan are improvement of the safety of bicycles and of bicycle riders.

In view of the relatively high injury risk of cyclists, the Dutch Masterplan includes strategies to improve this situation; in fact the study reported in this paper is part of the Masterplan.

The Problem of the Unregistered Accidents

Official accident statistics do not reflect the truth; there has always been much underreporting of non-motor vehicle accidents and of all types of minor accidents. However, even accidents involving both motor vehicles and bicycles appear to be heavily underreported (Harris, 1990). This phenomenon is not unique for the Netherlands but in view of the great amount of bicycles and the resulting traffic and traffic accident situation to be monitored, this could be called a major disaster.

The Dutch national accident statistics for 1989 show a number of 3450 hospitalized bicycle victims, while according to the hospitals' own data source there were some 6820.

In other words:

Almost half of all bicycle casualties, admitted for treatment (longer than one day) in hospitals, are not found in police statistics. A comparable problem exists for pedestrians. Since completeness of registration decreases with decreasing seriousness of the accident, the situation is even worse for so called minor bicycle and pedestrian accidents.

In this paper reliable data on hospital patients are used to illustrate the real problem: Almost 100% of all Dutch hospitals join a data system that includes relevant data of *all* patients admitted for at least one day treatment.

Apart from such obvious data as age and sex this source provides extensive injury data coded according to the WHO-ICD system and some relevant accident data, also coded according to the ICD system, in particular the external causes of injury system, so called E-codes.

The Dutch organization responsible for the registration and distribution of hospital data is called SIG, the data file is called LMR. SWOV receives a computer tape copy of the relevant data on a yearly base.

Data Selected

For the analysis reported in this paper, three groups were selected out of the total group of hospitalized traffic casualties for the year 1989. This total number in the Netherlands averages around 20.000 each year.

Selected were:

Bicycle casualties resulting from motor-vehicle accidents . . . . (B-MV)
Pedestrian casualties resulting from motor-vehicle accidents. . . . . (P-MV)
Bicycle casualties resulting from non-motor vehicle accidents . . . . (B-NMV)

The third group of cyclists was originally not included in the analysis design, since the problem to be studied focussed on motor-vehicle collisions. These are reported to cause 60 to 70% of all serious casualties amongst cyclists.

However, in view of the great number of resulting, not-included cyclists, this rest-group had to be studied more carefully and it was found that:

- the rest-group is by far the greatest separate traffic-casualty group in hospitals
- the rest-group shows some interesting differences with the motor-vehicle casualties

In the official police accident data the group of non-motor vehicle casualties admitted to hospitals is almost non-existent!!

In other words official accident statistics do not only lie, they give a totally wrong impression of the distribution of accident type.

Therefore they could lead to, and in fact have partly been leading to incorrect priorities in traffic safety policy.

Some additional explanation regarding the three selected casualty groups may be useful for the record: The groups are selected from the main data source, using E-codes: E 814.0 for the pedestrians against motor-vehicles; E 813.1 for the cyclists against motor-vehicles; and E 826 for the "rest-group" of cyclists.

Especially the latter group is a mixture of at least two separate casualty groups: 1. those colliding with other road users (not motor-vehicles!) such as pedestrians and other cyclists; and 2. those hitting obstacles or no other party at all (falls). All these casualties were injured severe enough to necessitate hospital admittance.

Numbers of Selected Casualty Groups, 1989

(Total number of hospital traffic casualties	:	20689)
Number of selected B-MV casualties	:	2072
Number of selected P-MV casualties	:	1737
Number of selected B-NMV casualties	:	4422

Using the selection criteria mentioned above, some 474 pedestrian casualties and some 324 cyclists were not included in the 3 groups, because of their different accident type.

General Characteristics of the Selected Casualty Groups

In this paragraph the distributions of 5 characteristics are shown:

- age-group
- sex
- average number of injuries
- where discharged
- length of stay in hospital

The distributions are presented in the following 5 tables.

Table 1. The 3 Casualty Groups by Age-Group (Absolute Numbers and Percentages) 1989

Age-Group (years)	B-MV	P-MV	B-NMV
0 - 15	479 (23,1)	644 (37,1)	1021 (23,1)
16 - 17	133 (6,4)	48 (2,8)	151 (3,4)
18 - 24	262 (12,6)	135 (7,8)	325 (7,3)
25 - 34	157 (7,6)	103 (5,9)	376 (8,5)
35 - 44	137 (6,6)	131 (7,5)	446 (10,1)
45 - 54	168 (8,1)	107 (6,2)	427 (9,7)
55 - 64	235 (11,3)	142 (8,2)	532 (12,1)
65 - 74	284 (13,7)	193 (11,1)	663 (15,0)
75 and older	217 (10,5)	234 (13,5)	481 (10,9)
Total	**2072 (100%)**	**1737 (100%)**	**4422 (100%)**

Table 1 shows more or less comparable age distributions for the two bicycle groups, while for the pedestrians more emphasis falls on the youngest and the oldest age-group.

Table 2. Sex of 3 Casualty Groups (Absolute Numbers and Percentages) 1989

Sex	B-MV	P-MV	B-NMV
Male	1132 (54,6)	969 (55,8)	2497 (56,5)
Female	940 (45,4)	768 (44,2)	1925 (43,4)
Total	**2072 (100%)**	**1737 (100%)**	**4422 (100%)**

The three groups have more or less the same distribution.

Table 3. Average Number of Injuries per Casualty for the 3 Casualty Groups

B-MV	2,0
P-MV	1,9
B-NMV	1,4

While there appears to be a comparable number of injuries for the two casualty groups colliding with motor vehicles, the average number of injuries for non-motor vehicle casualties is much lower.

This is the first sign that even though the three groups all contain hospitalized patients, the rest-group of cyclists is less severely injured.

Table 4. Discharge for the 3 Casualty Groups (Absolute Numbers and Percentages) 1989

Where Discharged	B-MV	P-MV	B-NMV
Home	184 (88,9)	1505 (86,6)	4198 (94,7)
To another hospital	97 (4,7)	97 (5,6)	101 (2,3)
To a nursing home	36 (1,7)	54 (3,1)	86 (1,9)
Died in hospital	97 (4,7)	81 (4,7)	46 (1,0)
Total	**2072 (100%)**	**1737 (100%)**	**4422 (100%)**

While again the figures for the motor vehicle casualties are comparable, it can be seen that the non-motor vehicle casualties show a far lower percentage of fatalities in hospitals.

Table 5. Length of Stay in Hospital for the 3 Casualty Groups (Absolute Numbers and percentage) 1989

Length of Stay in Hospital (days)	B-MV	P-MV	B-NMV
1 day	67 (3,2)	75 (4,3)	191 (4,3)
2-9 days	928 (44,8)	774 (44,6)	2406 (54,4)
10-19 days	564 (27,2)	368 (21,2)	995 (22,5)
20-29 days	217 (10,5)	183 (10,5)	459 (10,4)
30-39 days	103 (5,0)	104 (6,0)	147 (3,3)
40 or more days	193 (9,3)	233 (13,4)	224 (5,1)
Total	**2072 (100%)**	**1737 (100%)**	**4422 (100%)**

It appears that pedestrians stay the longest. This is illustrated by the emphasis on the last category compared to the other groups.

The non-motor vehicle cyclist casualties are overrepresented in the first two groups (a stay of less than 10 days), illustrating again their lower injury severity level.

Injury Patterns

The WHO-ICD system as applied in the Netherlands allows for the coding of one "main" injury and 8 other injuries.

The overall injury picture therefore has to be based on all 9 possible injuries.

However, since the first coded injury is called "main injury diagnosis" this is often used to represent the patients' injuries. Furthermore, as can be seen in table 3 from the previous paragraph, the average number of injuries is less than 2, implying that a large number of casualties have no more than one coded injury.

Though this may be contrary to the belief that traffic casualties are "multi-trauma" patients, it is in fact so for the majority of the hospitalized Dutch traffic casualties. Of course, as we know, the very small injuries, such as bruises and other little wounds, are underreported since they are far less severe than those injuries that caused hospitalization.

To learn about the difference, the two possible injury pictures are presented:

a. based on the main injury diagnosis only,
b. based on all coded injuries.

Injuries in this paper are presented as injury patterns, being the distribution of (all) injuries per patient over body regions.

Seven body regions are distinguished and one rest-group. The total number of injuries will therefore exceed the number of casualties, unless only the main injury diagnosis is used.

Table 6. Injury Pattern Based on the Main Injury Diagnosis

Body region	B-MV	P-MV	B-NMV
Head/skull/brain	1013 (48,9)	668 (38,5)	1566 (35,4)
Neck	19 (0,9)	11 (0,6)	21 (0,5)
Thorax	104 (5,0)	65 (3,7)	108 (2,4)
Back/pelvis	158 (7,6)	113 (6,5)	245 (5,5)
Abdomen	45 (2,2)	51 (2,9)	144 (3,3)
Arms	147 (7,1)	125 (7,2)	721 (16,3)
Legs	538 (26,0)	652 (37,5)	1455 (32,9)
Other/unknown	48 (2,3)	52 (3,0)	162 (3,7)
Total no. of injuries	**2072 (100%)**	**1737 (100%)**	**4422 (100%)**

Injuries to the head (including skull and brain) form the largest category for all casualty groups. However there some distinct differences:

Cyclists colliding with motor-vehicles show the highest number, cyclists not colliding with motor-vehicles the lowest.

This might partly explain the differences already mentioned with respect to injury severity aspects between the two groups, since brain and skull injuries are important indications of severe and fatal outcome of accidents.

Leg injury is the second highest category for all groups.

Pedestrians show more of them than the other groups. Both for pedestrians and the rest-group of cyclists, leg injuries rank almost as high as head injuries.

Another interesting difference between the groups is the relatively high proportion of arm injuries for the last category of casualties.

Possibly, the emphasis in this group on falls from the bicycle is the reason behind this difference.

Table 7. Injury Pattern Based on All Injury Diagnoses

Body region	B-MV	P-MV	B-NMV
Head/brain/skull	1681 (40,9)	1153 (34,2)	2229 (37,5)
Neck	44 (1,1)	23 (0,7)	31 (0,5)
Thorax	351 (8,5)	221 (6,6)	191 (3,2)
Back/pelvis	277 (6,7)	219 (6,5)	314 (5,3)
Abdomen	113 (2,8)	134 (4,0)	177 (3,0)
Arms	533 (13,0)	418 (12,4)	1058 (17,8)
Legs	984 (24,0)	1048 (32,1)	1681 (28,3)
Other/unknown	125 (3,0)	120 (3,6)	263 (4,4)
Total no. of injuries	**4108 (100%)**	**3372 (100%)**	**5944 (100%)**

Compared to the previous injury pattern (Table 6.) emphasis for all casualty groups is still on head injury. However while for the motor vehicle casualties (both cyclists and pedestrians), the relative proportion of head injury is lower than before, for the rest-group of cyclists the relative proportion is somewhat higher. In the first two casualty groups we see considerably higher proportions of arm injuries, while the proportion of leg injuries is smaller.

Age Differences

As we know, age has an important influence on the outcome of accidents.

Therefore the previous injury patterns (based on the main injury diagnosis only) will be presented for different age groups.

Table 8. Relation Between Age-Group and Injury Pattern for the B-MV Casualties

Body region	Age group (years)		
	0-14	15-54	55 +
Head/brain/skull	57,8	51,2	41,0
Neck	0,5	1,1	1,0
Thorax	1,0	5,0	7,3
Back/pelvis	3,2	7,4	10,3
Abdomen	3,4	2,7	0,8
Arms	6,1	7,3	7,3
Legs	26,2	22,8	29,8
Other/unknown	1,7	2,5	2,4
Total no of injuries:	408 (100%)	928 (100%)	736 (100%)

We see some relevant age differences for the head injuries, thorax injuries, abdominal injuries, back/pelvis injuries, and leg injuries.

While head injuries and abdominal injuries show a sharp decline with rising age, the other body regions show sharp rises. Only leg injuries appear to be lowest for the "middle age" group.

Table 9. Relation Between Age group and Injury Pattern for the P-MV Casualty Group

Body region	Age group (years)		
	0-14	15-54	55 +
Head/brain/skull	48,6	33,9	31,6
Neck	0,3	0,9	0,7
Thorax	1,9	4,2	5,3
Back/pelvis	3,2	7,6	9,1
Abdomen	4,3	3,5	0,9
Arms	4,2	8,7	9,1
Legs	35,9	38,0	38,8
Other/unknown	1,6	3,1	4,4
Total no. of injuries	**626(100%)**	**542(100%)**	**569(100%)**

More or less the same picture appears as for the cyclists casualties. An important shift appears in the two oldest groups: their relative proportions of leg injuries have become the highest separate groups, even exceeding head injuries.

Table 10. Relation Between Age Group and Injury Pattern for the B-NMV Casualty Group

Body region	Age group (years)		
	0-14	15-54	55 +
Head/brain/skull	46,3	45,4	18,6
Neck	0,1	0,9	0,2
Thorax	0,8	2,7	3,1
Back/pelvis	3,6	3,6	8,7
Abdomen	7,6	2,9	1,3
Arms	17,4	19,0	12,8
Legs	20,0	22,2	51,7
Other/unknown	4,4	3,3	3,6
Total no. of injuries	**927(100%)**	**1819(100%)**	**1676(100%)**

Again we see the same tendencies as for the other casualty groups. However there is a *spectacular* age influence as far as both head injuries and leg injuries are concerned. The oldest age group show a totally different picture from the rest. The amount of leg injuries for the oldest age group is a factor 2.5 higher than for the younger groups, while the amount of head injury is comparably lower. This phenomenon has been reported before (van Kampen, 1989).

This injury picture therefore is totally different from the previous ones.

Here again we find evidence that the injuries resulting from motor-vehicle collisions are different from the ones resulting from the non-motor vehicle collisions.

Clearly, within the bicycle population there are different needs for protection against collision forces.

Conclusions and Recommendations

There are several sets of conclusions to be drawn and recommendations to be made:

1. About the underreporting of accidents and casualties
2. About the injury problem in general and the need of protection
3. About specific problems such as age and the need of protection.

Ad 1. Underreporting of accidents and casualties in official accident statistics may cause those involved in policy making and establishing priorities to make incorrect decisions. This has happened already since the main focus regarding cyclists is definitely on casualties from motor vehicle accidents.

It now appears that the problem of the non-motor vehicle bicycle accidents is far more important than for any other separate group of road user, at least in numbers.

As far as severity of the problem is concerned, it appears that this group is less severely injured than those resulting from motor-vehicle collisions. However their apparent need for treatment in hospitals warrants far more public attention.

So in the first place improvement of the level of registration of this type of accidents is needed. In the second place more priority should be given tot accident prevention and injury prevention of this group of cyclists.

The amount of detail in the data source used for this paper, national hospital data, is however not sufficient to point right to the optimal way of injury preventive measures at this time. The casualty group is a mixture of those who collided with other road users (non-motor vehicles!) and those who did not, with emphasis on falls.

Therefore it is recommended to develop a study design to gather more knowledge about the different categories within this category.

Ad 2. The general injury problem of both cyclists and pedestrians, hit by motor vehicles and of the other cyclists, is such that there are at least two but probably three definite body areas in great need of protection: the head region (including skull and brain); the legs and the arms.

Since the problem does not only appear with regard to motor-vehicle collisions, the improvement of car front end design can only be seen as part of the solution, *however necessary.*

In view of the very great number of other casualties amongst cyclists, other injury-preventive measures have to be taken.

In the Netherlands, recommendations for the use of bicycle helmets are still fairly unpopular, both for policy makers and for the population at risk. Examples in other countries however show possibilities and benefits of this type of solution.

May the Dutch follow these examples! As far as arm and leg injury protection means are concerned we have still a long way to go.

Ad 3. In view of the specific age problem reported in this paper, it can be concluded that at least older people should not ride a bicycle without protected legs and arms, and of course protected head.

However, here again, the question of acceptability and available means of protection arises.

May reason win and may there become funds available for relevant measures and studies on the topic of proper solutions.

References

Harris, 1990. The Real Number of Road Traffic Accident Casualties in the Netherlands: A Year-Long Survey. In: Acc. Anal. & Prev. Vol. 22, No. 4, pp. 371-378, 1990.

van Kampen, 1989. Traffic Accidents of Elderly People in the Netherlands; they really are more vulnerable than other road users. In: Proceedings of the Twelfth ESV-Conference. Gothenburg, 1989.

S1-O-08

The Cause of Head Injuries in Real World Crashes

Pete Thomas
Mo Bradford
Edmund Ward
Research Institute for Consumer Ergonomics
Loughborough University of Technology

Abstract

European cars are built to conform to performance requirements that are intended to limit the hostility of various interior car components. However head injuries are frequently sustained by car occupants despite these regulations. This paper examines the circumstances that result in these head injuries to both the survivors and the fatalities. Restrained front seat occupants are analysed separately from unrestrained rear seat occupants. All directions of impact are included.

AIS 3+ head injuries are frequent amongst fatalities although other body areas often have injuries that are equally severe. Survivors sustain AIS 3+ injuries more often to other body areas than the head although they are less likely to have several AIS 3+ injuries.

Glazing materials are highlighted as a very common source of AIS 1 injuries while the roof, steering wheel

and pillars account for many of the more severe injuries. Intruding structures are found to be commonly associated with the most severe injuries as are contacts outside the vehicle. Head injuries are found to become more severe when the striking object supports the intruding structure. The value of restraint use by rear seat occupants is raised. The need for a better understanding of the role of intrusion and support from the striking object is stressed.

Introduction

Much research is being performed in an effort to understand the factors surrounding the head injuries that occur in car crashes. The most frequent approach is to examine the biomechanics of the injury to establish how the brain and cranium react to applied forces and how resulting movement causes injury. Mucciardi[1], Nusholt[2] and Stalnaker[3] are examples. Many authors such as Ward[4] and Tong[5] have proposed models of such injury causation. More recently Boock[6], Thibault[7] and Meaney[8] have made considerable advances concerning the cellular response of the brain to mechanical shock.

There have been fewer studies that have examined the real-world crash conditions that result in head injuries. Viano[9] stated that real-world crash data is necessary to provide the impact situations resulting in head injury. Walficsh[10] when investigating the realism of a whole vehicle perpendicular barrier test identified the steering wheel as a major source of head injury amongst restrained drivers in frontal collisions. Bradford[11] found a similar result with UK data but also recognised contact with objects outside the car such as trees, other cars and trucks as causing more frequent severe brain injury. Thomas[12] investigated injuries resulting from contact with the steering system and identified the steering wheel as a frequent cause of the face, head and torso injuries sustained by restrained drivers in frontal impacts. He noted that steering wheel intrusion was often associated with these injuries.

Several authors have examined the role of intruding structures as a factor in the causation of head injuries. Using CPIR and NCSS data sets collected between 1972 1979 Huelke[13, 14, 15, 16] examined the link between roof crush during a rollover and injury outcome. He concluded that there was no causal link between the amount of downward roof crush and AIS. He stated that any correlation was a result of relationships between vehicle impact severity and intrusion and vehicle impact severity and injury. This point has been amplified by Strother[17] who, in a thorough analysis, systematically examined the velocity - time curves of the events in side and roof impacts to show that injuries were sustained well before the intrusion was completed. Most recently in an investigation of the effect of roof strength on injury mechanics in roll-overs Bahling[18] observed that the absence of roof deformation may benefit occupants if it results in belted occupants not striking the roof.

Enoyre[19] used a free flight headform impactor to measure the deceleration on various interior parts of the car, he found typical values ranging between 66g to 99g for A-Pillar impacts and from 98g to 141g for side header impacts. Monk[20] used NASS and NCSS data to establish basic test conditions for a subsystem test to examine the hazard from the A-Pillar, front and side header rails. The tests were based on the real-world crash severity as measured by delta-V although no account was taken of any contact area deformation that occurred prior to the head impact.

Analysis sample

This analysis is based on a set of real-world accident data describing a section of the accident UK population whose accidents have been examined within the UK Cooperative Crash Injury Study. In-depth investigations of crashes in the Midlands, the North-East and South-West areas of the UK have continued since 1983. Accidents were selected for investigation according to a strict sampling protocol which emphasised the number of the more severe and fatal crashes. All accidents involved cars aged less than 6 years old at the time of the accident which were towed away from the accident site. The sampling system allowed the links to be drawn between the sample of accidents upon which this analysis is based and the population of accidents in the study catchment areas by the use of weighting factors.

Crashed vehicles were examined at recovery garages in considerable detail including the points of occupant contact and the quantity of crush and intrusion sustained. This data was supplemented by details of the injuries of both fatalities and survivors and is subsequently coded using AIS-85. The data collection system have been described in more detail elsewhere.[21,22]

Data presented in this paper are based on the unweighted accident sample, the equivalent weighted values, when given, are highlighted as population estimates. The sample describes the injuries of 6059 casualties who were occupants of 3444 cars. The data was collected between 1983 and 1990. All 6059 occupants were travelling in cars within which someone was injured. The seating position and restraint use of all 6059 casualties in the sample is shown in Table 1.

Table 1. Seating Position and Restraint Use of All Occupants

Seating Position	Restrained	Unrestrained	Restraint not known	Total
Front	3453	426	1032	4911
Rear	69	995	59	1123
Not known	0	20	5	25
Total	3522	1441	1096	6059

The table shows that 3453 (89%) of the 3879 front seat occupants for whom belt use was known were restrained, 995 (94%) of the rear seat occupants were unrestrained. To aid interpretation of this analysis only these two groups were selected for further examination.

Table 2 shows the direction of the impact that each occupant was involved in. The impact referred to is the one in which the casualty sustained the most severe injuries. 2195 (64%) of the restrained front seat occupants were involved in frontal collisions with a further 759 (22%) in side impacts.

Table 2. Impact Direction of Each Group of Casualties

Impact Direction	Restrained Front Seat Occupants		Unrestrained Rear Seat Occupants	
Front	2195	(64%)	534	(54%)
Struck-side	469	(14%)	113	(11%)
Non-struck-side	290	(8%)	85	(9%)
Rear	108	(3%)	41	(4%)
Rollover	381	(11%)	183	(18%)
Total	3453	(100%)	995	(100%)

2265 (65%) of the restrained front seat occupants were travelling in vehicles which were involved in only one impact, 977 (28%) suffered 2 impacts to the vehicle although in many cases the second impact was not severe. 585 (59%) of the unrestrained occupants were in cars which only suffered one impact and a further 345 (35%) suffered two impacts.

Occupant data in this spread of impact types was analysed to give an overview of the pattern of injury in the complete range of contact areas. A concentration on particular impact types such as frontal or side impacts can underestimate the frequency of some contact areas. For example an impact which results in a driver sustaining a head contact with an A-Pillar might be classified as a frontal impact under some conditions and a side impact under other conditions.

Data Analysis

Pattern of injuries

In this analysis the head is defined as the brain, cranium and soft surface tissues of the head excluding the forehead, it does not include the facial structures. The term AIS 3+ injuries refers to injuries of a severity equal to or greater than AIS 3. Table 3 shows the severity of all injuries sustained by all the 3453 restrained front seat occupants in the sample. In Table 3 the AIS level represents the most severe injury in each body area.

Within the group of restrained front seat occupants the legs most commonly sustained injuries of any severity. 1592 (46%) occupants sustained such an injury. The head ranked fifth in frequency behind the legs, chest, arms and face. 919 (27%) of the 3453 occupants in the sample sustained a head injury. However 307 (33%) of these 919 occupants with head injuries were AIS 1 representing cuts, abrasions and bruises or minor brain injury. Leg injuries, including injuries to the pelvis, were even more frequently minor. 1028 (65%) of the 1592 leg injuries were AIS 1. However this figure is influenced by the coding protocol which allocated abdominal bruising, typically from a seatbelt, as lying in the pelvis and therefore the leg area.

An injury with an AIS score of 3 or above represents the onset of a significant threat to life, it represents for example a comminuted tibia fracture or a cerebral contusion for example. Table 4 shows the rank in order of frequency of injury to each of the body regions. The most commonly injured body region ranks first and the least commonly injured ranks last. The second column shows the rank order for injuries of all levels of severity, the third for injuries of AIS 3+ of casualties who survived and the fourth shows the AIS 3+ injuries of those who died.

Table 4. Pattern of Injuries—3453 Restrained Front Seat Occupants

Rank Order	No with AIS1+ injury		AIS3+ Injuries of Survivors		AIS3+ Injuries of Fatalities	
Most Common	Legs	(46%)	Legs	(43%)	Chest	(82%)
2	Chest	(43%)	Chest	(27%)	Head	(67%)
3	Arms	(42%)	Head	(25%)	Abdomen	(37%)
4	Face	(35%)	Arms	(18%)	Legs	(33%)
5	Head	(27%)	Abdomen	(5%)	Spine	(15%)
6	Abdomen	(24%)	Spine	(5%)	Arms	(12%)
7	Spine	(21%)	Face	(4%)	Face	(11%)
Total Occupants	3453		332		190	

Table 3. Frequency of Injury to Each Body Area—3453 Restrained Front Seat Occupants

AIS	Head (%)		Face (%)		Spine (%)		Chest (%)		Abdomen (%)		Arms(%)		Legs (%)	
0	2534	73	2266	66	2729	79	1961	57	2630	76	2009	58	1861	54
1	307	9	976	28	604	17	999	29	669	19	1028	30	1165	34
2	404	12	178	5	77	2	250	7	65	2	335	10	222	6
3	84	2	27	1	25	1	88	3	25	1	81	2	202	6
4	49	1	6	0.2	1	0	79	2	27	1	-		2	0.1
5	49	1	-		5	0.1	45	1	37	1	-		-	
6	26	1	-		12	0.3	31	1	-		-		-	
N/k	-		-		-		-		-		-		1	
Total	3453	(100%)	3453	(100%)	3453	(100%)	3453	(100%)	3453	(100%)	3453	(100%)	3453	(100%)

Table 4 shows that the patterns of injury vary substantially depending on the severity of the injuries involved. When minor, AIS 1 injuries are included 46% of all restrained front seat occupants sustain a leg injury, and the legs are the most frequently injured body region. The chest and arms have similar frequencies of injury and the head ranks fifth. 27% of all restrained front seat occupants sustain head injuries.

When the less severe injuries are excluded and only AIS 3+ injuries examined the pattern of injuries changes. The survivors still have the legs as their most frequently injured body region, 43% sustaining an AIS 3+ injury. The head ranks third behind the chest with 25% of all restrained front seat occupants sustaining an AIS 3+ head injury. The Abbreviated Injury Scale is not the most appropriate measure for rating the importance of the injuries of survivors. AIS is primarily a measure of threat to life but for those who do not die other issues such as long term disability and the amount of hospital in-patient treatment may be more significant. For this reason it should not be concluded that the head injuries of survivors are insignificant, it is possible for AIS 3+ injuries to result in loss of mental ability and behaviour changes. In the absence of appropriate measurement scales it is not possible to make a clear comparison with other body regions.

The pattern of injuries amongst the restrained front seat occupants who die is quite different. 82% of all fatalities sustain an AIS 3+ injury to their chest and 62% to their head. These are the most common two injured body regions. Leg injuries rank fourth after abdominal injuries.

Table 5 summarises the pattern of injuries for the group of 995 unrestrained rear seat occupants. Despite the different seating environment and occupant kinematics the distribution of injuries is similar in many ways to that of restrained front seat occupants.

Table 5. Pattern of Injuries—995 Unrestrained Rear Seat Occupants

Rank Order	No with AIS1+ injury	AIS3+ Injuries of Survivors	AIS3+ Injuries of Fatalities
Most Common	Legs 44%	Legs 37%	Head 78%
2	Face 40%	Head 25%	Chest 78%
3	Arms 35%	Chest 14%	Abdomen 35%
4	Head 32%	Arms 11%	Legs 28%
5	Chest 16%	Spine 5%	Spine 25%
6	Abdomen 13%	Face 4%	Face 13%
7	Spine 12%	Abdomen 4%	Arms 3%
Total Occupants	995	81	40

When AIS 1 injuries are included 32% of all unrestrained occupants sustain head injuries and the head ranks fourth after the legs, face and arms. The head still ranks after the legs as the second most common site of the AIS 3+ injuries of survivors. However 78% of those within this group who die sustain AIS 3+ injuries to their head and the head ranks equal first with the chest as the most common site of AIS 3+ injuries.

The distribution of these head injuries amongst the groups of restrained front and unrestrained rear seat occupants selected for further analysis is summarised in Table 6.

Table 6. Head Injuries of Restrained Front and Unrestrained Rear Seat Occupants

Head Injury Severity	Restrained Front Occupants	Unrestrained Rear Occupants
AIS 0 (Uninjured)	2534	681
AIS 1	307	141
AIS 2	404	120
AIS 3+ Survivors	81	22
AIS 3+ Fatalities	127	31
Total	3453	995

The fatally injured casualties in both groups tended to sustain injuries that were more severe than the survivors. Amongst the restrained front seat occupants there were 11 (14%) of the 81 survivors who sustained AIS 5+ injuries compared to 64 (50%) of the 127 fatalities for example.

If a casualty has only one injury then the introduction of a measure to reduce injuries can make a large difference. Conversely if a casualty has many injuries then a countermeasure that reduces just one may make little difference to that casualty. The range of frequencies of injury to each body area shown in Tables 4 and 5 gives a measure of multiplicity of injury. When the tables show many body areas to be frequently injured it is likely that occupants may have several injuries. For example if 78% of unrestrained fatalities sustain an AIS 3+ head injury and 78% sustain AIS chest injury then if the injuries are distributed randomly 78% x 78% = 61% will have both head and chest AIS 3+ injuries. This is demonstrated more clearly in Table 7 which shows the number of body regions sustaining AIS 3+ injuries for the groups of restrained front and unrestrained rear seat occupants who survived and who died.

Table 7. Multiplicity of AIS 3+ Injuries

Number of Body Regions With AIS 3+ Injury	Restrained Front Seat Occupants		Unrestrained Rear Seat Occupants	
	MAIS 3+ Survivors	MAIS 3+ Fatalities	MAIS 3+ Survivors	MAIS 3+ Fatalities
1	265	34	63	10
2	53	63	7	12
3	12	55	0	6
4	2	26	0	9
5		10	1	2
6		2		1
Total Occupants	332	190	71	40
MAIS 3+ injured body regions	1.25	2.58	1.15	2.60

Table 7 shows that fatally injured occupants whether they are restrained front seat occupants or unrestrained rear seat occupants sustain an average of 2.6 AIS 3+ injured body regions per person. 34 (18%) of the restrained front seat fatalities and 10 (25%) of the unrestrained rear seat fatalities sustained only one AIS 3+ injured body regions.

In comparison the survivors tended to have fewer body regions with AIS 3+ injuries. The restrained front seat occupants sustained 1.25 per person and the unrestrained rear seat occupants sustained 1.15 per person. 265 (80%) of the front seat occupants and 63 (89%) of the rear seat occupants sustained only one body region with AIS 3+ injury.

If a countermeasure was introduced and it had the effect of preventing AIS 3+ injuries to one body region it is unlikely that the number of fatalities would decrease much as most will have other life-threatening injuries to other body areas. It would have a greater effect amongst the groups of survivors who have fewer injuries and are unlikely to have others of AIS 3+. In most cases a package of countermeasures will be necessary to prevent fatalities.

Causation of head injuries

The contacts that resulted in the most severe head injury for each occupant were coded and classified according to the general location. The 1233 occupants with a head injury sustained a total of 1271 contacts with identified objects and a further 316 with unknown objects. Some injuries were a result of contact with two separate objects, for example a windscreen and an A-Pillar, both of these contacts would be shown in the following tables. Where an injury is a result of 2 contacts no judgement has been made as to which is the dominant factor.

Contact Location Of Restrained Front Seat Occupants

Table 8 shows the contacts that resulted in the injuries of the restrained front seat occupants which are illustrated in Figures 1 and 2.

The single most frequent contact zone for those occupants whose most severe head injury was of AIS 1 was the side glass. This area accounted for 49 (19%) of the 262 identified contacts. The combined set of all glazing materials accounted for 86 (33%) injuries. The roof and associated structures accounted for 44 (17%) of the contacts and the steering wheel for 43 (16%) contacts.

The importance of the glazing contacts was lower amongst the AIS 2 injuries with the side window glass causing only 47 (11%) of the injuries. All glazing materials together accounted for 84 (20%) of all contacts ranking third. Most frequent were injuries arising from contact with the steering wheel (126 - 29%) followed by the pillars (67- 16%).

Table 8. Location of Head Contacts of Restrained Front Seat Occupants

Contact Location	AIS of most severe head injury			
	AIS 1	AIS 2	AIS 3+ survivors	AIS 3+ Fatalities
Interior				
Windscreen	10 (4%)	13 (3%)	5 (4%)	17 (4%)
Side Glass	49 (19%)	47 (11%)	2 (1%)	7 (2%)
Rear Glass	0 (0%)	0 (0%)	0 (0%)	3 (1%)
Unknown Glass	27 (10%)	24 (6%)	0 (0%)	2 (0%)
Steering Wheel	43 (16%)	126 (29%)	23 (17%)	55 (12%)
Facia	5 (2%)	21 (5%)	9 (7%)	13 (3%)
Roof	44 (17%)	60 (14%)	8 (6%)	91 (21%)
Pillars	22 (8%)	67 (16%)	24 (18%)	71 (16%)
Doors	12 (5%)	16 (4%)	13 (10%)	25 (6%)
Seats	18 (7%)	20 (5%)	2 (1%)	9 (2%)
Exterior				
Other Vehicle	2 (1%)	9 (2%)	23 (17%)	73 (16%)
Own Vehicle Exterior	5 (2%)	5 (1%)	2 (1%)	21 (5%)
Tree,Pole,Lamp,ground	3 (1%)	2 (0.5%)	9 (7%)	40 (9%)
Other Exterior	2 (1%)	2 (0.5%)	8 (6%)	2 (0%)
Crushing	(0%)	0 (0%)	0 (0%)	0 (0%)
Other	20 (8%)	12 (3%)	7 (5%)	14 (3%)
Not Known	100 -	159 -	26 -	31 -
Total Known Contacts	262 (100%)	431 (100%)	135 (100%)	443 (100%)
Total Contacts	362	590	161	474
Total Occupants	307	404	81	127

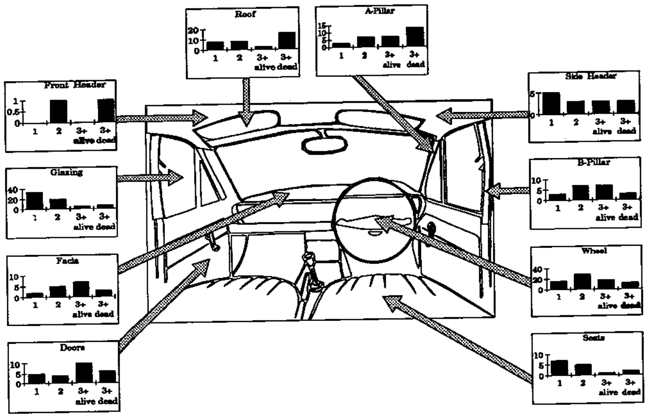


Figure 1. Interior Head Contacts of Restrained Front Seat Occupants

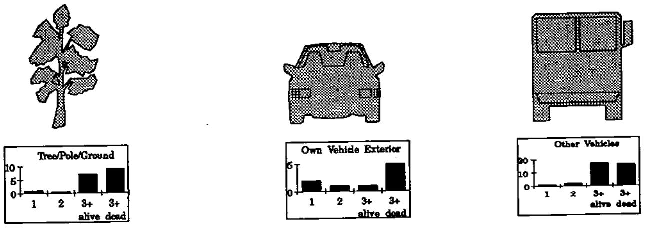


Figure 2. Exterior Head Contacts of Restrained Front Seat Occupants

The most common single zone causing AIS 3+ injuries to surviving restrained front seat occupants was the pillars accounting for 24 (18%) injuries. The steering wheel was contacted by 23 (17%) casualties as was the striking vehicle. Together objects outside the car were associated with 42 (31%) of these injuries.

The most severe injuries were those to the fatalities coded with AIS values between 3 and 6. The most common single contact was with the roof of the car, 91 (21%) of the 443 known contacts were in this area. Head contact on a striking vehicle in the impact was associated with 73 (16%) of the injuries followed by the pillars with 71 (16%) of the contacts. When all objects outside the car were grouped together they were associated with 136 (31%) of the head injuries of this group of fatal occupants. The steering wheel was associated with 55 (12%) of these injuries.

The involvement of objects outside the car was found to increase in frequency as the severity of the resulting injuries increased. At the level of AIS 1 these objects accounted for only 12 (5%) contacts rising to a total of 42 (31%) amongst the survivors with AIS 3+ injuries and 136 (31%) amongst the fatalities.

Contact Location Of Unrestrained Rear Seat Occupants

The contact locations of the head injuries of the unrestrained rear seat occupants are shown in Table 9 and illustrated in Figures 3 and 4.

Table 9. Location of Head Contacts of Unrestrained Rear Seat Occupants

Contact Location	AIS of most severe head injury			
	AIS 1	AIS 2	AIS 3+ survivors	AIS 3+ Fatalities
Interior				
Windscreen	6 (5%)	7 (5%)	0 (0%)	0 (0%)
Side Glass	9 (8%)	23 (17%)	5 (13%)	0 (0%)
Rear Glass	3 (3%)	0 (0%)	0 (0%)	0 (0%)
Unknown Glass	9 (8%)	2 (1%)	0 (0%)	0 (0%)
Steering Wheel	0 (0%)	0 (0%)	0 (0%)	0 (0%)
Facia	0 (0%)	2 (1%)	2 (5%)	5 (6%)
Roof	25 (23%)	32 (24%)	11 (28%)	8 (10%)
Pillars	13 (12%)	12 (9%)	8 (21%)	20 (26%)
Doors	5 (5%)	11 (8%)	1 (3%)	5 (6%)
Seats	28 (25%)	23 (17%)	4 (10%)	0 (0%)
Exterior				
Other Vehicle	0 (0%)	0 (0%)	0 (0%)	5 (6%)
Own Vehicle Exterior	0 (0%)	0 (0%)	0 (0%)	0 (0%)
Tree,Pole,Lamp,ground	9 (8%)	20 (15%)	5 (13%)	27 (35%)
Other Exterior	0 (0%)	0 (0%)	0 (0%)	5 (6%)
Crushing	0 (0%)	0 (0%)	0 (0%)	3 (4%)
Other	3 (3%)	3 (2%)	3 (8%)	0 (0%)
Not Known	55 -	67 -	8 -	22 -
Total Known Contacts	110 (100%)	135 (100%)	39 (100%)	78 (100%)
Total Contacts	165	202	47	100
Total Occupants	141	120	22	31

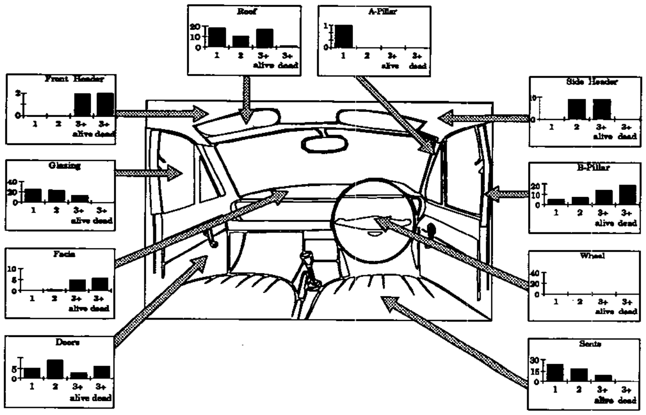


Figure 3. Interior Head Contacts of Unrestrained Rear Seat Occupants

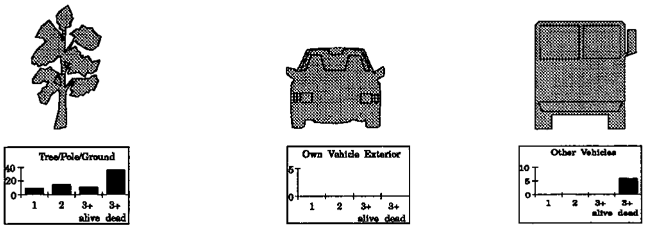


Figure 4. Exterior Head Contacts of Unrestrained Rear Seat Occupants

These occupants showed some differences in the sources of their head injuries. The most frequent sources of AIS 1 head injuries were the front seats and the roof structures accounting for 28 (25%) and 25 (23%) of contacts respectively. Glazing materials were associated with a total of 23 (24%) of injuries.

The most common source of the AIS 2 head injuries was the roof being associated with 32 (24%) of the injuries. The front seats and the side glass each accounted for 23 (17%) of the injuries. Altogether glazing materials caused 32 (23%) of the AIS 2 injuries. Head contact on off-road objects such as trees, lamp posts and the ground accounted for 20 (15%) of these injuries.

The 22 surviving unrestrained rear seat occupants who sustained AIS 3+ head injuries contacted 47 objects, 39 of which were identified. The roof and pillars were most commonly struck accounting for 11 (28%) and 8 (21%) of contacts.

The fatally injured rear seat occupants sustained 78 known contacts. Trees, lamp posts, other poles and the ground together accounted for 27 (35%) of the contacts. Altogether exterior objects comprised 40 (51%) of all contacts. The pillars were the most commonly contacted interior structure, accounting for 20 (26%) of all contacts.

Proposals have been made in both Europe and the US to introduce measures aimed at mitigating the head injuries resulting from contact with the header rails and pillars. The contact zone labelled "roof" in Tables 8 and 9 includes these areas and Tables 10 and 11 show the contacts broken down in more detail. The percentages given are based on the total number of contacts for each injury severity group within Tables 8 and 9.

Table 10. Roof and Pillar Head Contacts of Restrained Front Seat Occupants

	Head Injury Severity			
Contact Area	AIS 1	AIS 2	AIS 3+ Survivors	AIS 3+ Fatalities
W/S Header	1	4	0	6
Sun Visor	2	4	0	0
Side Header	14	11	4	13
Grab Handle	4	0	0	3
Roof	22	36	4	69
Sun Roof	1	5	0	0
A-Pillar	8	29	10	57
B-Pillar	9	30	10	14
C-Pillar	0	2	0	0
Swivel	5	6	4	0
Total	66 (13%)	127 (20%)	32 (24%)	162 (37%)

Table 11. Roof and Pillar Head Contacts of Unrestrained Rear Seat Occupants

	Head Injury Severity			
Contact Area	AIS 1	AIS 2	AIS 3+ Survivors	AIS 3+ Fatalities
W/S Header	0	0	1	4
Sun Visor	1	0	0	0
Side Header	0	11	3	0
Grab Handle	0	5	0	0
Rear Header	2	1	0	0
Roof	20	14	7	1
Sun Roof	2	1	0	3
A-Pillar	1	0	0	0
B-Pillar	5	8	5	13
C-Pillar	3	3	0	4
Swivel	4	1	3	3
Total	38 (35%)	44 (44%)	19 (49%)	28 (36%)

Table 8 showing the contacts of restrained front seat occupants revealed that there were 203 head contacts with the roof and its associated structures and 184 with the pillars. These 387 contacts are shown in Table 10. The roof alone was associated with 69 of the contacts of the AIS 3+ fatalities, this represents 16% of all of the 443 head contacts sustained by this group. B-Pillar contacts were also frequent in this group. 57 (13%) of the 443 head contacts were with B-Pillars. The side header rail was associated with only 13 (3%) of the contacts of the fatalities and 14 (5%) of those with AIS 1 head injuries.

There were a total of 76 roof contacts and 53 pillar contacts for unrestrained rear seat occupants shown in Table 9, these are shown in detail in Table 11. The roof was a frequent source of AIS 1 injuries accounting for 18% of all contacts but it was only rarely associated with the AIS 3+ injuries of fatalities. More common sources of the most severe head injuries were the B- and C-Pillars together accounting for 17 (22%) of all the head contacts of the fatalities with AIS 3+ injuries. Although the side header rail was not associated with any of the contacts of those who died or those with AIS 1 injuries, it was associated with 8% of the contacts of the remaining two groups.

Ejection

Table 9 showed that 51% of all of the head contacts of the fatally injured unrestrained rear seat occupants were with objects outside the car. It does not show whether this is a result of the exterior object intruding into the vehicle or whether the occupants were ejected. Table 12 shows the numbers of casualties with AIS 3+ injures who were ejected from the car.

Table 12. Ejection From the Car—All Casualties With AIS 3+ Head Injuries

Seating Position	No Ejection	Partial Ejection	Complete Ejection	Not Known
Restrained Front Seat				
Survivors	74 (96%)	2 (3%)	1 (1%)	4
Fatalities	109 (91%)	9 (8%)	2 (2%)	7
Unrestrained Rear Seat				
Survivors	19 (90%)	0 (0%)	2 (10%)	1
Fatalities	17 (59%)	4 (14%)	8 (28%)	2

Table 12 shows that ejection was rare amongst the restrained front seat occupants. 74 (96%) of the survivors and 109 (91%) of the fatalities with AIS 3+ head injuries were not ejected. However 9 (8%) of the fatalities were partially ejected. The 22 surviving unrestrained rear seat occupants with AIS 3+ head injuries showed a similar pattern 19 (90%) remaining in the vehicle. The two who were completely ejected however represented 10% of this group. The fatally injured rear seat occupants showed a markedly different pattern. Only 17 (59%) stayed within the vehicle, 4 (14%) were partially ejected and 8 (28%) completely ejected. Ejection from the vehicle is therefore an important factor for the group of unrestrained rear seat occupants who die.

Intrusion

Table 8 showed that amongst the group of restrained front seat occupants with AIS 3+ head injuries 42 (31%) of the survivors and 136 (31%) of the fatalities sustained head contacts with objects outside the car. The equivalent figures for the unrestrained rear seat occupants with AIS 3+ head injuries were 8 (21%) of the survivors and 40 (51%) of the fatalities. Table 10 shows that with the exception of the fatally injured unrestrained rear seat occupants ejection was rare in both groups. Since the casualty's head is seldom ejected from the car to hit an exterior object the alternative is that the object entered the car interior. It is therefore useful to consider the role of intrusion in injury causation.

Up to two contacts were coded for each injury, if all were with objects inside the car they are classified as interior, if all are with objects outside the car the contacts are classified as exterior. Some occupants contacted two objects, one inside and one outside the car, these are classified as mixed contacts.

It was suspected that the location of the striking object with respect to the contact point might influence the injury outcome. Some contacts were with a part of the car which exhibited residual intrusion. If the striking object was not immediately behind the contact point, the intrusion was classified as unsupported intrusion. If the striking object was immediately behind the contact area this was classified as supported intrusion. These classifications are illustrated in Figure 5.

Table 13 shows the location of the head contact area and the nature of the intrusion corresponding to the contacts causing the most severe head injuries sustained by each casualty. All casualties in the table are restrained front seat occupants who were not ejected from the car.

Table 13 shows that as head injuries become more severe the incidence of intrusion and of exterior object contact grows. 178 (96%) of the car occupants with only an AIS 1 head injury sustain their injuries from striking interior contacts alone. 50 (27%) were with intruding

Table 13. Head Contact Location, Intrusion and Influence of Exterior Objects—Non-ejected Restrained Front Seat Occupants

Contact Location	AIS of Most Severe Head Injury			
	AIS 1	AIS 2	AIS 3+ survivors	AIS 3+ Fatalities
Interior Contacts				
No Intrusion	125 (68%)	93 (37%)	10 (18%)	5 (5%)
Intrusion	50 (27%)	139 (56%)	27 (48%)	58 (57%)
Intrusion N/K	3 (2%)	6 (2%)	0 (0%)	2 (2%)
Subtotal	178 (96%)	238 (95%)	37 (66%)	65 (64%)
Exterior Contacts				
No Intrusion	0 (0%)	0 (0%)	2 (4%)	3 (3%)
Intrusion	4 (2%)	6 (2%)	15 (27%)	28 (28%)
Subtotal	4 (2%)	6 (2%)	17 (30%)	31 (31%)
Mixed Contacts				
No Intrusion	1 (1%)	0 (0%)	1 (2%)	0 (0%)
Intrusion	2 (1%)	6 (3%)	1 (2%)	5 (5%)
Intrusion N/K	0 (0%)	1 (0%)	0 (0%)	0 (0%)
Subtotal	3 (2%)	7 (3%)	2 (4%)	5 (5%)
Unknown Contacts				
Subtotal	104 -	135 -	18 -	8 -
Total	289	386	74	109

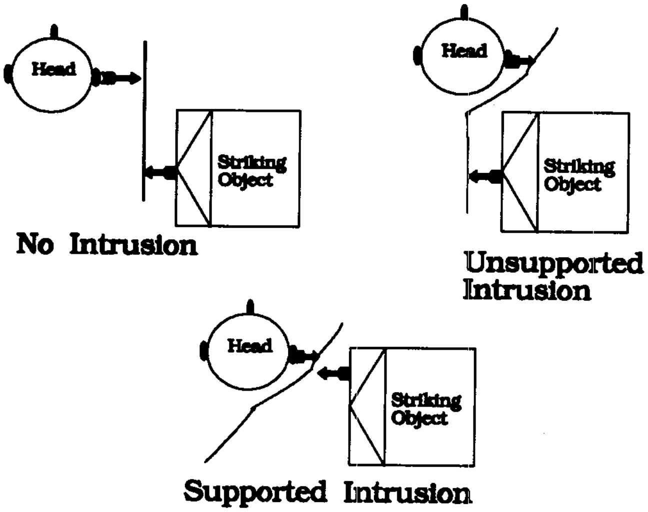


Figure 5. Unsupported and Supported Intrusion

contact areas. This was reduced to 37 (66%) survivors who sustained an AIS 3+ head injury and 65 (65%) fatalities. 31 (31%) of the fatalities sustained their head injuries from striking intruding objects alone.

Contact with exterior objects alone resulted in just 4 (2%) of the AIS 1 injuries but with 17 (30%) of the AIS 3+ injuries of survivors and 31 (31%) of the AIS 3+ injuries of the fatalities.

Intrusion, meaning the reduction in interior space of the vehicle is a measure of the response of the vehicle structure to the forces applied. As such it might be expected to be purely related to some measure of impact severity. The link between head injury severity and intrusion might therefore be a manifestation of the link between intrusion and impact severity. The correlations between the measures were examined using chi-squared tests. The head injury severity of the restrained front seat occupants was found to correlate with the presence of intrusion, the presence of supported intrusion, the amount of intrusion and the delta-V of the impact to the vehicle. All these correlations were at a level better than 0.1%. It can not be concluded therefore that intrusion is a causal factor for head injury.

Table 14 shows the support by exterior objects of the intruding interior contacts, the percentages are based on the column totals in Table 13. Support was not common amongst the group of casualties sustaining only AIS 1 injuries. 20 (11%) of the contacts were intruding and supported. 9 (16%) of the group of survivors sustaining AIS 3+ head injuries contacted supported intruding structures as did 41 (41%) of the fatalities. The variation of head injury severity with support from exterior objects is significant at a level better than 0.1% when tested using a chi-squared test.

Table 14. Nature of Support of Intruding Interior Head Contacts

Support	AIS of Most Severe Head Injury			
	AIS 1	AIS 2	AIS 3+ survivors	AIS 3+ Fatalities
Unsupported Intrusion	30 (16%)	100 (40%)	18 (32%)	17 (17%)
Supported Intrusion	20 (11%)	39 (16%)	9 (16%)	41 (41%)
Total	50 (27%)	139 (56%)	27 (48%)	58 (58%)

Safety Regulations

Head protection for car occupants is legislatively centred around the use of a standard headform impact test in which a 7 Kg headform impacts various parts of the car at a velocity of 24 k/hr. The deceleration is limited to a value of 80g for 3ms. The European requirements are contained either within ECE regulations or similar EC directives. The 80g for 3ms limit is based upon the tolerance curve for head injury developed at Wayne State University which defines combinations of deceleration and duration of head impulses that form the boundary below minor concussive injury. ECE 21 contains specifications for this test and in general requires the facia, grab handles, sun visors and the rear face of the front seats to comply. Regulation 21 employs a headform to identify potential head contacts in a zone defined by the use of a device that pivots about an arc between 736 mm and 840 mm. Objects within this zone, excluding the steering wheel and the pillars are required to comply with the headform test as do shelves and the rear of the front seats. Head restraints and front seats are covered more specifically within ECE 17 which again requires the headform impact to be performed. ECE 12 covering steering system performance contains an option for the headform impact to be performed as an alternative to the torso bodyblock impact although car manufacturers rarely choose this test.

The roof and the pillars are merely required to have a minimum radius of curvature or a limited downward projection.

The US regulations are broadly similar to the European regulations although FMVSS 201, which covers interior fittings, contains slightly larger areas exempted from its requirements.

Despite the intention of the regulations this analysis has shown that car occupants frequently sustain head injuries in crashes regardless of restraint use and that these injuries can be severe. While head injuries may not always be the most frequent when all levels of severity are considered they are very common amongst the more severely injured casualties. Because survivors who sustain AIS 3+ injuries have a relatively low multiplicity of AIS 3+ injury the prevention of head injuries might be expected to benefit this group more than other groups. Fatalities who sustain AIS 3+ injuries have on average 2.6 body areas injured at this severity. Although 67% have such an injury to their head it is likely that the prevention of head injuries will leave other life threatening injuries remaining.

The parts of the car interior that are subject to the headform test requirements of the interior fittings regulation do not appear to be frequent sources of injury. The restrained front seat occupants who only sustained AIS 1 head injuries made 11 (4%) of the contacts within these zones together with an additional 18 (7%) on some part of the seat structure. Slightly more sustained AIS 2 head injuries from these sources, 32 (7%) with another 20 (5%) from striking the seat. These contacts were less often associated with the more severe injuries.

The low number of injuries arising from a contact with parts of the car subject to ECE Regulation 21 could be a measure of its effectiveness. The energy absorption capabilities could be preventing any head contact from resulting in large numbers of injuries even at AIS 1. However it is not easy for field investigations to allocate a contact with a part of the body when there is no injury and the CCIS data does routinely record this. Equally the effect of restraint use might be to prevent a head contact with the facia or other structures subject to the headform test. Injuries would then be low even if the Regulation was completely ineffective. It is not possible to distinguish between each of these hypotheses and the effectiveness of the Regulation can not be established. The low numbers of head injuries from parts of the car subject to the headform test do not indicate a need to change the Regulation.

Other contact areas pose a greater problem causing larger numbers of head injuries.

The selection procedure for the sample of accidents investigated was such that accidents with more severely injured casualties were preferentially selected for study. Casualties with head injuries were not preferentially studied over casualties with other types of injury. The total numbers in each severity group of head injuries can not be compared although the percentages can. The 307 restrained front seat occupants in the sample shown in Table 8 represent 1549 in the population whereas the 127 fatalities represent only 202.

By definition minor head injuries do not pose a serious threat to life but they are very common in the accident population. The most frequent source of the AIS 1 injuries of the restrained front seat occupants was the side-glass. 19% of the casualties with AIS 1 head injuries alone sustained them from the side-glass. All of the vehicles in the sample were fitted with toughened side-glass. Injuries from all glazed areas together represented 33% of all AIS 1 head injuries of the restrained front seat occupants and 22% of those of the rear occupants. The very large number of casualties sustaining injuries from glass indicates a need for improved glazing systems aimed at reducing minor injuries.

The steering system was a frequent source of injuries to restrained front seat occupants. It accounted for 16% of their AIS 1 head injuries, 29% of their AIS 2 injuries and 17% and 12% of the AIS 3+ injuries of the survivors and fatalities respectively. Although it is possible that some steering wheels did comply with the headform test defined in ECE Regulation 12 there is no central source that records this. It has been observed that some designs of steering wheel have large, well padded hub areas, padded rims and recessed mounting nuts while others have exposed metal spokes and protruding hub nuts. Although this study does not attempt to examine the effects of the various designs it is reasonable to hypothesize that the injuries will vary. The high frequency of head injuries of all levels of severity indicates an urgent need to improve steering wheel design.

Tables 8 and 9 indicated that the roof zone and the pillars frequently accounted for injuries of all levels of severity. 21% of the AIS 3+ injuries of the restrained front seat fatalities involved roof contact and 16% involved a pillar contact as did 26% of the head contacts of the unrestrained rear seat fatalities. The manner in which ECE Regulation 21 defines the construction of the pillars and the roof is clearly inadequate to prevent many severe injuries. Tables 10 and 11 show that injuries resulting from contact with the side header rails are rare being between 3% and 5% of all head injuries of restrained front seat occupants. The consequence of adopting proposals to reduce such injuries do not appear likely to be able to affect a major portion of those with head injuries.

It is not evident however that the extension of the headform test to cover the roof and pillars will completely address all head injuries from these sources. Table 13 has shown that intrusion is a frequent characteristic of the interior contacts that result in the most severe injuries. However other studies have shown that intrusion is also a reflection of the severity of the impact to the vehicle and that the velocity of the head contact is also an important factor. Inspection of the accident case records suggests that most interior contact areas can exhibit intrusion. This suggests that there may be two types of crash condition between which the effect of intrusion may vary. One condition concerning struck side occupants, roll-overs and underruns for example, frequently show head contacts that occur at an early stage of the crush. The normal position of the head is close to the structure it eventually strikes and such a contact is often inevitable. It is this condition that Huelke and Strother have examined to show that the residual intrusion is a manifestation of the crash severity and is not a cause of head injury in itself.

Another condition, concerning frontal impacts and non-struckside occupants for example, finds head contact areas that are not close to the normal head position. These areas might include the steering wheel or the far side door. In this condition a head contact might not be inevitable. When intrusion occurs it can move these parts of the car interior closer to the occupant and raise the likelihood of such a contact occurring. If the impact severity and intrusion are sufficiently severe the object will inevitably be moving at the moment of contact. The degree of intrusion in this condition is still a manifestation of crash severity as Strother and Huelke describe but the influence on injury is more complex.

This analysis has found that the severity of head injury increases with the presence and amount of intrusion as well as with delta-V, this is in line with Strother and Huelke. The proportion of casualties sustaining intruding contacts was approximately constant at injury levels above AIS 1. It also shows that as head injuries become more severe the contacts that cause them become more commonly directly supported by the striking object. 11% of those sustaining AIS 1 head injuries alone contacted an interior structure that was supported as did 16% of the AIS 2 and AIS 3+ surviving restrained front seat occupants that were not ejected. However 41% of the AIS 3+ fatalities sustained such a contact and this variation was highly significant. It is useful to consider the possible effects of a contact with a supported structure. When a contact is supported its stiffness can change dramatically, the sheet of metal forming the roof can be very different when it is supported by a tree or a truck bumper. It seems likely that this could influence the severity of head injury and is the cause of the increased incidence of supported contacts amongst the fatalities. The head injuries of the fatalities tended to be more severe than those of the survivors with AIS 3+ injuries. Although this is likely to be influenced by the severity of the impact to the vehicle the presence of a supporting striking object is also likely to be a factor. This effect of supported contact areas is of also likely to apply to other injured body areas of the fatalities.

The interaction of the head with intruding and supported structures has to be examined in more detail either experimentally or using computer simulations. Real-world crash investigations cannot determine the location or the velocity of an intruding structure at the moment a head contact occurs. An understanding of the link has to be achieved before the optimum counter-measures or legislation can be introduced.

Head contacts with objects outside the car were often associated with the most severe injuries. The restrained front seat occupants who survived with AIS 3+ head injuries made contact with an exterior object in 31% of cases, a similar portion of the fatalities made contact with an object outside the car. Amongst the unrestrained rear seat occupants the proportion was even higher with 51% of the head contacts of the fatal group being outside the car. Table 12 shows that ejection was not common in any of these groups except for the fatally injured unrestrained rear seat occupants. It is expected that restraint use will prevent some of the head injuries of this last group by preventing ejection and changes in injury patterns following the recent introduction of mandatory rear seat-belt use in the UK will be monitored with interest. Table 12 shows that most of the injuries from exterior contacts are not a result of either partial or complete ejection so many of these objects must be intruding into the car. The head contact conditions are therefore similar to those with a supported intruding structure. The only techniques available for mitigating these injuries involve avoiding contact when the intruding structure is remote or by controlling the occupant head kinematics perhaps by improved restraint performance. Neither approach is easy but unless the problem is tackled the numbers of severe head injuries will not diminish. Again a more complete understanding of the relation between head injury and intrusion is required before these injuries can be fully addressed.

Summary

- 67% of restrained front seat fatalities sustain AIS 3+ head injuries as do 78% of unrestrained rear seat fatalities.
- Survivors sustain injuries to other body areas more frequently than fatalities.
- Fatalities whether restrained or unrestrained sustain AIS 3+ injuries to 2.6 body areas on average while MAIS 3+ survivors sustain between 1.15 and 1.25.
- Glazing materials were very common sources of minor head injuries while the roof, pillars, steering wheel and front seats were frequent sources of AIS 3+ injuries.
- Contacts with objects outside the car were very frequently associated with the fatally injured casualties with AIS 3+ head injuries.
- The contacts causing the most severe injuries were commonly intruding into the car and often supported by exterior objects.
- 42% of the unrestrained fatally injured rear seat occupants were either partially or completely ejected from the car. 91% of the restrained front seat occupants who died were not ejected at all.

- The majority of head injuries were caused by contact with parts of the car not covered by current regulations. These regulations do not take into account the effects of intrusion or support from the striking objects.
- The paper calls for improvements in the crash performance of glass, steering wheels, pillars and roof structures.
- There is a need to improve the understanding of the interaction between the head and intruding supported structures and with objects outside the car.

References

[1]Mucciardi, A. Prediction of brain injury measures from head motion parameters. 21st Stapp car crash conference 1977.

[2]Nusholt, GS. Head impact response-skull deformation and angular acceleration. 28th Stapp car crash conference 1984.

[3]Stalnaker, RL; Low, TC. Translational energy criteria and its correlation with injury in the sub-human primate. IRCOBI 1987.

[4]Ward, C. Finite element models of the head and their use in brain injury research. 26th Stapp car crash conference 1982.

[5]Tong, P; Eppinger, R. Finite element modelling of head injury caused by inertial loading. 12th Experimental Safety Vehicle Conference 1989.

[6]Boock, RJ; Thibault, LE. An Experimental and analytical approach to the development of a range of neurovascular trauma indices. IRCOBI 1990.

[7]Thibault, LE; Genarelli,TA; Margulies,SS;Marcus,J; Eppinger,R. The strain dependant pathophysiological consequences of inertial loading on central nervous tissue. IRCOBI 1990.

[8]Meaney, DF; Thibault, LE. Physical model studies of cortical brain deformation in response to high strain rate inertial loading. IRCOBI 1990.

[9]Viano, DC. Perspectives on head injury research. IRCOBI 1985.

[10]Walfisch, G; Pouget, D; Thomas, C; Tarriere, C. Head risks in frontal impacts: Similarities and differences between tests and real-life situations. 12th Experimental Safety Vehicle Conference 1989.

[11]Bradford, MA; Otubushin, A; Thomas, P; Robertson, NKB; Green, PD. Head and face injuries to car occupants in accidents—field data 1983—85. IRCOBI 1986.

[12]Thomas, P. Head and torso injuries to restrained drivers from the steering system. IRCOBI 1987.

[13]Huelke, DF; Marsh, JC; Sherman, HW. Analysis of Rollover Accident Factors and Injury Causation. 16th Conference of the American Association for Automotive Medicine 1972.

[14]Huelke, DF; Marsh, JC; Dimento, L; Sherman, HW; Ballard, WJ. Injury Causation in Rollover Accidents. 17th Conference of the American Association for Automotive Medicine 1973.

[15]Huelke, DF; Lawson, TE; Marsh, JC. Injuries, Restraints and Vehicle Factors in Rollover Car Crashes. Accident Analysis and Prevention Vol 9 pp 93-107 1977.

[16]Huelke, DF; Compton, CP. Injury Frequency and Severity in Rollover Car Crashes as Related to Occupant Ejection, Contacts and Roof Damage. Accident Analysis and Prevention Vol 15 pp 395-401 1983.

[17]Strother, CE; Smith, GC; James,MB; Warner, CY. Injury and Intrusion in Side Impacts and Roll-overs. SAE 840403 1984.

[18]Bahling, GS; Bundorf, RT; Kaspzyk, GS; Moffatt, EA; Orlowski, KF; Stocke, JE. Rollover and Drop Tests - The Influence of Roof Strength on Injury Mechanics Using Belted Dummies. 34th Stapp Car Crash Conference, 1990.

[19]Penoyre, S. An impact test programme using 6 models of lower-medium sized car. 10th Experimental Safety Vehicle Conference 1985.

[20]Monk, MW; Gabler, HC; Sullivan, LK. Subsystem testing for head to upper interior safety. 11 Experimental Vehicle Conference 1987.

[21]Otubushin, A; Galer, MD. Crashed Vehicle Examination Techniques. SAE Congress, 1986.

[22]Mackay, GM; Galer, MD; Ashton, SJ; Thomas, P. The Methodology of in-depth studies of car crashes in Britain. SAE paper 850556 1985.

Acknowledgements

The authors would like to thank all the members of the Accident Research Units at Loughborough and Birmingham Universities and the Department of Transport Traffic Area Teams who collected the data on which this paper is based. The financial support of the UK Department of Transport, the Transport and Road Research Laboratory, the Vehicle Inspectorate Executive Agency, Ford Motor Company Ltd, Rover Group and Nissan Motor Company has been essential.

The help from all the hospitals, HM Coroners and Police Forces in the UK that have helped the study by providing data has also been invaluable. Keith Clemo at the Motor Industry Research Association and John Cow at the Department of Transport gave the authors essential assistance with interpretations of the regulations.

S1-O-09

Car Model Safety Rating—Further Development Using the Paired Comparison Method

v Koch M, Kullgren A, Lie A, Tingvall C
Folksam Research and Chalmers
University of Technology

Abstract

During the last years, the interest in rating the interior safety of different cars and constructions have increased. Several methods have been used, based on either laboratory crash tests or on real life accident data. Several limitations are related to both methods, and there is no universally accepted method to rate cars in relation to each other.

One technique that has been proved to be powerful in car safety rating is the paired comparison method proposed by Evans. In this method, the most important exposure parameter, accident severity, can be controlled. The method has, however, some fundamental drawback and that is the fact that only a part of the accident population can be used. Single accidents, and accidents with trucks, buses etc must be omitted.

In this presentation a technique to expand the accident data is showed. It is also shown how aggressiveness can affect the results in safety rating, together with some other results of using paired comparisons.

Background

One of the most difficult problems in the field of rating cars and car design by using real life accidents, is to handle the exposure problem. This problem is though both a problem of how many vehicles or occupants that are involved in accidents. but also the severity of these accidents.

The severity of accidents is known to be a strongly predicting parameter for injuries. In large scale data bases it is, however, most complicated to have measurements that can be used for accident severity estimates by accident reconstruction. An indirect method where the accident severity can be taken care of within the accident material can therefore be helpful. Such a method has been developed for car accidents by Evans (3) and further developed by Tingvall and others. In this method, called paired comparison (single and double paired) the whole exposure complex can be handled.

In this study, the method has been developed further, and some specific questions are studied by using the method. Such questions are the influence of vehicle mass vs vehicle design. As it is believed that there is a relationship between these two variables, the are often mixed together, and it is believed that the influence of weight is overestimated (1).

The objectives of the study were to:

- Find ways to increase the study material in paired comparison technique,
- Analyze the influence of true mass effects in relation to design,
- Study the influence of aggressiveness.

Method

The fundamental problem can be described with probability distribution functions. In Fig. 1 two hypothetical curves showing the risk of injury linked to accident severity for two different car models is showed. One car is better than the other in that the distribution is shifted to the right, that is for a given accident severity, the probability of injury is lower.

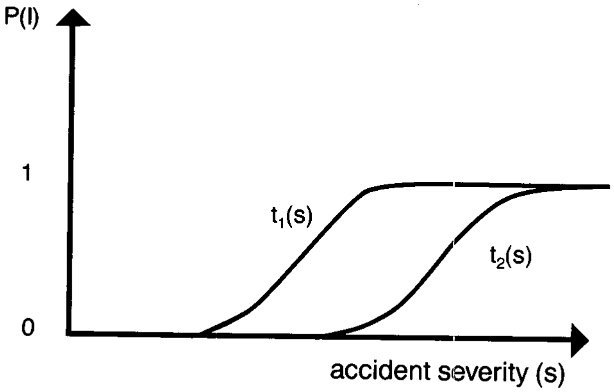


Figure 1. Scematic Probability Functions for Injury Risk for Different Accident Severity. $t_1(s)$ refers to car 1 and $t_2(s)$ to car 2.

In Fig 2. Two accident severity distributions for two car models is showed. The distributions are hypothetical. Car (2) is involved relatively more frequently in severe collisions compared to car (1).

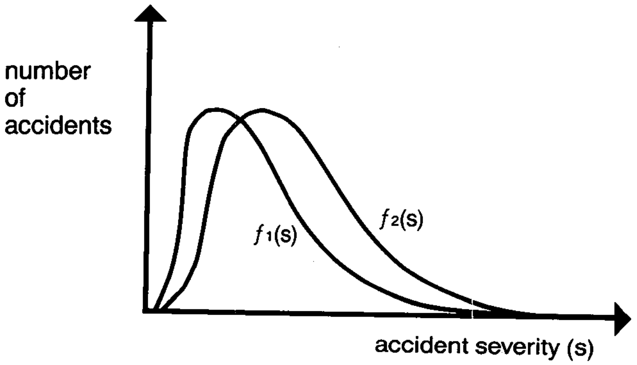


Figure 2. Schematic Distribution of Acident Severity. $f_1(s)$ refers to car 1 and $f_2(s)$ to car 2.

The accident severity distribution is, however, unknown for different car models. This would not create any problem if all accident severity distributions for different cars were identical. This seems however to be a too optimistic assumption. There is though one situation where this is true and that is when the two different car models collide with each other (given a mass relation of 1:1).

According to Evans, the relation of injuries for car 1 and 2 given the same accident severity distribution is: d/e where:

d = the number of injured in car 1 = $N\int t_1(s)f(s)ds$

e = the number of injured in car 2 = $N\int t_2(s)f(s)ds$

N = total number of accidents

For a given segment m where the accident severity can be considered to be constant (Fig. 3) d and e can be considered to be products of two probabilities; P_1 and P_2, where P_2 is the risk to injured in car 1 for a given severity and P2 the corresponding probability for car 2.

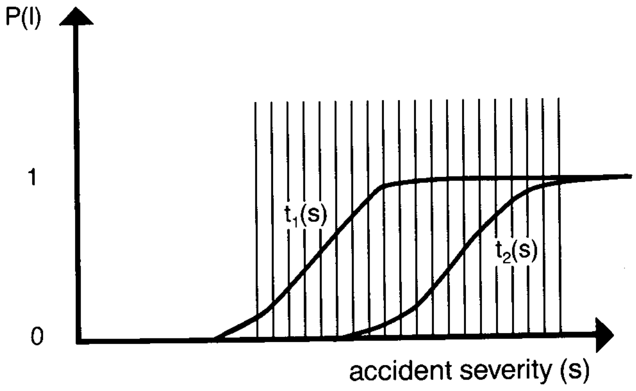


Figure 3. Segmented Probability Functions for Injury Risk for Different Accident Severity for Car 1 $t_1(s)$ and Car 2 $t_2(s)$

Table 1a. Probabilities of Injury in Car 1 and 2 in a Given Segment of Accident Severity

		Car 2		
		injured in	not injured in	total
Car 1	injured in	$N \cdot p_1 \cdot p_2 = x_1$	$N \cdot p_1 \cdot (1 - p_2) = x_2$	$Np_1p_2 + Np_1(1 - p_2) = Np_1$
	not injured in	$N \cdot (1 - p_1) \cdot p_2 = x_3$	$N \cdot (1 - p_1) \cdot (1 - p_2) = x_4$	
	total	$Np_1p_2 + N(1 - p_1)p_2 = Np_2$		

In table 1a the probabilities are separated. The probabilities are assumed to be independent for all given segments where the accident severity and probabilities of injury respectively can be considered as constant. It can be seen that the ratio d/e in this segment is equal to the ratio

$R = x_1+x_2/x_1+x_3$ (where $d=x_1+x_2$ and $e = x_1+x_3$)

which is the same as

$$R=p_1/p_2 \left[\frac{Np_1 \cdot p_2 + Np_2 \cdot (1-p_1)}{Np_1 \cdot p_2 + Np_1 \cdot (1-p_2)}\right]$$

X_y is not used due to the fact that accidents with uninjured are not known in most data materials.

It is easy to show that if p_1/p_2 is the estimator for a given segment, it is also true for the whole range of accident severity. Identical formulas are therefore used for all accidents together.

The complete accident material used is shown in table 1b.

Table 1b. Probability of Injury and Number of Injured for All Segments of Severity of Accidents: Drivers and Passengers

		Car 2		
		injured	not injured	
Car 1	injured	$\sum_{i=1}^{m} (N_i\, p_{1i}\, p_{2i}) = X_1$	$\sum_{i-1}^{m} (N_i\, p_{1i}\, (1 - p_{2i})) = X_2$	Np_i
	not injured	$\sum_{i-1}^{m} (N_i\, (1 - p_{1i})\, p_{2i}) = X_3$		
		Np_2		

It is also possible to include passengers under some simple assumptions. By assuming that all cars have a similar proportion of front sent passenger, all accidents where there are injured passengers can be used, although it is not known from the accident material if there was an uninjured passenger in the vehicle, too.

The individual N_1 is the number of accidents in a given segment, It is easily understood, that a higher proportion of severe accidents will lead to a relatively larger X_1 vs X_2 and X_3.

The same assumptions and theory are used for estimating the variance of the estimates p_1/p_2. By using Cochran's theorem for subdivision of variances, it can be seen that the variance could be calculated from the estimates of p_1 and p_2. By using Gauss approximation for the variance of ratios, the variance is calculated by:

$$\hat{V}(R) = \frac{p_1*}{p_2*}\left[\frac{(1-p_1*)}{(x_1+x_2)} + \frac{1-p_2*}{(x_1+x_3)}\right]$$

p_1*/p_2* is estimated by R, while p_1* and p_2* must be chosen arbitrarily.

It can be understood from the formulas that the method as described above cannot be used directly on a true accident material, as the number of combined accidents for different cars will be to few. Instead, the opposite car (ie car 2) will be all cars that were involved in accidents (with car 1). Thereby, it must be assumed that the distribution of all opposite cars is similar for all investigated car models, or can be normalized. If so, the opposite cars must be known concerning make, model and weight. It is also obvious that there must be a possibility to compensate for other mass relation than 1:1 as the opposite car can gain from a low weight car and vice versa.

In table 2, an example of one car is shown. The weight of this car is approx. 1200 kg, but no attention has been paid to the mass ratio to the opposite cars. The correct interpretation of R is that in 84% of the accidents, where at least one driver was injured, there was an injury in the SAAB 900.

Table 2. The Number of Drivers Injured in SAAB 900, and Cars Colliding with SAAB 900. x_1 refers to drivers injured in both cars. x_2 is the number of cars where the driver injured in SAAB 900 but not in the opposite case while x_3 refers to the opposite case.

$x_1 = 122$
$x_2 = 166$
$X_3 = 220$
$R = 0.84$
$S_R = 0\text{-}04$

Results

The influence of weight and design

In general, the influence of design can be defined in a way where it is possible to extract this influence in a double pair equation. In crashes with cars of identical weight (no mass influence), the probability of injury can be separated in the following way in a case where just one car model or class of vehicles is studied. The design parameter is noted as c.

Scheme for Subdividing Cars with Identical Mass

		CAR 1	
		injured	not injured
CAR 2	injured	c^2p^2	cp(1-cp)
	not injured	cp(1-cp)	

The relation between the number of cases where just one is injured compared to cases with injuries in both vehicles is a measure of p. A large p leads to many cases of injured in both cars, assuming that the accident severity distribution is identical. The design factor can be isolated if sets of accidents with *identical vehicles in terms of mass* or other characteristics is divided according to the given scheme. If cars of 100 kg difference are compared we can isolate the design factor. In table 3 this 100 kg design factor is shown. To isolate the design effect the following calculation is made.

$$R_d = (X_1/X_2)_{800}/(X_1/X_2)_{900}$$

Table 3. Relation of Injuries According to Scheme, for Cars of Different Weight

weight	relation (R_d)
1000- 900 kg	0.91
1100-1000 kg	1.12
1200-1100 kg	0.76
1300-1200 kg	0.87
1400-1300 kg	1.08

The average design effect is 5.2% in this comparison. It could however to some extent be influenced by a higher accident severity for the heavier cars. This is, however, in contrast to the lack of consistency in the design factor.

The weight effect is calculated from the relation when cars of *different weight are colliding*. In table 4 the relation for cars colliding with other cars of 100 kg higher service weight are compared.

Table 4. Relative Injury Risk Level for Cars of Different Weight

weight	relation (R_{d+w})
1000- 900 kg	0.85
1100-1000 kg	0.87
1200-1100 kg	0.91
1300-1200 kg	0.89
1400-1300 kg	0.86

The average design and weight effect was 11%. This means that the true weight effect was only 7% for every 100 kg while the rest was the design effect. The weight effect is though doubled as it gives a positive effect to one of the cars and a negative to the other, so the true weight effect is only half of the calculated 7%, that is 3.5% in the limited range given in the table.

The compensation for mass effects in the paired comparison models should be lowered that what seems to be correct from the beginning.

The Use of Passengers in the Paired Comparison Method

In the original method only the drivers were included. The passengers can though be treated in the same way. This though is based on an assumption that there are identical numbers of passengers in all cars compared. This may be a too optimistic assumption, and therefore a comparison of the driver and passenger risk was compared. In fig 4 this is done and by using a polynomial model, and a good relationship was established.

The results of the paired comparison method used on car rating will change when mass and passenger effects are taken into account. The difference is shown in table 5.

In table 5 it can be seen that the weight and the passenger factor changes the outcome to different amount for different car models. In general, the difference between the small and the large car is becoming smaller.

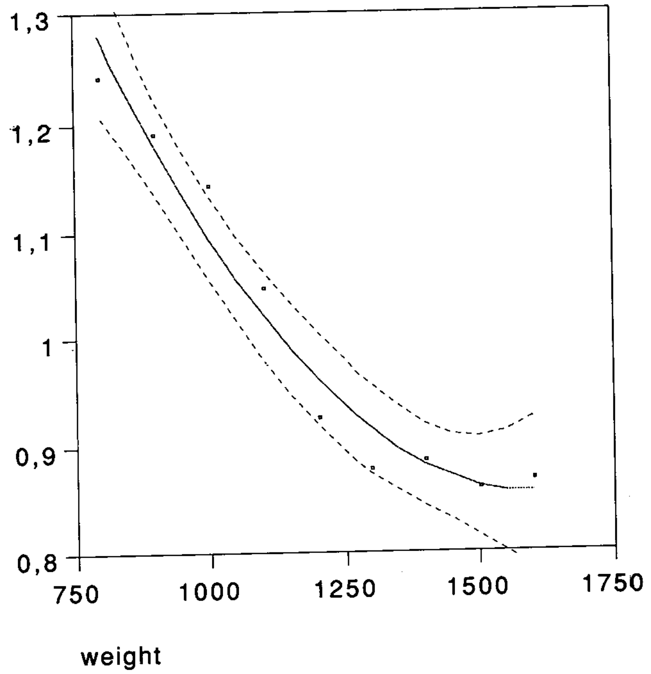


Figure 4. Relation Between Driver/Passengers and Weight of the Vehicle in a Paired Comparison. The polynom has the equation $Y = 2.54 - 2.01 * 10^{-3} X + 6.5 * 10^{-7} X^2$.

Table 5. Examples of Corrections of Paired Comparisons When Correcting for Passengers and Weight Factor

Car model	weight	uncorrected score	corrected score
Opel Corsa	800	1.62	1.44
Nissan Micra	800	2.13	1.89
Ford Sierra	1200	1.04	1.08
Audi 80	1200	1.02	1.05
MB W 201	1300	0.95	1.02
Volvo 700	1400	0.69	0.76

Aggressiveness

If a car is more aggressive in collisions with other vehicles, it could have certain effects on the accident figures in a paired comparison. The term aggressiveness is not defined, but in this study, the structural aggressiveness was separated from aggressiveness due to mass. In order to have an idea about the structural aggressiveness a list of cars were presented to a car manufacturer with the aim to categorize the cars into three groups; "soft, medium and stiff" cars. 8 cars were possible to divide into the three groups. In table 6 the results of the in a paired comparison is presented. It can be seen that while the cars chosen had a similar overall result (R), the relative ratio when the car collided with itself was very high for the stiff cars, especially for car A, while when colliding with all other cars it was normal for the size of the car. The soft cars, however, had a completely different profile, where the relative ratio was very low.

Table 6. The Relative Ratios in Paired Comparisons for Different Car Types Where A is a Stiff Car, B Are Soft Cars, While C Was Considered to be a Normal, But Stiff Car

	R	X1/X2+X3 to itself	X1/X2+X3 to other
A	0.67	0.59	0.35
B	0.71	0.25	0.37
C	0.66	0.45	0.37

An explanation that the stiff car was involved in more high speed accidents does not seem to be plausible, as the ratio of cases with two drivers injured vs one of them was not higher when the "stiff" car collided with all types of cars (0.35). When the "stiff" car collided with the "soft" cars, the relative paired ratio $R_{A/B}$ was 0.84 which was lower than expected (0.94). When the "medium-stiff" car (C) collided with A and B respectively, the result was better for C (0.88 and 0.86 respectively).

In summary, the "stiff" car seems to have a higher injury risk when colliding with another stiff car, but also have a slightly better position when colliding with a "soft" car, while when "soft" cars collide with each other, the total outcome is far better than other combinations.

Discussion

The possibility to compare different aspects in car populations concerning interior safety is of particular interest not only to the consumer, but also to research and car construction. In such comparisons, however, the safety performance of different cars is difficult to isolate, as it may be confounded by driver behavior and type of vehicle use leading to different accident experience. The possibility to collect data where i e accident severity is assessed is difficult on a large scale data basis, both as it is costly and time consuming, but also because it normally will lead to insufficient data quality (5).

The development and use of the paired comparison method has been successful in taking care of the two most serious problems in analyzing large scale data materials; exposure in terms of how many accidents that occur, and accident severity. It is however an indirect and relative method that will leave measurements on absolute relations between exposure and injuries hidden. It is also a method that, at least at this moment, does not take all accidents into account. Single accidents and accidents with trucks etc will not be covered by the method.

In this study, the influence of some critical parameters was analyzed using the paired comparison method. Firstly, the influence of mass vs design was studied. Several studies during a long period of years have shown, that there is a strong and consistent relationship between car weight and risk of injury (4). This is a causal relation as it is easily shown that a car of a lower weight will experience a higher change of velocity than heavier cars and as change of velocity is correlated to injuries, it is not surprising that smaller cars will generate more injuries compared to bigger cars, given that they will be involved in accidents with each other. It seems, however, that in most studies, the weight has been the only factor taken into account when comparing different car designs. It has though been pointed out (1) that there might be an overestimation of the influence of vehicle weight. A larger and more heavy car will most often also have larger interior dimensions, more distance to deform and a better safety design that also will influence the outcome in accidents. If weight and these factors are highly correlated, it is easily understood that the "weight" factor also will include "design." In the present study, a simple method to separate weight from design, was tried. With some assumptions about accident severity, it was shown that the influence of design in general was more important than weight. In average, the 100 kg more service weight was associated with 3.5% lower injury risk, while the design factor for the same amount of weight increase was 5.2%.

The above mentioned results are of great importance when discussing downsizing as well as small car safety in the future. A smaller car seems to have a possibility to be more safe by design, given that it can be constructed in a good way. In the present material, it was shown that among small cars (800 kg) there are cars with the safety of much larger cars and, if there are only cars of the same size, the total safety does not have to be much influenced. The relation between design and weight makes it more important to evaluate the influence of different safety measures and to use scientific methods to evaluate the safety of different cars and constructions.

In order to expand the data material available for compared comparisons, the integration of passengers into the method was studied. In this presentation, all passengers of 18 years were included, and a method to take the size of the car and the proportion of passengers into account was shown. The possibility to include also the passenger even if two-car accidents are studied makes it possible to evaluate safety designs also for the passenger, such as seat belt pretensioners, airbags etc.

Aggressiveness, defined as the harm produced by one car to another, might influence the paired comparison method. A method where some car models were divided into "stiff" and "soft" cars were applied to the data. If was found, that while there where only small differences in the overall results for these cars, the outcome was quite different when they collided with each other. In such cases, the "stiff" cars had a high proportion of cases where there were injuries in both cars, while in the "soft" cars this occurred more seldomly than normal. This fact could not be explained by a higher accident severity among the "stiff" cars. It was also found, that the relative injury risk was higher than expected when a "stiff" car collided with a "soft" car, though this difference was fairly small.

The results presented points out an important issue for the future. Dynamic test methods used in legislation and consumer guidance might influence the structural behaviour desired in car construction in a way that it might lead to cars not optimized for a real life accident population. It is therefore of great importance that this field is given more priorities by i e collecting more adequate data from the real life, and by studying the relative importance of different factors associated with the structure of cars.

References

1. Gloyns PF, Rattenbury SJ, Kullgren A, Lie A, Tingvall C, Edwards J, Hill R. The correlation between the Consumer's Association secondary safety rating system and the Folksam car safety ratings. In: Proc IRCOBI Conf 1991:49-60.
2. Krafft M, Kullgren A, Lie A, Nygren Å, Tingvall C. Car model safety rating based on real life accidents. In:Proc IRCOBI Conf 1991:25-39.
3. Evans L. Double pair comparison--a new method to determine how occupant characteristics affect fatality risk in traffic crashes. Acc. Anal and Prev. Vol 18 no 3 pp 217-227. 1986.
4. Nygren Å. Injuries to car occupants—some aspects of the interior safety of cars. A study of a five-year material from an insurance company. Thesis. Acta Otolaryngologica suppl 395 Stockholm 1984.
5. Kamren B, v Koch M, Kullgren A, Lie A, Nygren Å, Tingvall C. Advanced accident data collection—description and potentials of a comprehensive data collection system. Accepted for publ ESV Conf 1991.

S1-O-10

Driver Fatality Risk in Two-Car Crashes: Dependence on Masses of Driven and Striking Car

Leonard Evans and Michael C. Frick
General Motors Research Laboratories

Abstract

Relative risk of driver death in a two-car crash is estimated as a function of the mass of each car using driver and (to measure exposure) pedestrian fatalities coded in the Fatal Accident Reporting System (FARS). Because mass effects are less strong for more recent cars, the study uses model-year 1980 and later cars. A three parameter analytical function fitted to the estimated risks generated the following findings. When a driver transfers to a lighter car that driver's fatality risk increases, while the other involved driver's risk declines. When cars of the same mass crash into each other, fatality risk is lower when both cars are heavier. If one of the equal-mass cars is replaced by another lighter by any amount, the increase in fatality risk to the driver in the car of reduced mass exceeds the reduction in fatality risk for the driver in the unchanged car (that is, net risk increases). Net driver fatality risk (or net fatalities) in a car population increases if any car in the population is replaced by a lighter one, or if one population of identical cars is replaced by another population of lighter identical cars. Making all cars in a population of uniform mass while keeping the average mass constant increases net fatality risk. The safety disadvantage of lighter and smaller cars is intrinsic—it cannot be negated by design changes if these are also available to larger heavier cars because, when all other factors are equal, more mass and more space can be used to provide increased safety. Fuel economy and safety (like higher speed limits and safety) are intrinsically in conflict; individual and national choices require a balancing of advantages.

Introduction

One of the most firmly established effects in traffic safety is that a car occupant's risk of injury or death in a crash is inversely related to the size or mass of the car in which the occupant is travelling. A large number of studies, conducted over more than two decades, have explored many aspects of relationships between car size and safety [Evans 1991]. For the case of two-car crashes, mass is a particularly appropriate variable because of its central role in equations describing the dynamics of collisions. One recent study [Evans and Frick 1991a] reports precise relationships between the ratio of driver fatality risk in the lighter compared to the heavier car and the ratio of the heavier to the lighter car mass. These relationships show that when late model year 900 kg and 1800 kg cars crash into each other, driver fatality risk in the 900 kg car is six times what it is in the 1800 kg car, or when 1000 kg cars and 1500 kg cars crash into each other, driver fatality risk in the 1000 kg car is three times what it is in the 1500 kg car. Because that study focussed exclusively on risk ratios, it could be conducted without any exposure measure. However, the relationships derived do not allow us to compare, say, the risk faced by a driver in a 900 kg car crashing into a 1800 kg car to the risk faced by a driver of a 1000 kg car kg crashing into a 1500 kg car. Comparisons of this type require an estimate of exposure to crash involvement.

Method

Data

The Fatal Accident Reporting System (FARS) is a computerized data file maintained by the National Highway Traffic Safety Administration containing detailed information on all traffic crashes occurring in the United States since 1 January 1975 in which anyone was killed [National Highway Traffic Safety Administration 1991]. The exposure data, as well as driver fatality data, are extracted from crashes coded in FARS involving cars of known mass. The main results are derived using data from 1980 through 1989, and include only cars of model year (MY) 1980 or later. We focus mainly on MY ≥ 1980 data because earlier analyses [Evans and Frick 1991a] showed substantial changes in mass dependencies between later and older MY cars. For comparison and modeling purposes, the analyses are also applied to cars of all model years. The average model year of cars in the analysis with unrestricted model years was 1976.2, compared to 1983.4 for the MY > 1980 case; when no ambiguity arises, we shall sometimes refer to these simply as "older" and "newer" cars. The average MY values are lower than the mid-point of the FARS years because 1980 MY cars (say) appear in 1989 FARS but 1989 MY cars cannot contribute to 1980 FARS.

Driver fatalities

The driver fatality data are for two-car crashes in which at least one of the drivers was killed. The data were segmented into categories, or ranges, of mass each containing equal numbers of crashes (and consequently unequal intervals of mass). The number of categories chosen was the number which maximized the precision with which model parameters (discussed below) were determined.

From a formal perspective, each of the cars involved in a two-car crash has a symmetrical role—they crash into each other. However, for expository clarity it is convenient to arbitrarily distinguish between them. We use the terms "first," "ith," "struck," "subject," "driven," or "your" car to identify a car in the ith mass category; the average mass of cars in the ith mass category will be represented by m_i. The terms "second," "jth," or "striking," identifies the "other" car, which is in a category with average mass m_j.

The pedestrian fatality exposure approach

A number of applications of this method [Evans 1984] are described in Evans [1991]. The aim is to estimate the exposure of cars to crashes in general using FARS data. The vast majority of crashes into such objects as trees, other vehicles, etc. are not coded in FARS, because only crashes in which someone is killed are included in the file. However, if the crash involves a pedestrian, and the pedestrian is killed, then the crash is coded. The assumptions that pedestrian fatalities are proportional to pedestrian crashes, and that cars strike pedestrians in the same proportion they strike other objects in the driving environment, implies that the number of pedestrian fatality crashes in which a group of cars is involved is proportional to the exposure of that group of cars to crashes in general. The assumption that pedestrian fatalities are proportional to pedestrian crashes holds if the probability of a pedestrian fatality in a crash does not depend on the mass of the car. This is a reasonable assumption on physical grounds because the lightest car is so much heavier than the heaviest pedestrian that the car's crash trajectory is relatively unaffected by the collision.

Table 1. The Number of Driver Fatalities in Car i (with mass in the ith mass category) When This Car is in Collision with Car j (mass in the jth category)

Car i ↓	Car j →							
	w1*	w2	w3	w4	w5	w6	w7	w8
w1	$\boxed{62}$	103	106	118	118	153	160	146
w2	76	$\boxed{88}$	90	101	129	129	133	132
w3	58	59	$\boxed{94}$	101	93	116	116	132
w4	52	68	67	$\boxed{92}$	99	106	123	134
w5	41	63	78	72	$\boxed{94}$	82	95	126
w6	42	51	54	62	76	$\boxed{76}$	88	113
w7	40	31	61	68	68	61	$\boxed{91}$	93
w8	28	32	37	37	59	59	58	$\boxed{80}$

* The average masses of the 8 mass categories are:

w1 = 870 kg; w4 = 1147 kg; w7 = 1472 kg;
w2 = 985 kg; w5 = 1241 kg; w8 = 1683 kg.
w3 = 1079 kg; w6 = 1380 kg;

Data for MY ≥ 1980 cars, FARS years 1980 through 1989.

Results for MY ≥ 1980 Cars

Restricting the analysis to MY ≥ 1980 excludes 87% of the otherwise available two-car crashes in FARS; the data reduction is so large because so many crashes between one MY ≥ 1980 car and another MY ≤ 1979 car are excluded. Sample size limitations make it infeasible to perform analyses for more recent sets of model years. In order to confine all aspects of the analyses to the 1980s, data for FARS years 1980-1989 were used, thus excluding the very few crashes in 1979 involving two 1980 model year cars.

Table 1 shows driver fatality data for two-car crashes segmented into 8 categories of car mass, with average values w1, w2, w3,.... w8. Using essentially the same approach and terminology as Evans and Wasielewski [1987] introduced to address a similar problem using earlier data, we define

$$N(i,j) = \text{Number of drivers in cars in mass category } m_i \text{ killed in crashes with cars in mass category } m_j, \quad (1)$$

where i and j assume values from 1 to 8. The risk of a driver fatality in a car in the ith mass category compared to the risk in a car in the jth mass category when these cars crash into each other is given by N(i,j)/N(j,i). For example, 28 drivers in m_i = w8 cars (average mass 1683 kg) were killed when these cars were in collision with m_j = w1 (870 kg) cars. In these same crashes between w1 and w8 cars, 146 drivers in the w1 cars were killed. We can immediately conclude that when w1 and w8 cars collide, driver fatality risk in the lighter car is 146/28 = 5.2 times what it is in the heavier car.

In order to progress to the general case some measure of exposure is necessary. Exposure is estimated using pedestrian fatality crashes. The numbers of single-car crashes in which at least one pedestrian was killed is shown in Table 2, in which

$$E(i) = \text{number of crashes by cars in mass category } m_i \text{ in which at least one pedestrian was killed} \quad (2)$$

The number of crashes between cars in the ith and jth categories is assumed proportional to the product of their exposure, E(i)xE(j). The number of driver deaths per unit of exposure, $R'_{observed}(i,j)$ is therefore given by

$$R'_{observed}(i,j) = N(i,j)/[E(i)xE(j)]. \quad (3)$$

For convenience, the values of $R'_{observed}(i,j)$ are rescaled so that the nominally lowest driver risk case (the risk in the heaviest car crashing into the lightest) is assigned the value 1. This is achieved by dividing eqn 3 by a constant, K, given by

$$K = N(8,1)/[E(8)xE(1)]. \quad (4)$$

Thus we obtain the sought-after measure of driver risk, $R_{observed}(i,j)$, given by

$$R_{observed}(i,j) = N(i,j)/[KxE(i)xE(j)]. \quad (5)$$

Table 2. The Number of Single-Car Crashes in Which at Least One Pedestrian Was Killed Segmented into the Mass Categories Used in the Driver Fatality Analysis

Category	Mass, kg			Number of Crashes
	Minimum	Maximum	Average	
1	655.0	929.0	869.7	1580 = E(1)
2	929.9	1041.9	984.8	1481 = E(2)
3	1042.4	1112.7	1078.7	1400 = E(3)
4	1113.1	1183.9	1146.8	1411 = E(4)
5	1184.3	1307.7	1240.7	1379 = E(5)
6	1309.6	1424.7	1380.4	1397 = E(6)
7	1425.2	1556.3	1472.4	1707 = E(7)
8	1558.1	2131.9	1682.7	1695 = E(8)

Data for MY ≥ 1980 cars, FARS years 1980 through 1989.

Table 3 shows the computed values of $R_{observed}(i,j)$. Apart from the values $R_{observed}(1,8) = 5.21$, and the arbitrarily fixed $R_{observed}(8,1) \equiv 1$, all other values are influenced by the exposure measure. The highlighted diagonal elements, representing cars of similar mass crashing into each other, show an increasing trend with decreasing common mass, although the relationship is noisy.

Table 3. The Fatality Risk to a Driver in Car i When This Car Crashes into Car j, Each Car Being in the Category with the Indicated Average Mass

Car i ↓	Car j → w1*	w2	w3	w4	w5	w6	w7	w8
w1	2.38	4.21	4.58	5.06	5.18	6.63	5.67	5.21
w2	3.11	3.84	4.15	4.62	6.04	5.96	5.03	5.03
w3	2.51	2.72	4.59	4.89	4.61	5.67	4.64	5.32
w4	2.23	3.11	3.24	4.42	4.87	5.14	4.88	5.36
w5	1.80	2.95	3.86	3.54	4.73	4.07	3.86	5.16
w6	1.82	2.36	2.64	3.01	3.77	3.72	3.53	4.56
w7	1.42	1.17	2.44	2.70	2.76	2.45	2.99	3.07
w8	1	1.22	1.49	1.48	2.41	2.38	1.92	2.66

* The average masses of the 8 mass categories are:

w1 = 870 kg;
w2 = 985 kg;
w3 = 1079 kg;
w4 = 1147 kg;
w5 = 1241 kg;
w6 = 1380 kg;
w7 = 1472 kg;
w8 = 1683 kg.

All values are relative to a value one for the lowest risk case, that faced by a driver of a car in the heaviest mass category crashing into a car in the lightest mass category. Data for MY ≥ 1980 cars, FARS years 1980 through 1989.

The estimated risk for w1 cars crashing into w1 cars departs particularly from the general trend, the value being less than for w2 cars crashing into w1 cars (physically implausible) and much less than for the other adjacent cell, w1 cars crashing into w2 cars. In contrast, the other diagonal values in Table 3 are similar to their adjacent non-diagonal elements. The departure from the trend is larger than plausible due to the sample size of fatally injured drivers (62, giving a standard error of about 13%).

For a number of reasons it seems unlikely that when two very light cars crash into each other risk is really less than when two slightly less light cars crash into each other. First, it is implausible on physical grounds. Second, three independent studies using state data to examine injury risk as a function of the mass of each of two involved cars (Joksch [1983], Evans and Wasielewski [1987], and Klein, Hertz, and Borener [1991]) find that when the masses are the same, risk increases with decreasing mass without any evidence of anomalous behavior at the lowest masses. The unsystematic effect for w1 cars crashing into w1 cars is more likely reflecting departures from the assumptions of the pedestrian fatality exposure approach. The w1 cars may be more likely to be used in environments in which pedestrian-fatality crashes are more likely, thereby indicating that their drivers were more exposed to fatality risk than they were. If the w1 cars had a distribution of crashes by severity more skewed towards lower severity crashes, this would reduce the ratio of driver to pedestrian fatalities; support for such an interpretation is provided by the finding that the probability that driver is killed when a right-front passenger is killed is lower for w1 cars than for other cars. Any error in the exposure for any group of cars has a particularly strong effect on the highlighted diagonal values in Table 3 because the square of the exposure measure appears in their calculation. For example, if the actual exposure was 25% less than estimated by E(1), then the top-left cell in Table 3 would be 4.23 rather than 2.38.

In order to better illuminate and explore the trends and dependencies in the data in Table 3, it is desirable to fit an analytical function to these data. An analytical function has important additional advantages. It can be used to examine the net safety effect when any car is replaced by another of a different mass. An analytical function can be used to compute how system safety responds to changes in the mix, by mass, of cars.

Analytical fit

The data in Table 3 were fitted to

$$R'_{predicted}(m_1,m_2) = m_1^{V} [1 - \exp(G \times \mu^{W})] \qquad (6)$$

where

$$\mu = m_2/m_1 \qquad (7)$$

is the mass ratio, defined as in Evans and Frick [1991a].

This functional form was chosen not only because it provides a satisfactory fit to the data, but additionally because it exhibits physically reasonable behavior for the special cases of the masses being equal, and for the case of the mass of the struck car becoming arbitrarily large.

In analogy with eqns 3 and 4, we define the constant k as

$$k = R'_{predicted}(m_1 = w8,\ m_2 = w1) \qquad (8)$$

This enables us to define

$$R_{predicted}(m_1,\ m_2) = m_1^{V}\ [1 - \exp\ (G \times \mu^{W})]\ /\ k \qquad (9)$$

The inclusion of the constant k ensures that eqn 9 gives the value one for m_1 = w8, m_2 = w1 irrespective of the values of the parameters. The criterion for best fit of eqn 9 to the data in Table 3 was the set of V, G and W parameters which minimized the quantity $S = \Sigma Z^2$, where summation is over the 63 estimates, and Z = log $(R_{predicted}/R_{observed})$. Estimating twice or half the observed value adds equally to S. At the minimum, the root mean square value, $\sqrt{(S/63)}$, is 0.1591. The interpretation is, very approximately, that the standard error of an estimate is about 16% of its value. The selection of 8 mass categories was based on minimizing the errors in the parameter estimates, and not minimizing S, which is achieved by 7 categories; more mass categories tends to increase the precision of the parameter estimates because it extends the mass range.

The parameter values that provide the best fit are

$$V = -\ 0.322 \pm 0.139 \qquad (10)$$

$$G = -\ 1.175 \pm 0.181 \qquad (11)$$

and

$$W = \ 2.427 \pm 0.121 \qquad (12)$$

where error limits throughout this paper are one standard error. All three parameters are dimensionless, so that the equation applies regardless of the mass units. Because of the way eqn 9 is normalized by the use of eqn 8, the parameter V is really raising the dimensionless ratio, m_1/w8, to the power V. This is why the value of V is unaffected by whether masses are measured in, say, kg or pounds.

The standard errors given for the parameters reflect only differences between eqn 9 and the data in Table 3, and do not include any contributions from underlying uncertainty in the overall method; in particular, the use of pedestrian fatalities to estimate exposure. Errors from this source have the potential to influence results, especially strongly for the case of cars in the same mass category crashing into each other, as discussed previously.

Predicted compared to observed values

Table 4 shows the values of $R_{predicted}$ computed using eqn 9 with the parameter values shown in eqns 10-12. The predicted values may be compared to the observed values in Table 3. Figure 1 shows the predicted versus observed values, with Figure 2 displaying, on a log scale, the ratio of predicted to observed values. Of the 63 predicted values, 54 are within 20% of the observed values, which range over a factor of five. The largest error, 4.05/2.38 = 1.70, is that for the previously discussed case of w1 cars crashing into w1 cars.

In what follows we assume that eqn 9 estimates the risk of fatality to a driver in a car of given mass when it crashes into another car of known mass, so that by examining the properties of this equation we can derive additional results relating to two-car crashes.

Table 4. Driver Fatality Risks Computed Using Eqn 7 with the Parameters for MY ≥ 1980 Cars Given in Eqns 10-12

Car i ↓	Car j → w1*	w2	w3	w4	w5	w6	w7	w8
w1	$\boxed{4.05}$	4.67	5.06	5.28	5.50	5.71	5.78	5.85
w2	3.27	$\boxed{3.90}$	4.33	4.61	4.92	5.24	5.39	5.56
w3	2.75	3.34	$\boxed{3.78}$	4.07	4.42	4.83	5.02	5.30
w4	2.42	2.98	3.42	$\boxed{3.71}$	4.07	4.52	4.74	5.09
w5	2.05	2.56	2.97	3.25	$\boxed{3.62}$	4.09	4.35	4.78
w6	1.61	2.04	2.40	2.67	3.01	$\boxed{3.49}$	3.78	4.30
w7	1.38	1.77	2.10	2.34	2.67	3.14	$\boxed{3.42}$	3.98
w8	$\boxed{1}$	1.30	1.56	1.76	2.04	2.45	2.71	$\boxed{3.28}$

* The average masses of the 8 mass categories are:

w1 = 870 kg;
w2 = 985 kg;
w3 = 1079 kg;
w4 = 1147 kg;
w5 = 1241 kg;
w6 = 1380 kg;
w7 = 1472 kg;
w8 = 1683 kg.

Derivations from the Analytical Fit to MY ≥ 1980 Data

The effect of mass when cars of similar mass crash into each other

If two cars of the same mass, say M, crash into each other, the relative driver fatality risk (equal in each car) is given by substituting m_i = M and m_j = M into eqn 9.

Because the mass ratio is equal to one, the relative risk, R(M), for this case simplifies to

$$R(M) = C\,M^{V}, \qquad (13)$$

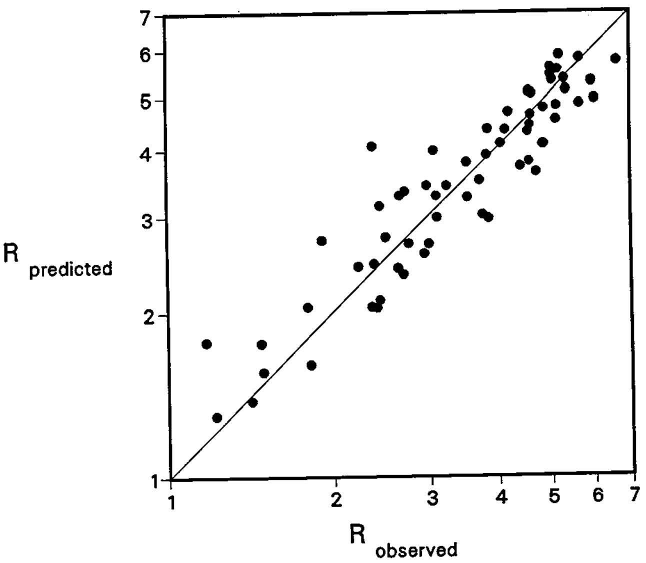


Figure 1. Predicted Driver Fatality Risks (Table 4) Versus Values Estimated from Fatality Ratios (Table 3) for MY ≥ 1980 Cars

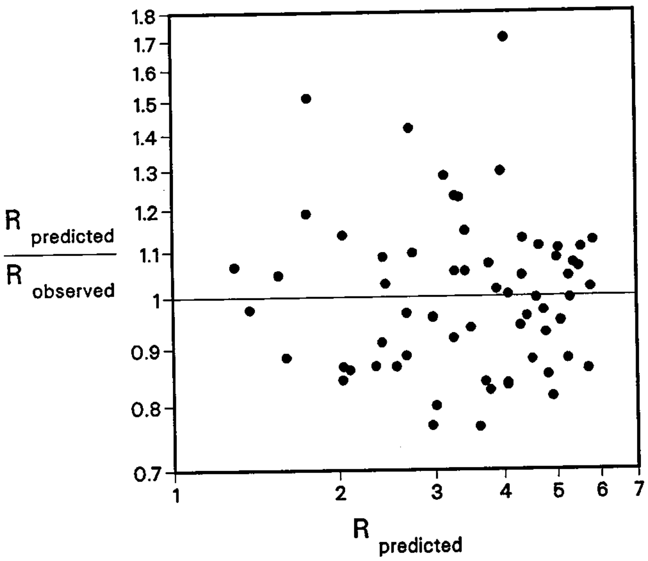


Figure 2. Predicted Driver Fatality Risks (Table 4) Relative to Values Estimated from Fatality Ratios (Table 3) Versus the Predicted Value for MY ≥ 1980 Cars

where all the mass-independent factors have been included in the one constant C. In terms of the illustrative example of 900 kg cars crashing into 900 kg cars compared to 1800 kg cars crashing into 1800 kg cars, eqn 12 with V = -0.322 gives that the driver fatality risk in the light/light car crash is 25% greater than in the heavy/heavy car crash. This is much less than the factor of two found for substantially older model-year cars by Evans and Wasielewski [1987].

Effect of car mass when crashing into an essentially infinite mass

As m_2 becomes large, further increases in m_2 have ever decreasing influence on the probability that the driver in the first car is killed. Thus, in the limit of crashing into very large cars, the asymptotic behavior of eqn 9 gives that the fatality risk to the driver in the first car, $f(m_1)$, depends on the first car)s mass according to

$$f(m_1) = c\ m_1^{\ V}\ , \qquad (14)$$

where c includes all the mass-independent terms. The finding that the dependence of driver fatality on the mass of the car in which the driver is travelling is the same for crashes into identical cars as for crashes into hypothetically extremely heavy cars is in keeping with the often made analogy between a barrier crash test and two identical cars crashing into each other.

Effect on system safety when a car is replaced by one of different mass

Let us suppose that an individual driver replaces a present car with one of a different mass. For expository convenience, let us describe the processes in terms of a driver replacing a presently used car by one of lower mass, although all the equations derived apply for changes in either direction.

When a driver replaces a present car by a lighter one, that driver's fatality risk increases in a two car-crash, regardless of the mass of the other involved car. On the other hand, the fatality risk for the other driver declines, as a consequence of crashing into a car that is lighter. These effects are firmly established by many studies, including the present one (eqn 9), and are so compellingly suggested by physical intuition that they should be regarded as essentially "laws" [Evans 1991; Evans and Frick 1991a]. A question that is much more complex, and for which physical intuition offers little guidance, is "When a driver transfers to a lighter car, is this driver's increase in fatality risk larger or smaller than the risk reduction to other drivers?" In other words, when an individual driver transfers to a lighter car, does this lead to an increase or decrease in net fatality risk.

Equation 9 gives the fatality risk for the first driver when that driver's car crashes into another car; the equation is from the perspective of the first driver. By transposing m_1 and m_2 and adding, we estimate the fatality risk to both drivers combined, $T = T(m_1,m_2)$, as

$$\begin{aligned} T(m_1,m_2) = \{&m_1^{V}\ [1 - \exp\ (G \times \mu^{W})] \\ &+ m_2^{V}\ [1 - \exp\ (G \times \mu^{-W})]\}/k\ . \end{aligned} \qquad (15)$$

If the first driver replaces an initial car of mass m_1 by another of different mass m_1', then a new net fatality risk to both drivers, T', is calculated by substituting m_1' for m_1 in eqn 15 (and also using eqn 7 to compute a new mass ratio). It is convenient to consider the fractional change, P, in T when a car is replaced by one of a different mass, given by

$$P = [T' - T]/T\ =\ T'/T - 1. \qquad (16)$$

If the new mass is some fraction, d, less than the old mass, defined by

$$m_1' = (1 - d)m_1 , \qquad (17)$$

then P does not depend explicitly on m_1, but only on the initial mass ratio and the fractional decrease, d, in the mass of the first car. From eqns 15-17 we derive

$$P = \frac{1 + y^V - \exp(Gy^W) - y^V \exp(Gx^{-W})}{1 + x^V - \exp(Gx^W) - x^V \exp(Gx^{-W})} - 1 \qquad (18)$$

where

$$x = 1/\mu \qquad (19)$$

and

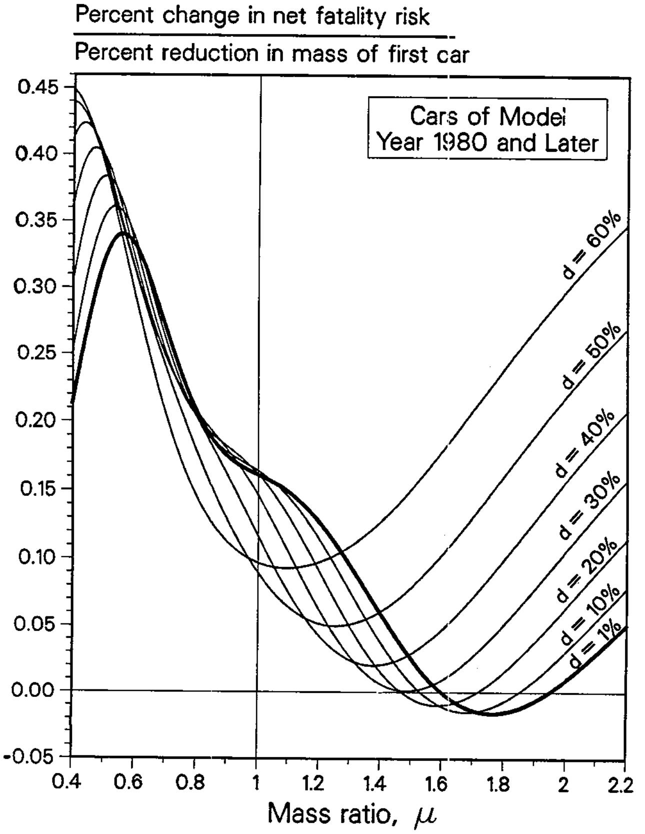
$$y = (1\text{-}d)x . \qquad (20)$$

Figure 3 shows P/d plotted versus d for illustrative values of d. When d is small (say less than about 0.05), P/d is essentially independent of d. To clarify the interpretation of P/d let us focus on d = 0.01, or 1%, (highlighted in bold), keeping in mind that this same relationship applies to any change in the mass of the first car, provided it is not more than about 5%. Suppose an initial scenario of two 1500 kg cars crashed into each other is compared to a new scenario in which one of these cars is replaced by a car 15 kg lighter. Reading the graph at $\mu = 1$ shows that the combined fatality risk increases by 0.16%. If the first car had become lighter by 7.5 kg (0.5%) or 30 kg (2%) instead of 15 kg, then the net increase in fatality risk would have been 0.08% and 0.32%, respectively, but the percent change in net fatality risk per percent change in the mass of the first car would remain constant at 0.16%. As d becomes larger, these relationships of proportionality no longer hold—hence the curves for higher values of d.

If the cars in the example had been 800 kg cars, with one becoming 8 kg lighter, the same 0.16% increase in fatality risk would apply. However, as the initial risk is higher for two lighter cars crashing into each other, this would be 0.16% of a larger quantity, so a larger increase in net absolute fatality risk would result.

For d = 1%, the largest net fatality increase of 0.34% occurs at $\mu = 0.56$. Some combinations of initial car masses generate net fatality reductions, the largest of these being a net fatality change of -0.02% at $\mu = 1.77$. Thus, replacing a 1000 kg car crashing into a 1770 kg car by a 990 kg car crashing into a 1770 kg car generates a net fatality reduction of 0.02%. This net risk reduction arises because the increase in fatality risk to the driver in the car of reduced mass is smaller than the reduction to the other driver.

The other curves cover cases in which cars are replaced by ones of substantially different mass. In all cases the value for $\mu = 1$ is positive; that is, if two cars are of identical mass, replacing one by another lighter by any amount always increases net driver fatality risk.



The curves are computed using eqn 18 with parameters for MY ≥ 1980 cars.

Figure 3. How Net Driver Fatality Risk Changes When a Driver in a Subject Car Transfers to a Car Lighter by d% Versus the Ratio, μ, of the Mass of the Other Car to the Original Mass of the Subject Car

Thus if we have a population of identical cars of any mass, replacing any one of them by a lighter car will always increase population fatality risk.

Reductions in fatality risk occur from some combinations of mass ratio and percent reduction in the mass of the first car (provided it is not greater than 30%). However, the greater magnitude of positive values, and their overwhelming preponderance over negative values in Figure 3 shows that replacing any real car population by another containing generally lighter cars will always increase the total number of driver fatalities if other factors are equal.

Because the values plotted in Figure 3 reflect small differences between two relatively large quantities, they are highly dependent on the precise values of the large quantities, and hence on the values of the parameters, eqns 10-12. Because of the already considerable complexity in Figure 3, it is not feasible to present an analytical sensitivity analysis. Choosing a number of categories other than 8 considerably affects Figure 3, as does fitting the data to functional forms other than eqn 9. However, even though the details vary substantially, the general finding that net fatality risk increases when

m_1 declines for most values of μ, and that declines are of larger magnitude than the few increases that occur, are findings common to all of many different analyses performed. Thus, the general conclusions are fairly robust even if specific details in Figure 3 are not.

Does making all cars the same mass reduce risk?

Let us consider a crash between two cars of the same mass, $M = 800$ kg. The risk to each driver is calculated from eqn 9 as 4.164, for a total risk of 8.328 (in arbitrary units). If one of the cars becomes $\Delta m = 100$ kg heavier, and the other Δm lighter (thus preserving the same 800 kg average mass), eqn 9 computes risks of 5.566 and 2.737 for the drivers of the 700 kg and 900 kg cars, respectively. The new total risk of 8.303 is 0.3% less than for the equal mass case. Repeating for different values reveals a reduction in net risk for all feasible values of Δm in conjunction with any value of M.

Given that transforming equal mass cars into unequal mass cars (while preserving average mass) always decreases risk, it follows that the opposite process will always increase risk. This implies that, assuming the average mass of a car population is to be set at some value, the distribution which provides the highest net fatality risk is the one in which all the cars are of identical mass. Although making all cars of equal mass, while keeping the average mass constant, will lead to a more equitable distribution of risk, it will also increase fatalities.

Eqn 9 has many applications beyond those illustrated above, including determining the total risk in a car population with a given distribution by mass. This enables changes in risk to be computed when the distribution by mass changes as might happen if cars are systematically replaced by lighter ones.

Results for Cars of all Model Years

By using all model year cars contained in the FARS data for 1975 through 1989, much larger sample sizes are obtained, as shown in Table 5 for data in 12 mass categories. The total number of crashes contributing to Table 5 is 41,755, compared to 5,470 for Table 1; so even though there are 144 cells compared to the former 64, there are still more fatalities per cell. Apart from the greater number of categories, the analysis proceeds exactly as before, with the results in Tables 5 - 8, (compare to Tables 1 - 4) and Figures 4 - 6 (compare to Figures 1 - 3).

The parameters of the fit of eqn 9 to the data in Table 7 are

$$V = -1.159 \pm 0.056 \tag{21}$$

$$G = -1.100 \pm 0.082, \text{ and} \tag{22}$$

$$W = 2.132 \pm 0.037. \tag{23}$$

Table 5. The Number of Driver Fatalities in Car i (with mass in the ith mass category) When This Car Is in Collision with Car j (mass in the jth mass category)

Car i ↓	Car j →											
	w1*	w2	w3	w4	w5	w6	w7	w8	w9	w10	w11	w12
w1	$\boxed{154}$	250	392	379	472	535	498	558	563	640	639	649
w2	168	$\boxed{260}$	338	336	431	491	432	489	517	560	504	550
w3	156	210	$\boxed{352}$	355	391	406	457	456	471	494	457	506
w4	117	158	224	$\boxed{331}$	330	352	438	393	506	473	446	479
w5	87	157	209	252	$\boxed{285}$	312	312	364	452	486	444	502
w6	100	141	182	221	265	$\boxed{274}$	319	333	383	403	444	467
w7	72	106	187	198	220	263	$\boxed{288}$	354	350	389	358	403
w8	67	86	138	148	195	211	243	$\boxed{320}$	371	378	406	405
w9	46	54	95	134	161	197	214	250	$\boxed{284}$	319	361	364
w10	44	64	94	107	156	193	182	185	240	$\boxed{266}$	288	310
w11	45	59	65	92	130	163	171	227	234	273	$\boxed{331}$	359
w12	32	32	55	77	109	123	119	156	173	199	247	$\boxed{263}$

* The average masses of the 12 mass categories are:

w1 = 834 kg;
w2 = 960 kg;
w3 = 1085 kg;
w4 = 1181 kg;
w5 = 1294 kg;
w6 = 1397 kg;
w7 = 1463 kg;
w8 = 1560 kg;
w9 = 1643 kg;
w10 = 1747 kg;
w11 = 1867 kg;
w12 = 2076 kg.

Data for all model year cars, FARS 1975 through 1989.

Table 6. The Number of Single-Car Crashes in Which at Least One Pedestrian Was Killed Segmented into the Mass Categories Used in the Driver Fatality Analysis

Category	Mass, kg			Number of Crashes
	Minimum	Maximum	Average	
1	655.0	897.7	834.0	3081 = E(1)
2	898.1	1029.7	960.0	3325 = E(2)
3	1030.1	1131.7	1084.9	3658 = E(3)
4	1132.2	1227.0	1181.3	3816 = E(4)
5	1227.4	1362.6	1294.4	4062 = E(5)
6	1363.1	1423.8	1397.3	4323 = E(6)
7	1424.3	1508.7	1463.2	4551 = E(7)
8	1509.1	1599.4	1560.0	4830 = E(8)
9	1600.3	1685.6	1643.4	4924 = E(9)
10	1686.0	1799.4	1747.4	5293 = E(10)
11	1800.3	1932.3	1867.1	5353 = E(11)
12	1933.2	2606.4	2076.4	5272 = E(12)

Data for all model year cars, FARS years 1975 through 1989.

Table 7. The Fatality Risk to a Driver in Car i When This Car Crashes into Car j, Each Car Being in the Category with the Indicated Average Mass

Car i ↓ \ Car j →	w1*	w2	w3	w4	w5	w6	w7	w8	w9	w10	w11	w12
w1	$\boxed{8.23}$	12.4	17.7	16.4	19.1	20.4	18.0	19.0	18.8	19.9	19.7	20.3
w2	8.32	$\boxed{11.9}$	14.1	13.4	16.2	17.3	17.9	15.5	16.0	16.2	14.4	15.9
w3	7.03	8.76	$\boxed{13.4}$	12.9	13.4	13.0	13.9	13.1	13.3	13.0	11.9	13.3
w4	5.05	6.32	8.15	$\boxed{11.5}$	10.8	10.8	12.8	10.8	13.7	11.9	11.1	12.1
w5	3.53	5.90	7.14	8.25	$\boxed{8.77}$	9.02	8.57	9.42	11.5	11.5	10.4	11.9
w6	3.81	4.98	5.84	6.80	7.66	$\boxed{7.44}$	8.23	8.10	9.13	8.94	9.74	10.4
w7	2.61	3.56	5.70	5.79	6.04	6.79	$\boxed{7.06}$	8.17	7.93	8.20	7.46	8.53
w8	2.29	2.72	3.96	4.08	5.05	5.13	6.61	$\boxed{6.96}$	7.92	7.51	7.97	8.07
w9	1.54	1.67	2.68	3.62	4.09	4.70	4.85	5.34	$\boxed{5.95}$	6.21	6.95	7.12
w10	1.37	1.85	2.46	2.69	3.68	4.28	3.84	3.67	4.67	$\boxed{4.82}$	5.16	5.64
w11	1.38	1.68	1.68	2.29	3.03	3.58	3.56	4.46	4.51	4.89	$\boxed{5.86}$	6.46
w12	$\boxed{1}$	0.93	1.45	1.94	2.58	2.74	2.52	3.11	3.38	3.62	4.44	$\boxed{4.80}$

* The average masses of the 12 mass categories are:

w1 = 834 kg;
w2 = 960 kg;
w3 = 1085 kg;
w4 = 1181 kg;
w5 = 1294 kg;
w6 = 1397 kg;
w7 = 1463 kg;
w8 = 1560 kg;
w9 = 1643 kg;
w10 = 1747 kg;
w11 = 1867 kg;
w12 = 2076 kg.

All values are relative to a value one for the lowest risk case, that faced by a driver of a car in the heaviest mass category crashing into a car in the lightest mass category. Note that the risk for the lowest risk case here is not the same as in Table 3. Data for all model year cars, and FARS 1975 through 1989.

Table 8. Driver Fatality Risks Computed Using Eqn 7 with the Parameters for Cars of All Model Years in Eqns 21-23

Car i ↓ \ Car j →	w1*	w2	w3	w4	w5	w6	w7	w8	w9	w10	w11	w12
w1	$\boxed{13.2}$	15.3	16.9	17.8	18.6	19.1	19.3	19.5	19.6	19.7	19.7	19.8
w2	9.38	$\boxed{11.2}$	12.8	13.8	14.7	15.4	15.7	16.1	16.3	16.5	16.6	16.8
w3	6.80	8.33	$\boxed{9.73}$	10.7	11.7	12.4	12.8	13.2	13.6	13.9	14.2	14.4
w4	5.39	6.69	7.93	$\boxed{8.81}$	9.74	10.5	10.9	11.4	11.8	12.2	12.5	12.9
w5	4.16	5.24	6.30	7.08	$\boxed{7.93}$	8.63	9.04	9.57	9.98	10.4	10.8	11.3
w6	3.33	4.24	5.15	5.83	6.60	$\boxed{7.26}$	7.64	8.17	8.58	9.03	9.46	10.0
w7	2.91	3.72	4.54	5.17	5.89	6.51	$\boxed{6.88}$	7.39	7.79	8.24	8.69	9.30
w8	2.41	3.10	3.81	4.36	5.00	5.56	5.91	$\boxed{6.39}$	6.77	7.22	7.67	8.31
w9	2.06	2.66	3.29	3.78	4.36	4.87	5.19	5.64	$\boxed{6.01}$	6.44	6.89	7.54
w10	1.71	2.22	2.76	3.19	3.69	4.15	4.44	4.85	5.20	$\boxed{5.60}$	6.03	6.68
w11	1.39	1.82	2.27	2.64	3.08	3.48	3.73	4.10	4.41	4.78	$\boxed{5.19}$	5.82
w12	$\boxed{1}$	1.31	1.66	1.93	2.27	2.59	2.79	3.09	3.35	3.66	4.01	$\boxed{4.59}$

* The average masses of the 12 mass categories are:

w1 = 834 kg;
w2 = 960 kg;
w3 = 1085 kg;
w4 = 1181 kg;
w5 = 1294 kg;
w6 = 1397 kg;
w7 = 1463 kg;
w8 = 1560 kg;
w9 = 1643 kg;
w10 = 1747 kg;
w11 = 1867 kg;
w12 = 2076 kg.

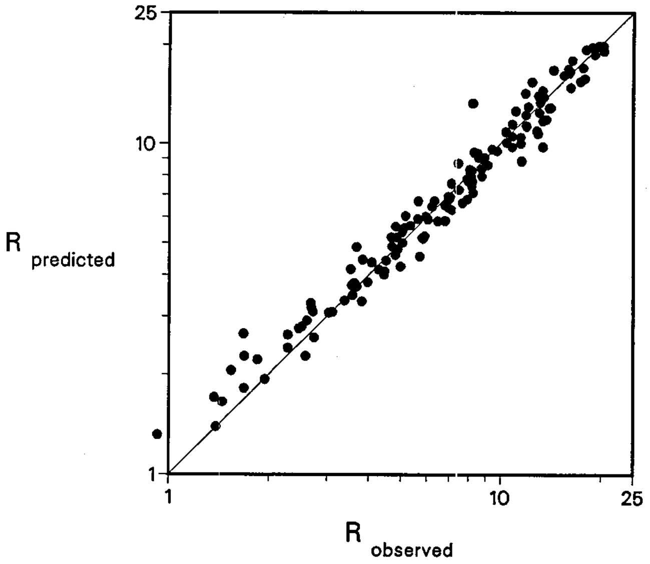


Figure 4. Predicted Driver Fatality Risks (Table 8) Versus Values Estimated from Fatality Ratios (Table 7) for Cars of All Model Years Combined

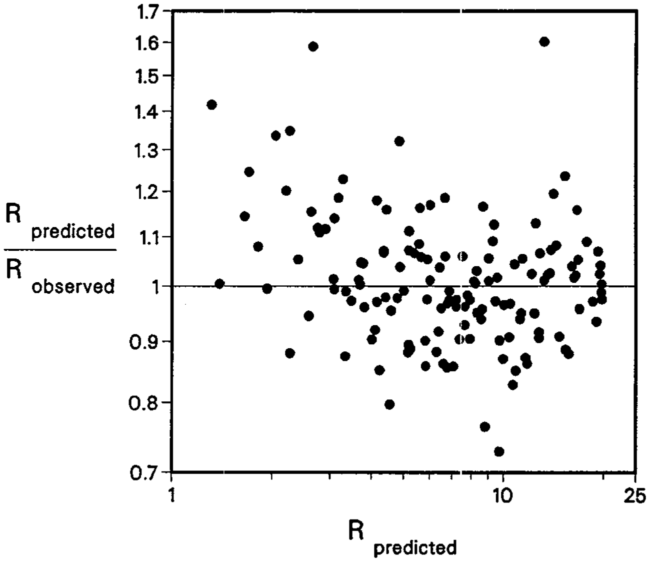
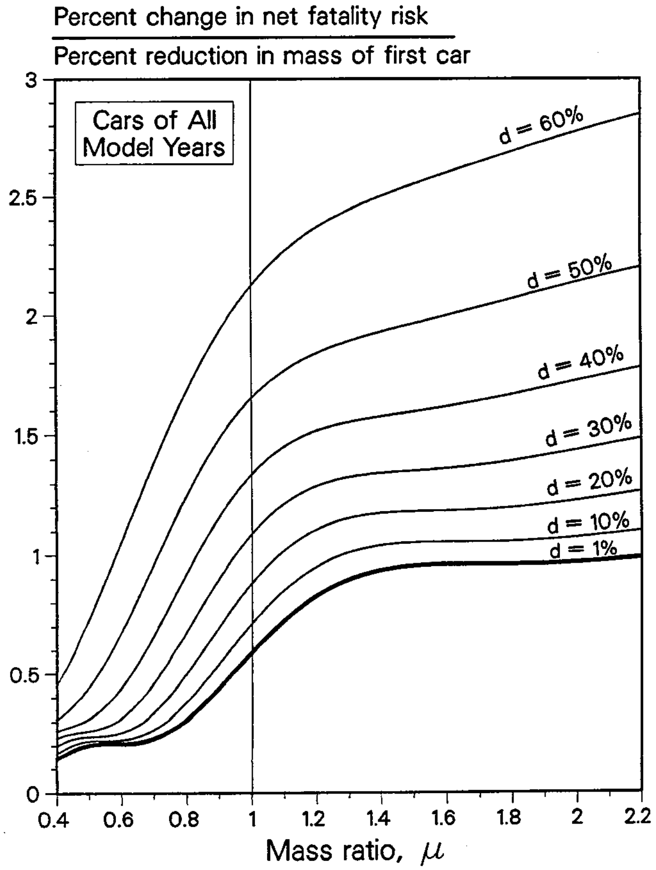


Figure 5. Predicted Driver Fatality Risks (Table 8) Relative to Values Estimated from Fatality Ratios (Table 7) Versus the Predicted Value for Cars of All Model Years Combined

The main difference between these parameters and eqns 10-12 for MY ≥ 1980 cars is the larger value of V. Substituting this into eqn 13 gives that the driver fatality risk for two 900 kg cars crash into each other is 2.2 times the value for two 1800 kg cars crashing into each other, compared to an earlier estimate also equal to 2.2. (Earlier work, including a different analytical fit to two-car crash data by Joksch [1983], is summarized by Evans [1991, p. 64-78]). Eqn 14 estimates this same 2.2 factor for the ratio of fatality risk in a 900 kg car crashing into a car of infinite mass compared to an 1800 kg car crashing into a car of infinite mass. This may be compared to a ratio of 2.4 between the risk in a 900 kg car in a single-vehicle crash to the risk in an 1800 kg car in single-vehicle crashes.

Figure 6 shows that for the case of all model year cars, a driver transferring from a car of any mass to a car of mass lower by any amount always generates an increase in net fatality risk. This applies to "average" cars from the distribution on which the analysis is based.



The curves are computed using eqn 18 with parameters for cars of all model years combined.

Figure 6. How Net Driver Fatality Risk Changes When a Driver in a Subject Car Transfers to a Car Lighter by d% Versus the Ratio, μ, of the Mass of the Other Car to the Original Mass of the Subject Car

Why is the mass effect less of the newer model year cars?

Some preliminary analysis were performed to attempt to understand better why the results for MY ≥ 1980 cars are so different from those for all cars. While it is not possible to perform the entire analysis in narrower segments of model year than those used, the relationship between fatality risk and mass ratio was examined in finer detail with the results shown below:

Average MY	Risk in 900 kg car / Risk in 1800 kg car
1973	10
1974	12
1975	17
1976	16
1977	13
1978	12
1979	11
1980	9
1981	8
1982	7
1983	6
1984	5
1985	6
1986	7
1987	7
1988	11
1989	12

The interpretation is as follows. The entry for 1980 (say) was derived by considering all crashes involving MY 1980, as well as MY 1979 and MY 1981 cars crashing into any other car in these same three model year categories, centered at MY 1980. These crashes were used to determine the relationship between relative driver fatality risk and mass ratio (eqn 5 of Evans and Frick [1991a]). Substituting mass ratio (μ) = 2 gives the values shown for the driver fatality risk in a 900 kg car compared to in an 1800 kg car when these cars crash into each other.

What appears to be happening is that the strength of the mass effect declined for cars built in the mid-1980s, reaching a low round about MY 1984 (recall that for the MY ≥ 1980 analysis, the average model year was 1983.4, and for the all MY analysis, 1976.2). The decline in the strength of the mass effect for the early 1980s models may be because smaller cars in that period were more likely to have undergone more substantial redesign than larger cars. Thus crashes between small and large cars did not only involve differences in mass, which provided increased protection to occupants in heavier cars, but differences in extent of redesign, which increased the protection of occupants in the more redesigned lighter cars. As larger cars were later subject to more redesign, such differential design differences would have diminished, so that mass again became the more exclusive factor, leading to the relationship with mass becoming more like what it was for the earlier cars. If this tentative interpretation is correct, the conclusions based on the MY ≥ 1980 cars may underestimate the strength of car-mass effects in future fleets.

Discussion

Is it mass, or some correlate of mass, such as size?

All the relationships in this paper have been in terms of mass. Yet mass is strongly correlated with other characteristics of a car, especially its size. We examined two crash types in which mass, as such, should not play an important role. These are crashes between cars of similar mass, and cars crashing into other cars of essentially infinite mass. For both crash types we find higher driver fatality risks in lighter cars. In the most simple dynamical model of these crashes, mass does not affect any vehicle trajectory. Thus any effect dependent on mass likely reflects some other property of the vehicle, such as its size.

A further indication that mass is not the physical factor influencing risk in these two crash types is that newer cars exhibit a smaller mass dependence than do older cars. (Compare eqns 13 and 14 with the values of V given by eqns 10 and 21). In contrast, the much larger differences in fatality risk that occur when cars of dissimilar mass crash into each other appears intrinsically related to mass, and to the differences in speed change required by Newton's laws of motion.

The vehicle factor producing the correlations with mass in the two crash types for which mass should not play a major role is likely to be vehicle size. Increased vehicle size makes more crush space available to manage energy, and more space in which to ride down the crash. However, recent studies [Evans and Frick 1991b] find that mass is substantially more important than size in determining outcome. When cars of the same wheelbase but different mass crashed into each other, the driver in the lighter car was more likely to be killed than was the driver in the heavier car. When cars of similar mass but different wheelbase crashed into each other, any effect due to differences in wheelbase was too small to be detected by the same method that demonstrated clear effects dependent on car mass.

Can lighter smaller cars be made as safe as larger heavier cars?

Vehicle mass and vehicle size each influence safety in crashes in different ways. Their influences are important in single- and in two-car crashes. In a crash into an immovable infinitely hard barrier, mass does not affect vehicle dynamics, and should therefore not much affect outcome, whereas increased size can be used to make available more space for energy management and ride down. However, most struck objects are not like barriers, but instead may bend, distort, break or move. The extent to which they do so reduces the striking vehicle's speed change and consequent forces on occupants. The greater the mass of the vehicle, the less are these potentially injury producing forces.

Occupant protection devices can improve safety for smaller cars, but if applied also to larger cars will likewise improve safety. Specific information is available for the case of safety belts. Three studies [Evans 1985; Evans and Frick 1986;1991a], each using different methods and independent data all find that lap/shoulder belts provide an approximately equal reduction (of about 42%) in driver fatality risk, independent of the size of the car Because the base risk is larger for the smaller car, the absolute benefit of belt wearing is greater in the smaller car, but the studies find no difference in the proportionate reduction.

When averaged over either single-vehicle or over two-vehicle crashes the following generalizations appear to be beyond reasonable dispute:

- If all other factors (including size) are the same, the heavier the vehicle, the lower the occupants' risk in a crash.
- If all other factors (including mass) are the same, the larger the vehicle, the lower the occupants' risk in a crash.

In the above, all other factors being the same includes the assumption that stiffness scales with mass.

Relation to fuel economy standards (CAFE)

Increasing car mass increases fuel use as a consequence of increased rolling resistance and, during acceleration, increased inertial forces. Increasing car size increases fuel use because of increased aerodynamic drag, but this effect tends to be smaller than that due to mass. Motivated by a desire to reduce personal fuel use, many drivers have transferred to lighter, smaller cars. Corporate Average Fuel Economy (CAFE) standards have been adopted with the goal of reducing fuel use at the national level. Following these changes, the average mass of cars in the US car population declined.

Many previous studies, especially the recent one by Evans and Frick [199la], find that when other factors are equal, a driver transferring to a lighter car incurs an increased risk of being killed in a crash. The present study shows that when all cars in a fleet become lighter, overall system fatality risk from two-car crashes increases. The equation derived by Klein, Hertz, and Borener [1991] from state injury data leads to the same conclusion. A fleet of identical lighter cars is less safe than a fleet of identical heavier cars.

Changes that reduce fuel use may increase or decrease safety. For example, the 55 mph speed limit, introduced to save fuel, also increased safety. Indeed, its effect on safety was larger than that on fuel use because, approximately, fuel consumption per unit distance of travel is proportional to speed, whereas fatality risk is proportional to speed to the power four [Evans 1991, p. 154]. Many factors in addition to car mass and size influence safety, and it is clearly possible for a lighter car to be safer than a heavier one if the cars differ in other features important for safety. However, if the same safety features are incorporated into each of the cars, the larger heavier one will always be safer.

Keeping mass constant, and increasing car size by, for example, using lower density construction materials, will reduce occupant risk at only a modest fueluse penalty. However, in a fleet consisting exclusively of cars made from lower density material, the lighter cars in the fleet would still be at greater risk than the heavier cars. If the lower density material were instead used to reduce the mass of all cars while keeping their sizes fixed, this would reduce fuel with no obvious influence on risk in two-car crashes. Risk could increase or decrease depending on such engineering details as material stiffness. Although there is no simple physical reason why risk in two-car crashes should change if cars became lighter without changing size, there are compelling physical reasons why single-car crash risk would increase. Struck objects may move, dent, or break, and their tendency to do so increase with increasing mass of the striking vehicle, thereby providing increased protection to occupants as mass increases. It appears that whatever change is applied uniformly to all cars will always leave the driver of a lighter car at greater net risk than the driver of a heavier car when other factors are the same. A similar comment applies for car size, and both comments apply to fleets of cars as well as to individual drivers.

The finding that an individual transferring to a lighter car increases that individual's fatality risk, or that society choosing lighter cars leads to increased net traffic fatalities, does not determine what mass vehicle any individual or society should choose. Such choices involve the balancing of many factors in addition to safety. When all other factors are the same, heavier or larger vehicles offer intrinsically more occupant protection in ways that cannot be negated by vehicle design changes applied to all vehicles, or by material substitutions in all vehicles. The relationships between mass/size and both safety and fuel consumption is perhaps analogous to the relationship between safety and speed. There can be little doubt that an individual driver increases risk by travelling faster, and that society increases net societal risk by choosing higher rather than lower speed limits. It follows that the safest traffic system consists of exclusively gargantuan massive vehicles moving at near zero speeds. Such a system offers little to fulfill the primary goals of transportation, even if it greatly diminishes the undesired by-product of losses from traffic crashes. Any individual or societal decision on such questions should be based on balancing of the known effects.

Conclusions

- An analytical function fitted to fatality data shows that net driver fatality risk (or net fatalities) for a car population is increased if:
  - Any car in the population is replaced by a lighter one
  - One population of identical cars is replaced by another population of lighter identical cars
  - The car population becomes of uniform mass while maintaining the average mass constant
- The safety disadvantage of lighter and smaller cars is intrinsic—it cannot be negated by design changes if these are also available to larger heavier cars because, when all other factors are equal, more mass and more space can be used to provide increased safety.
- Fuel economy and safety (like higher speed limits and safety) are intrinsically in conflict; individual and national choices require a balancing of advantages.

Acknowledgments

Valuable inputs from James A. Bennett, Daniel P. Faust, Robert A. Frosch, Dana B. Kamerud, Harold J. Mertz, Jr., and David C. Viano contributed greatly to this project and are gratefully acknowledged. Helpful discussions with Robert M. Goor and Gary C. McDonald regarding the possibility of analytically determining the extrema of eqn 9 are gratefully acknowledged.

References

Joksch, H.C. Light-weight car safety analysis, phase II, part II: occupant fatality and injury risk in relation to car weight. Performed under contract CEM-8102C1160, Center for the Environment and Man, Hartford, CT; June 1983.

Evans, L. Driver fatalities versus car mass using a new exposure approach. Accident Analysis and Prevention 16:19-36; 1984.

Evans, L. Fatality risk for belted drivers versus car mass. Accident Analysis and Prevention 17:251-271; 1985.

Evans, L. *Traffic Safety and the Driver*. New York, NY: Van Nostrand Reinhold; 1991.

Evans, L.; Frick, M.C. Safety belt effectiveness in preventing driver fatalities versus a number of vehicular, accident, roadway and environmental factors. Journal of Safety Research 17:143-154; 1986.

Evans, L.; Frick, M.C. Mass ratio and relative driver fatality risk in two-vehicle crashes. General Motors Research Publication GMR-7419, 29 July 1991a.

Evans, L.; Frick, M.C. Car size or car mass—which has greater influence on fatality risk?, General Motors Research Publication GMR-7462, 30 August 1991b.

Car size or car mass—which has greater influence on fatality risk?, Leonard Evans and Michael C. Frick, General Motors Research Publication GMR-7462, 30 August 1991.

Evans, L.; Wasielewski, P.F. Serious or fatal driver injury rate versus car mass in head-on crashes between cars of similar mass. Accident Analysis and Prevention 19:119-131; 1987.

Klein, T.M.; Hertz, E.; Borener, S. A collection of recent analyses of vehicle weight and safety. Washington, DC: National Highway Traffic Safety Administration, report DOT HS-807767, May 1991.

National Highway Traffic Safety Administration. Fatal Accident Reporting System 1989. Document DOT HS 807 693. Washington, DC; March 1991.

S1-O-11

A Collection of Recent Analyses of Vehicle Weight and Safety

Terry M. Klein
Ellen Hertz, Ph.D.
Sherry Borener, Ph.D.
National Highway Traffic Safety
Administration

Abstract

This report documents the results of an analysis of the effect of car weight on safety. The analysis encompassed a number of crash modes including fatality risk in single-vehicle nonrollover crashes, serious injury and fatality risk in car-to-car crashes, and serious injury risk in collisions of cars with medium/heavy trucks. This work was undertaken as part of an effort to study the long-term effects of the major reductions in passenger car weight of the 1970's and 1980's.

Data from the State of Texas for accident years 1984 through 1987 and the State of Maryland for accident years 1984 through 1988 were used. The analysis employed logistic regression methods to model the (conditional) risk of serious injury as a function of a number of accident-level and person-level covariates.

The findings of these analyses are as follows:

- In car-to-car crashes, the change in injury rate associated with the reduction in vehicle fleet weight from 3,700 to 2,700 pounds has been estimated from the Texas data to be an additional 14 percent. The Maryland data produced an estimated increase in the serious driver injury rate of 4 percent for the shift from a 3,700 to a 2,700 pound average fleet weight. The impact on fatal injuries was not statistically significant, possibly due to a paucity of state data for fatally injured drivers.
- In collisions involving cars and medium/heavy trucks, the change in the serious injury rate associated with the reduction in vehicle fleet weight from 3,700 to 2,700 pounds has been estimated from the Texas data to be an increase of approximately 11 percent.
- For single-vehicle nonrollover crashes, the change in fatal injury rate associated with the reduction in vehicle fleet weight from 3,700 to 2,700 pounds has been estimated from the Texas data to be an increase of approximately 10 percent.

Background

The objective of this effort was to study the relationship between passenger car weight and safety. Two measures of safety were used for these analyses: the rate of driver fatal or incapacitating injury (K+A) per driver involved, and the rate of fatal injury per driver involved (using the KABC injury coding scheme, K = fatal injury, A = incapacitating injury, B = non-incapacitating injury, and C = possible injury). In the remainder of this report the rate of fatal/incapacitating injury will be referred to as the serious injury rate, using "serious" in the general sense (rather than referring to the Abbreviated Injury Scale (AIS)). Driver injury rate was selected for the metric because information is routinely available for all drivers involved in crashes, while information for other car occupants (e.g., right-front passengers) may be available only if the occupant was injured. The relationship between car weight and safety was studied accounting for the effects of other background variables, such as driver age, posted speed limit, collision mode (left, right, rear, head-on), etc., in order to avoid their effects confounding the conclusions regarding car weight and safety.

The National Highway Traffic Safety Administration maintains a collection of state accident data files. Two states were used in this analysis: Maryland (1984-88) and Texas (1984-87; data for 1988 were not yet available). These accident data tapes were supplemented by data obtained from R. L. Polk and the Fatal Accident Reporting System on vehicle curb weight.

Methodology

The dependent variable was defined as a dichotomous outcome (0,1) indicating whether the specific driver received a serious injury in the crash. The initial independent variables used included the weight of the driver's vehicle, the weight of the other vehicle in the crash, driver age, driver sex, safety belt use, and posted speed limit or a surrogate thereof. The data used for model estimation were always restricted to those cases for which the predictor variables all had known values.

Since the dependent variable was dichotomous, the analytical method of choice was logistic regression. This methodology was selected because it presents the (conditional) probability of an outcome as a function of several independent variables, allowing the analyst to construct a model that adjusts for covariate factors, while measuring the effect of weight.

Through the use of a logit transformation [$\text{logit}(p) = \ln(p/(1-p))$], the logistic regression model [$p(x) = (\exp(a+bx))/(1+\exp(a+bx))$] has many of the desirable properties of a linear regression model; that is, the logit is linear in its parameters, it may be continuous, and may take any value (rather than being confined to the range (0,1)).

The Statistical Analysis System (SAS) was used to conduct the analysis; specifically, the program PROC LOGIST was employed. The LOGIST program is not part of the normally available SAS procedures, but is supplied as a product of the SAS User Group set of procedures. The output of PROC LOGIST includes, among other diagnostics, a table showing the estimate of the intercept and predictor variable coefficients, their standard errors, and measures of the variables' statistical significance. High values of a variable's chi-square statistic are associated with high statistical significance of the estimated predictor variable coefficients. Variables are considered to be statistically significant if P is less than a pre-selected value of alpha, often 0.05, as used in the current context.

In the logistic regression model, the log odds ratio of the outcome (that is, the logit) is a linear combination of the independent variables, i.e., the independent variable's coefficient represents the change in the log odds ratio of the outcome (K+A injury) as a result of a unit change in the independent variable.

For example, for dichotomous (0,1) predictor variables such as driver sex, the coefficient represents how much more likely (or unlikely) it is for a K+A injury to occur to males than for a K+A injury to occur to females, all other factors being held constant. On the other hand, for a continuous independent variable such as vehicle weight, the coefficient represents the change in the log odds ratio for an increase of one pound in weight. To provide a useful interpretation for continuous scaled variables such as vehicle weight, discussion of the changes associated with this variable can be scaled to units of, for example, one hundred pounds. This is a simple linear function of the initial coefficients appearing in the output tables.

In determining an overall approach to the modeling, it was decided initially to develop models for each individual crash mode; that is, cars with left-side damage, cars with right-side damage, those with rear-end damage, those with frontal damage (the "striking" vehicle in left-side, right-side, and rear-end collisions) and the head-on crashes (separately from the frontal-damaged vehicles due to the unique forces resulting from the head-on crash mode). This was done to accommodate the intuition that there should be differential likelihoods of K+A injury to drivers in the different modes. However, due to small sample sizes, or when indicated by model results (such as in the presence of homogeneous estimated coefficients of weight across crash modes), all two-car crash cases were combined into a single larger analytical model, with the impact type accounted for by additional independent indicator and interaction variables.

Analysis of Car-to-Car Crashes

In this analysis, the data were restricted to cars (passenger cars, station wagons, and police vehicles) involved in two-car crashes in which the first harmful event was a collision with another passenger car, and for which curb weight could be determined either by use of the vehicle identification number (VIN) or make/model code.

Description of the Injury Analyses by State

Texas

The data were classified by crash mode using the variables VEH_DAM and VEH_MOV. VEH_DAM is coded according to the National Safety Council Vehicle Damage Scale and contains the location of the damage as well as the severity. VEH_MOV was used primarily to differentiate between head-ons and other striking vehicles with frontal impacts (strikers). CITY, indicating when RD_CLASS=5, is used as an indication of speed, differentiating generally between urban and rural roads, and thus, may also include some effects of roadway geometry. Each of these analyses addressed the following independent variables:

WEIGHT	vehicle weight,
OTHER_WT . .	the weight of the other vehicle involved in the crash,
DR_AGE	the age of the driver,
MALE	an indicator variable for driver sex,
VEH_AGE . . .	the age of the vehicle,
BELTED	an indicator variable for belt use, determined by RES_DEV,
CITY	an indicator variable for RD_CLASS=5 (this was used as a surrogate for posted speed limit, since this is not coded on the Texas police accident report), and
PCIMPCT	indicator variable for passenger compartment impact determined by VEH_DAM (applicable to right-and left-side impacts).

The dependent variable was INJURY, defined by SEVERE = 1 or 4, indicating whether or not the driver sustained a serious injury. In addition, since the Texas file does not contain VIN, but contains a make/model code that could be merged with FARS to obtain vehicle weights, there was no need to restrict the analysis to cars of model year 1981 and later, as was necessary in Maryland. Thus, all model years were included for which weight could be obtained.

A summary of the coefficients of WEIGHT and OTHER_WT from these individual crash mode analyses is presented in Table 1.

Table 1. Weight Coefficients Resulting from Initial Model Estimation (Texas)

Impact mode	BETA for WEIGHT	BETA for OTHER WT
Head-on	-.00036236	.00021315
Striking	-.00050480	.00026335
Left	-.00048558	.00028987
Right	-.00052093	.00032001
Rear	-.00019119 (*)	.00029249

(*) Not statistically significant at alpha=.05, (P=.1518).

Because of the close agreement between the coefficients of WEIGHT and OTHER_WT across crash modes (with the exception of WEIGHT for rear), a logistic regression was performed on all the Texas data combining the various crash modes and representing them by indicator variables. The variables LEFT, RIGHT, HEADONS and REAR were used, with STRIKING as the reference group.

The coefficient of the belt use variable, BELTED, was highly statistically significant. Inspection of the dichotomous variable revealed an overall mean of over 0.79, implying a 79 percent safety belt usage rate for drivers in crashes between the years 1984-1987. This rate appears to be higher than what one might expect, since observational surveys in the state indicate that before the mandatory safety belt usage law became effective in September 1985, usage was 13 percent; after the law was implemented, usage varied between 54 and 64 percent, and usage among accident-involved drivers tends to be lower than that in the general driving population. Thus, a new model was estimated using the same variables as before with the exception of the BELTED variable. Since none of the coefficients of the other variables changed very much from the earlier crash mode models, (except for a decrease in the intercept), this last model was adopted for further use. The resulting estimated coefficients, standard errors and chi-square values are displayed in Table 2.

While WEIGHT and OTHER_WT are significant at a level of alpha less than 0.0001, it can be seen from the CHI-SQUARE column that the two vehicle weight variables are not the most significant factors in determining the probability of a serious injury, as compared to the variables HEADONS, CITY and PCIMPCT.

To evaluate how well the model fits the data, the following procedure was employed: The predicted probability of serious driver injury was calculated for each driver using the BETA coefficients. On the basis of these predicted probabilities, the data were organized into deciles of risk (probability of K+A injury): Group 1 consists of the lowest tenth percentile,....Group 10 is the highest tenth percentile. In each of these ten groups, the predicted and actual number of injuries werecomputed. The results are displayed in Table 3.

Table 3. Actual vs. Predicted K+A Injuries for Deciles of Risk (Texas)

Decile	1	2	3	4	5	6	7	8	9	10
Actual	42	64	77	107	97	133	147	183	215	569
Predicted	37	56	71	87	105	128	157	200	276	553

The goodness-of-fit of a particular model was assessed along the lines proposed by Hosmer and Lemeshow (*Applied Logistic Regression,* John Wiley & Sons, 1989), forming groups of observations based on the values of the estimated probabilities of a driver K+A injury. The groups were formed based on deciles (lOth percentiles), resulting in a test statistic with distribution closer to the chi-square distribution with g-2 (the number of groups minus two) degrees of freedom, than is possible with groups based on fixed cutpoints. The ten groups formed based on the deciles are often referred to as the "deciles of risk," a term borrowed from the health sciences.

The goodness-of-fit statistic is distributed approximately chi-square on eight degrees of freedom when the predicted probabilities are correct. Clearly, each cell of the implied 2-by-10 table (the rows are yes/no—whether or not the driver received a K+A injury; the columns are the deciles) presented in Table 3 has sufficient cell size (greater than 5). The resulting statistic has a value of 12.8811, less than the critical value of 15.51 for alpha = 0.05 with 8 degrees of freedom. Thus, the model fits the data sufficiently well.

It should be noted that unfortunately, there is no directly analogous test statistic to the linear regression R-squared, to describe the fit of the logistic regression model.

Table 2. Results of Final Model Estimation Using WEIGHT and OTHER_WT (Texas)

VARIABLE	BETA	STD ERROR	CHI-SOUARE	P
INTERCEPT	-4.13099793	0.17616148	549.91	0.0000
HEADON	1.38896833	0.07080320	384.84	0.0000
CITY	-0.72298186	0.05198303	193.43	0.0000
PCIMPCT	0.98958098	0.07394381	179.10	0.0000
WEIGHT	-0.00043636	0.00004225	106.66	0.0000
DR_AGE	0.01176224	0.00153882	58.43	0.0000
REAR	-0.85190000	0.12755110	44.61	0.0000
MALE	-0.31794031	0.05087432	39.06	0.0000
OTHER_WT	0.00024772	0.00004014	38.08	0.0000
LEFT	0.26278595	0.07394426	12.63	0.0004
RIGHT	-0.29230134	0.08337704	12.29	0.0005

During model years 1970-1982, passenger cars became substantially smaller in the United States. The median curb weight of cars decreased by about 1,000 pounds, the wheelbase by about ten inches, and the trackwidth by two or three inches. Since model year 1982, car weight has remained rather stable. The weight reductions of the 1970-1982 period were the result of a market shift from full-sized cars to subcompact and imported cars, and, after 1975, downsizing within many domestic car lines.

What would be the effect on the expected number of injuries as the average weight of the fleet changed from 3,700 to 2,700 pounds?

In order to estimate the effects of downsizing, an assumption was made regarding the means by which vehicle fleet weights changed. It was assumed that the weight of cars would be reduced proportionally; that is, by a constant percentage rather than by a fixed amount. Thus, for example, two cars weighing 5,000 pounds and 3,000 pounds would lose 500 and 300 pounds, respectively, under an assumption of 10 percent downsizing. This seemed a more reasonable assumption compared to one which subtracted 400 pounds from each car, but achieved the same overall weight reduction.

Under this assumption, a last model was estimated which permits one to focus on this assumed method of downsizing and produce estimated effects with an associated confidence interval. This last model involves the use of the driver's vehicle's weight and the ratio of the vehicle's weight to the other vehicle's weight. These two weight variables (WEIGHT and RATIO_WT) are mathematically equivalent to the information provided by the two individual vehicle weights (WEIGHT and OTHER_WT). The advantage of this approach is that by assuming proportional downsizing, only one variable (WEIGHT) changes in the hypothetical scenarios while the ratio of the two vehicle weights (RATIO_WT) remains constant before vs. after the downsizing, facilitating the computation of estimated effects with their associated standard errors.

The results of estimating this model are presented in Table 4. As can be seen in Table 4, the coefficient of RATIO_WT is statistically significant, indicating a strong relationship between the ratio of the car weights in two-car crashes and the likelihood of driver serious injury; that is, as the ratio of the weights of person A's car to person B's car increases, there is a decreased likelihood that person A will suffer a serious injury. In this analysis, the coefficient of WEIGHT is statistically significant, indicating that, given the knowledge of the ratio of the two car weights, the absolute weight of person A's car is a significant factor in determining the likelihood of serious injury to person A in a two-car crash; the negative coefficient of WEIGHT indicates that as the weight of person A's car decreases, the driver's likelihood of serious injury increases.

The coefficients in Table 4 were used to estimate the effect on the expected number of injuries as the average weight of the fleet changed from 3,700 to 2,700 pounds. This was accomplished as follows. Recall that in the model, the logit(p) is a linear function of the independent variables, with the estimates of the coefficients given in Table 4. If the values of the independent variables other than WEIGHT are held constant, the logit(p) becomes a linear function of WEIGHT. Selecting those values (not necessarily population averages) that make wbar (the real average WEIGHT from the data) correspond to pbar (the real proportion of serious injuries from the data), results in the function Q(WEIGHT) = logit(pbar) -0.00013549 * (WEIGHT-(wbar)). Q is a function of WEIGHT for which the derivative is the coefficient of WEIGHT in Table 4 and such that Q(wbar)=logit(pbar).

Applying Q at WEIGHT=2,700 (and 3,700) and computing the antilogit results in the predicted probability of serious injury in an otherwise "typical" car/accident under the assumption of the average fleet weight of 2,700 (and 3,700) pounds. The two values are compared to compute the estimated percentage change in the likelihood of injury for a fleet average of 2,700 pounds vs. 3,700 pounds. Upper and lower confidence bounds are obtained by substituting bounds for the coefficient of WEIGHT using the standard error presented in Table 4.

Table 4. Results of Final Model Estimation Using WEIGHT and RATIO_WT (Texas)

VARIABLE	BETA	STD ERROR	CHI-SOUARE	P
INTERCEPT	-3.10601898	0.05785469	2882.25	0.0000
HEADON	1.39523779	0.03186439	1917.28	0.0000
CITY	-0.72872027	0.02369631	945.71	0.0000
PCIMPCT	0.98333735	0.03458127	808.5	0.0000
RATIO_WT	-1.01634198	0.05312060	66.06	0.0000
REAR	-0.77223357	0.05796910	177.46	0.0000
DR_AGE	0.00718748	0.00069573	106.73	0.0000
MALE	-0.19367537	0.02279700	72.18	0.0000
RIGHT	-0.28439361	0.03827928	55.20	0.0000
LEFT	0.23720049	0.03387546	49.03	0.0000
WEIGHT	-0.00013549	0.00002426	31.19	0.0000

Assuming all other factors remain constant, a reduction in the average vehicle weight from 3,700 pounds to 2,700 pounds would result in an estimated increase of 14.3 percent in the number of driver K+A injuries. The 95 percent confidence interval ranges from an increase of 9.1 percent to an increase of 19.8 percent. It should be kept in mind that this effect represents the NET change accrued by both drivers in the crash; the actual changes that occurred individually for each driver associated with the changes for each car are larger in magnitude. That is, while one driver would accrue a benefit if the other driver's car were lighter, the other driver would experience a liability (increased likelihood of injury) larger than the first driver's benefit, resulting from the smaller weight of his car. The model predicts a net liability from the decrease in weight of the car since the coefficient for WEIGHT is greater in magnitude (absolute value) and with opposite sign from the coefficient for OTHER_WT, as evidenced by the model results in Table 3 and the negative coefficient of WEIGHT in Table 4.

Maryland

Vehicles were categorized into crash modes using the variables point of impact (PT_IMPCT) and collision type (COL_TYPE) to distinguish the role of the car in the crash as head-on (both cars with frontal damage), striking (frontal damage in other than a head-on crash), left-side damaged, right-side damaged or rear-end damaged. PT_IMPCT is a vehicle-level variable that indicates what part of the car's body was contacted; COL_TYPE is an accident-level variable that describes the type of crash; specifically, it generically identifies the pre-crash paths of the two vehicles that collided. COL_TYPE was used in the two-car analysis to identify two-car crashes, eliminate sideswipes, and differentiate head-on crashes from other crashes in which the front portion of one vehicle hit another vehicle (referred to hereinafter as "striking" vehicles). The first analyses considered these five crash modes individually.

In each of the individual crash mode models, the independent variables employed as candidates were:

WEIGHT ..... vehicle weight,
OTHER_WT .. the weight of the other vehicle involved in the crash,
DR_AGE ..... the age of the driver,
MALE ...... an indicator variable for driver sex,
VEH_AGE ... the age of the vehicle in years,
TWO_DR .... an indicator variable for two-door vehicles determined by the VIN-derived body type (VINA_BD)
WET .... an indicator variable for wet road surface,
BELTED ..... an indicator variable for belt use determined by DR_SAFE,
SPD_LIM .... speed limit on a scale of 2 to 8 (2 corresponds to up to 25 mph,..,8 corresponds to 55 mph), and
PCIMPCT .... an indicator variable denoting a passenger compartment impact (i.e., between the axles) determined by PT_IMPCT.

The dependent variable was INJURY, an indicator variable for a driver serious injury (K+A) determined by the variable DR_INJ = 4 or 5. It is the absence or presence of such a K+A injury for each driver, associated with that driver's particular set of driver, vehicle, and environmental factors, that forms the basis for estimating the effect of these factors on the probability of driver injury.

In all of the initial five crash mode models, the coefficients of TWO_DR, VEH_AGE and WET were never statistically significant and were dropped from further analysis. In each of the five crash modes, the coefficient of WEIGHT was negative (denoting an inverse relationship between the driver's vehicle's weight and injury probability), and the coefficient of OTHER_WT was positive (denoting a direct relationship between driver injury rate and the weight of the other vehicle in the crash).

In these five crash mode analyses, the levels of statistical significance for the variables WEIGHT and OTHER_WT appeared to be related to the sample sizes. For example, there were over 11,000 vehicles in the striking category (624 drivers of which received a K+A injury) and in this group all variables in the model that were significant at level alpha = 0.05 were also significant at alpha = 0.01. In the head-on category, with about 1,700 vehicles and 254 K+A driver injuries, WEIGHT was not significant and OTHER_WT was significant at level alpha = 0.05 but not at alpha = 0.01. A summary of the samples sizes by crash mode is displayed at Table 5.

Table 5. Sample Sizes for Various Crash Modes (Maryland)

Crash Mode	K+A Injury	No Injury	Total	Pr(K+A)
HEADON	254	1,455	1,709	0.149
STRIKING	624	10,431	11,055	0.056
LEFT	436	5,941	6,377	0.068
RIGHT	306	5,343	5,649	0.054
REAR	289	4,855	5,144	0.056

To make use of a larger database, all crash modes were combined with STRIKING as the baseline, or reference group, and HEADON, LEFT, RIGHT and REAR as indicator variables (the five nominal levels of the crash mode can be represented by four dichotomous variables). In this analysis, the modes HEADON and LEFT were statistically significant, while REAR and RIGHT were not, matching the similarity of the overall probabilities of K+A injury calculated in the rightmost column of Table 5.

Another analysis was performed using all the Maryland data with indicator variables only for the modes HEADON and LEFT, significant from the previous model estimation. In this analysis, interaction terms mode*WEIGHT and mode*OTHER_WT were included for the significant modes (HEADON and LEFT). Passenger compartment impact (PCIMPCT) and its interaction with WEIGHT and OTHER_WT were also included in this second combined Maryland analysis. None of the interaction terms were significant at the level 0.05; thus, the interaction terms were dropped from subsequent consideration.

A subsequent logistic regression model was estimated using the following independent variables: WEIGHT, OTHER_WT, PCIMPCT, SPD_ LIM, DR_AGE, MALE, BELTED, RIGHT, REAR, LEFT and HEADON. The variables that were significant were WEIGHT, OTHER_WT, HEADON, SPD_LIM, MALE, PCIMPCT, BELTED and RIGHT. This model appears to produce a reasonable fit. The coefficient of the belt use variable, BELTED, was highly statistically significant. However, inspection of the dichotomous variable revealed an overall mean of over 0.76, implying a 76 percent safety belt usage rate for drivers in crashes during the years 1984-1988. This rate appears to behigher than what one might expect, since observational surveys in the state indicate that before the mandatory safety belt usage law became effective in July 1986, usage in the general driving population was 28 percent; after the law was implemented, usage varied between 60 and 74 percent, and usage among accident-involved drivers tends to be lower than that in the general driving population. Thus, a new model was estimated using the same variables as before with the exception of the BELTED variable. Since the omission of BELTED resulted in very little change in any of the other coefficients except for a decrease in the intercept (a constant term relating to the overall injury likelihood), and because this model also produced a reasonable fit, this last model was adopted for further use. The results are displayed in Table 6.

While WEIGHT and OTHER_WT are significant at a level alpha less than 0.0001, it can be seen from the CHI-SQUARE column that vehicle weights are not the most significant factors in determining the probability of a serious injury as compared to HEADON, SPD_LIM, and MALE.

The chi-square diagnostic statistic indicates that the model fits the data sufficiently well. It should also be remembered that neither weight nor the other car's weight was the most statistically significant predictor variable in the model, and that the fit of the model is a reflection of ALL of the variables employed therein.

From Table 6, the estimated coefficient for WEIGHT is negative and for OTHER_WT, the estimated coefficient is positive. This indicates that the likelihood of a serious driver injury in a two-car crash decreases with increasing vehicle weight, but increases with the increasing weight of the other vehicle. However, the harm of decreasing the weight of one's own vehicle is less than offset by the benefit of decreasing the weight of the other vehicle, as evidenced by the coefficients of WEIGHT and OTHER WT.

In order to estimate the effects of downsizing, a last model was estimated which permits one to focus on this assumed method of downsizing and produce estimated effects with an associated confidence interval. This last model involves the use of the driver's vehicle's weight and the ratio of the vehicle's weight to the other vehicle's weight, as was done in the Texas analysis. The results of estimating this model are presented in Table 7.

As can be seen in Table 7, the coefficient of RATIO_WT is statistically significant, indicating a strong relationship between the ratio of the car weights in two-car crashes and the likelihood of driver serious injury; that is, as the ratio of the weights of person A's car to person B's car increases, there is a decreased likelihood that person A will suffer a serious injury. In simpler terms, in car-to-car crashes, the driver of the lighter car faces a significantly greater risk of serious injury than does the driver of the heavier car. However, the coefficient of WEIGHT is not statistically significant,

Table 6. Results of Final Model Estimation Using WEIGHT and OTHER_WT (Maryland)

VARIABLE	BETA	STD ERROR	CHI-SOUARE	P
INTERCEPT	-3.15868444	0.17156814	338.95	0.0000
HEADON	1.19617502	0.07569392	249.73	0.0000
SPD_LIM	0.18845292	0.01232934	233.63	0.0000
MALE	-0.69666459	0.04949274	198.14	0.0000
PCIMPCT	0.71227758	0.07402425	92.59	0.0000
WEIGHT	-0.00027215	0.00004469	37.08	0.0000
OTHER_WT	0.00019035	0.00004115	21.40	0.0000
RIGHT	-0.02609507	0.00697340	13.00	0.0002

Table 7. Results of Final Model Estimation Using WEIGHT and RATIO_WT (Maryland)

VARIABLE	BETA	STD ERROR	CHI-SOUARE	P
INTERCEPT	2.64515627	0.12653093	437.03	0.0000
HEADON	1.27161193	0.07175126	314.09	0.0000
SPD_LIM	0.19696302	0.01188887	274.47	0.0000
MALE	-0.69616218	0.04767112	213.26	0.0000
PCIMPCT	0.71971128	0.07143688	101.50	0.0000
RATIO_WT	-0.60466966	0.11096896	29.69	0.0000
RIGHT	-0.25122848	0.06739234	13.19	0.0002
WEIGHT	-O.00004509	0.00005984	0.57	0.4512

indicating that, given the knowledge of the ratio of the two car weights, the absolute weight of person A's car is not a significant factor in determining the likelihood of serious injury to person A in a two-car crash.

The coefficients in Table 7 were used to estimate the effect on the expected number of injuries as the average weight of the fleet changed from 3,700 to 2,700 pounds. This was accomplished as was done for the Texas analysis.

Applying Q at WEIGHT=2,700 (and 3,700) and computing the antilogit results in the predicted probability of serious injury in an otherwise "typical" car/accident under the assumption of the average fleet weight of 2,700 (and 3,700) pounds. The two values are compared to compute the estimated percentage change in the likelihood of injury for a fleet average of 2,700 pounds vs. 3,700 pounds. Upper and lower confidence bounds are obtained by substituting bounds for the coefficient of WEIGHT using the standard error presented in Table 7.

Assuming all other factors remain constant, a reduction in the average vehicle weight from 3,700 pounds to 2,700 pounds would result in an estimated increase of 4.3 percent in the number of driver K+A injuries. The 95 percent confidence interval ranges from a decrease of 6.5 percent to an increase of 16.5 percent.

Description of Fatality Analysis

The analysis of the effect of car weight on fatality risk was conducted in the same manner as the previous analyses of injury risk. The number of fatalities that occurred in the State of Maryland during the period 1984-1988 in two-car crashes was too small for meaningful analysis. However, data for the State of Texas during the period 1984-1987 provided a sufficiently large sample size to attempt to estimate the regression model, with the proviso that crashes involving pre-1981 model year cars could be included in the analysis. This produced a dataset of 638,178 driver observations of which 533 were fatally injured.

In this analysis the coefficient of WEIGHT was not statistically significant. The small number of fatal injuries in this dataset (533 out of 638,178 involved drivers) likely precludes one from drawing any firm inferences on the effect of vehicle downsizing on fatal injury risk.

Analysis of Car-Medium/Heavy Truck Crashes

Only the State of Texas provided sufficient numbers of car-medium/heavy truck (gross vehicle weight rating (GVWR) greater than 10,000 pounds) crashes for analysis. As the Texas data did not contain the vehicle identification number (VIN) FARS data were used to estimate passenger car weights. The FARS weight is the average weight reported in FARS 1984 through 1989, for passenger cars of the same make, model and model year. The Texas logistic regression addressed the following independent variables:

WEIGHT	FARS weight,
DR_AGE	the age of the driver,
DR_SEX	an indicator variable for driver sex,
HEAD_ON ...	an indicator variable for head-on impact, and
LEFT	and indicator variable for left-side impact.

The dependent variable was INJURY, defined by SEVERE = 1 or 4, indicating whether or not the passenger car driver sustained a fatal or incapacitating injury. The analysis included 19,256 passenger car drivers involved, of which 898 received serious injury.

There are several reasons why the truck weight and the truck driver's injury were not incorporated into the model. First, the weight of the truck is not readily available since trucks generally are classified by their gross vehicle weight rating. Second, whether or not the vehicle was carrying cargo at the time of the crash is not always available on the accident files; the presence of cargo can significantly alter the weight characteristics of the truck. Third, the sheer size of the truck is likely to be equivalent to a passenger car colliding with a fixed object such as a barrier. The absence of the truck driver injury in the model is based upon the premise that the truck driver's injury likelihood is not very sensitive to changes in the weight of the passenger car, especially if the car collides with the trailer, which can be far removed from the truck cab.

The resulting estimated coefficients, standard errors and chi-square values are displayed in Table 8.

Note that while the coefficient of vehicle weight is statistically significant at the 0.05 level, it is not the most significant factor in predicting the likelihood of incapacitating injury.

What would be the effect on the expected number of injuries as the average weight of the fleet changed from 3,700 to 2,700 pounds? The coefficients in Table 8 were used to estimate the effect on the expected number of injuries as the average weight of the fleet changed from 3,700 to 2,700 pounds. This was accomplished in the same manner as previously.

Assuming all other factors remain constant, a reduction in the average vehicle weight from 3,700 pounds to 2,700 pounds would result in an estimated increase of 11.0 percent in the number of driver serious injuries in crashes between a car and a medium/heavy truck. The 95 percent confidence interval ranges from an increase of 0.5 percent to an increase of 22.7 percent.

Analysis of Fatal Single-Vehicle Nonrollover Crashes

Only the State of Texas provided sufficient numbers of fatal single-vehicle nonrollover crashes for analysis. As the Texas data did not contain the vehicle identification number (VIN) FARS data were used to estimate vehicle weights. The FARS weight is the average weight reported in FARS 1984 through 1989, for vehicles of the same make, model and model year. The Texas logistic regression addressed the following independent variables:

WEIGHT ..... FARS weight,
DR_AGE ..... the age of the driver,
DR_SEX ..... an indicator variable for driver sex,
TWO_DR .... an indicator variable for two-door vehicles
WET_RD .... an indicator variable for wet road surface,
SPEED ...... an indicator variable for a 55 mph road,
FRONT ...... an indicator variable for front impact, and
DAMAGE .... an interval scaled variable representing TAD, a description of the damage to the vehicle (0 to 7).

The dependent variable was FATAL, defined by SEVERE = 4, indicating whether or not the driver sustained a fatal injury. The analysis included 112,486 drivers involved, of which 1,119 were fatally injured.

The resulting estimated coefficients, standard errors and chi-square values are displayed in Table 9.

Note that while vehicle weight is not the most significant factor in predicting the likelihood of incapacitating injury, the coefficient is statistically significant at a level of alpha less than 0.05.

What would be the effect on the expected number of injuries as the average weight of the fleet changed from 3,700 to 2,700 pounds? This was computed as in the same manner as was done previously.

Assuming all other factors remain constant, a reduction in the average vehicle weight from 3,700 pounds to 2,700 pounds would result in an estimated increase of 9.8 percent in the number of driver fatal injuries in single-vehicle nonrollover crashes. The 95 percent confidence interval ranges from an increase of 0.5 percent to an increase of 19.9 percent.

Table 8. Results of Model Estimation (Texas)

VARIABLE	BETA	STD ERROR	CHI-SOUARE	P
INTERCEPT	-3.02422238	0.16760401	325.58	0.0000
HEAD_ON	1.67401291	0.10146955	272.17	0.0000
DR_AGE	0.00519428	0.00206640	6.32	0.0119
WEIGHT	-0.00010937	0.00005339	4.20	0.0405

Table 9. Results of Model Estimation (Texas)

VARIABLE	BETA	STD ERROR	CHI-SOUARE	P
INTERCEPT	-9.49777721	0.19388549	2399.68	0.0000
DAMAGE	0.93292219	0.02039251	2092.90	0.0000
DR_AGE	0.02981796	0.00202257	217.34	0.0000
DR_SEX	0.38937032	0.07537914	26.68	0.0000
WEIGHT	- 0.00009420	0.00004563	4.26	0.0390

Discussion

As a result of the analyses reported herein, there is evidence that drivers of downsized vehicles have a higher risk of injury in crashes involving passenger cars than would have been the case had the 1,000 pound downsizing not occurred. However, the evidence does not show a significant association of vehicle weight with fatality risk in two-car crashes.

The means of demonstrating this has been to use the models developed for the Maryland and Texas accident data to estimate the number of K+A injuries and fatal injuries that would have occurred had the two state car fleets averaged 3,700 pounds vs. 2,700 pounds. This change in car weight is the estimated effect of the weight reduction that occurred during the 1970-1982 time period.

The effects of changes in passenger car weight reported herein represent changes as the vehicles were used in contrast to as the vehicles were engineered. That is, for example, cars of different weights may be driven more or less aggressively. If there were a tendency for smaller cars to be driven by younger drivers, and if they in turn tended to drive their cars more aggressively than did older drivers, this would lead to accidents with greater pre-crash or closing speeds, compared to accidents involving larger cars driven by older drivers. While the Maryland analysis incorporated posted speed limit in the analysis, this may not be sufficient to account for the potential differences in pre-crash travel speeds within the categories of posted speed limit. While differential closing speeds would not be an issue in accidents involving a larger and a smaller car, under this hypothesized scenario, accidents involving two small cars may involve higher pre-crash travel speeds than do accidents involving two large cars, accounting for some of the higher predicted K+A injury rate. However, the state data files used in these analyses did not report pre-crash travel speeds. In spite of this, the analyses and effects reported herein are valid representations of the effects of car weight as these cars were used.

Changes in Two-Car Crashes

The change in injury rate associated with the reduction in vehicle fleet weight from 3,700 to 2,700 pounds has been estimated from the Texas data to be an additional 14.3 percent serious injuries to drivers. The Maryland data produced an estimated increase in K+A driver injuries of 4.3 percent for the shift from a 3,700 to a 2,700 pound average fleet weight.

The NASS General Estimates System for 1989 reports that the number of passenger car driver K+A injuries in two-car crashes was 85,768 (total occupant K+A injuries in these crashes numbered 128,974).

Generalizing the results to all occupants of passenger cars and applying the estimated effects derived in the analysis leads to estimated national annual net increases of 16,156 K+A injuries based on the Texas analysis, and 5,329 K+A injuries based on the Maryland analysis, associated with the 1,000 pound shift in vehicle weight.

Under the assumption that the effects noted for drivers could be generalized to all passenger car occupants, one can estimate the changes in total occupant injury associated with the 1,000 pound shift. All of these estimates and their associated 95 percent confidence intervals are presented in Table 10.

Table 10. Estimated National Annual Changes in Injuries to Occupants of Passenger Cars in Two-Car Crashes Associated with the Shift in Fleet Average Weight from 3,700 to 2,700 Pounds

Category	Estimate	95% Lower Confidence Bound	95% Upper Confidence Bound
Drivers			
K+A Injuries			
Texas	10,744	7,132	14,187
Maryland	3,544	- 5,972	12,141
All Occupants			
K+A Injuries			
Texas	16,156	10,725	21,334
Maryland	5,329	- 8,981	18,257

The estimates presented represent the NET effect of the 1,000 pound decrease in curb weight, which, generally speaking, are the sum of the benefits and liabilities accruing to each driver in turn. However, since smaller cars experience higher injury rates in two-car crashes, there is a net liability that results from the weight reduction of all cars in the fleet.

Changes in Car-Medium/Heavy Truck Crashes

The change in fatal and incapacitating injury rate associated with the reduction in vehicle fleet weight from 3,700 to 2,700 pounds has been estimated from the Texas data to be an estimated increase in fatal driver injuries of 11.3 percent for the shift from a 3,700 to a 2,700 pound average fleet weight.

The NASS General Estimates System for 1989 reports that the number of passenger car driver serious (K+A) injuries in crashes involving a car and a medium/heavy truck was 12,139 (total occupant serious injuries in these crashes numbered 17,858). Applying the estimated effect derived in the analysis and generalizing the results to all passenger car occupants leads to estimated national annual net increases of 1,770 serious injuries associated with the 1,000 pound shift in vehicle weight. The 95 percent lower and upper confidence bounds are an increase of 80 serious injuries and an increase of 3,303 serious injuries.

Changes in Single-Vehicle Nonrollover Crashes

As a result of the analysis reported herein, there is evidence that drivers of smaller cars have a higher risk of fatal injury in single vehicle non-rollover crashes than do drivers of larger cars.

The means of demonstrating this has been to use the model developed for the Texas accident data to estimate the number of fatal injuries that would have occurred had the two state car fleets averaged 3,700 pounds vs. 2,700 pounds. This change in car weight is the estimated effect of the weight reduction that occurred during the 1970-1982 time period.

The change in fatal injury rate associated with the reduction in vehicle fleet weight from 3,700 to 2,700 pounds has been estimated from the Texas data to be an estimated increase in fatal driver injuries of 9.8 percent for the shift from a 3,700 to a 2,700 pound average fleet weight.

Data from the Fatal Accident Reporting System for 1989 shows that there were 4,880 fatally injured drivers in single-vehicle nonrollover crashes, and a total of 7,108 fatally injured occupants (including drivers) in such crashes. Applying the estimated effects derived in the analysis leads to estimated annual net increases of 435 driver fatalities and 633 total occupant fatalities based on the analysis of Texas accident data, associated with the 1,000 pound shift in vehicle weight. The 95 percent lower and upper confidence bounds for these estimates are: 23 and 811 for driver fatalities; 33 and 1,182 for total occupant fatalities.

Concluding Remarks

The estimated effects reported herein are based on historical relationships between car weight and injury rates as evidenced by the crash experience of all cars for the 1984-1987 Texas accident data and 1981 and later model year cars during the 1984-1988 Maryland accident data time frames.

Differences between the crashworthiness levels of the fleet of the 1970's compared with that of the 1980's could not be addressed in the current analysis of Maryland data, since only vehicles of model years 1981 and later were included in the Maryland accident data analysis. These statistical models and results do not account for changes in the number of crash involvements that might occur under the assumptions of downsizing, but do represent the real-world experience as manifested in the States of Maryland and Texas. To the extent that car weight reduction affects the relative likelihood of crash involvement, the models and estimated effects do not take this into account, leaving the projected involvement of cars by weight in the same relative proportions as that which occurred in the accident data. Analyses of different states would probably produce somewhat different results. Differences in the results between the Maryland and Texas analyses could be attributable in part to normal variation; differences in reporting threshold of accidents; differences in the coding of injuries (e.g., an injury may be called incapacitating in one state and non-incapacitating in another); differences in the availability of known driver, vehicle and accident data (in this study, only complete cases were used; that is, where all variables had known attributes); and other factors that might affect the reporting and coding of accident characteristics.

With regard to reporting threshold, the State of Maryland has a threshold of $100, a fatality or personal injury; the State of Texas has a threshold of $250, a fatality or personal injury. However, the reality of reporting threshold may be substantially different than that which has been reported by states to NHTSA in the past. Differences in reporting threshold affect the overall probability of injury as well as the mix of accidents reported by a state. Since data are not collected in any uniform or consistent manner from one state to another, it is difficult to reconcile observed differences. Thus, the reported effects are presented separately for each state rather than as a range, or as an average effect.

S1-O-12

Compatibility Problems of Small and Large Passenger Cars in Head on Collisions

G. Ernst; Dr. Brühning, E;
Glaeser, K.P.; Schmid, M.
Federal Highway Research Institute, BASt

Introduction

Road accidents may involve collisions between vehicles of different weights under a variety of circumstances. It is rare for vehicles of equal weight to collide. The range of vehicle curb weights (masses) extends from less than 700 kg (e.g. VW Polo) to over 2,000 kg (e.g. Daimler Benz, S-class). In accordance with the impact laws of mechanics, the consequences of collision involving smaller and larger vehicles are mostly more serious for the driver and passengers of the smaller vehicle. In the past, it has not always been possible to completely quantify the seriousness of accidents or the risk of being injured or killed in Germany because there is no direct link between vehicle mass and the seriousness of passenger injuries. All that is available at present is a study by an insurance association [5] based on single accident cases. This analysis covered front-seat passengers using seat belts as well, but not only the drivers.

An American study [7] estimate the risk of being killed in an accident in a small car (subcompact) very generally as being 8 times higher than the risk in a larger vehicle (fullsize car). Examining cars of different masses and of equal masses involved in accidents (comparison between vehicles weighing 900 kg and vehicles weighing 1,600 kg), in [4], on the basis of the FARS (Fatal Accident Reporting System), note a ratio of 2:1 for the risk of being fatally injured in a small car as against the risk of being fatally injured in a larger vehicle. However, the results of US studies cannot always be translated to European conditions, since America's car population is quite different from the European on account of the large number of extremely large vehicles on US roads.

A Swedish study by FOLKSAM Insurance—which also included single-car accidents—found that drivers of 800 kg vehicles have an injury frequency twice as high as that of 1,400 kg vehicles [6].

Following an evaluation of the accident data for North-Rhine/Westphalia now available for research purposes and extended to include automotive features, it is now possible to obtain results for the "compatibility" problem in Germany and in the car population involved in accidents here. First results were published in [8]. The study is concerned with the seriousness of injuries focused to car drivers involved in accidents with on-coming traffic.

Physical and Automotive Aspects of the "Compatibility" Problem

The seriousness of accidents can be described using the impact laws of mechanics; one measure is the "change of velocity" in the accident.

In the standard impact test against a rigid barrier, the deformation behaviour of the vehicle front is examined, and the protection afforded against serious injuries measured.

Still, although impact against the rigid barrier is a well established testing procedure, it does constitute a special case in the real accident world. Where a vehicle drives into a rigid barrier at e.g. 50 km/h, kinetic energy is transformed to deformation of the vehicle front. The vehicle undergoes a 50 km/h change of velocity.

To ensure optimal transformation of impact energy into work of deformation, the stiffness of the front is designed in such a way that, to meet the safety standard FMVSS 208, which provides for an impact at 30 mph (48 km/h) against a rigid barrier, advantage is taken of the max. deformation path of approx. 50 to 60 cm of the vehicle front, and also that the survival area in the vehicle cell is not destroyed. The vehicle structure, i.e. primarily the stiffness of the front side member, is optimated to this standard. This keeps the mean deceleration of the vehicle and its passengers (using seat belts) within limits. Where a large vehicle has, e.g., double the mass of a smaller vehicle, double the kinetic energy must be destroyed. This means—assuming the same front length (deformation distance)—double hardness for the front structure (stiffness), or—assuming the same stiffness of the front (force level)—double the length of front (or a combination of these two options).

Where two vehicles are involved in a head-on crash—for the sake of clarity, only head-on collisions are considered here—the change of velocity in the two vehicles results from the law of conservation of momentum applying to a plastic impact. This means—to remain with this example—in the case of an impact of 30 mph per vehicle and an assumed ratio between large vehicle mass and small vehicle mass of mL:ms=2:1, that the large vehicle continues driving in its direction at 10 mph, while the smaller car is reversed and is pushed back by the larger vehicle at a speed of 10 mph. The large vehicle undergoes a 20 mph change of velocity, the small vehicle one of 40 mph. We have a double change of speed in the smaller vehicle, whose normally softer structure must absorb double the energy.)[1]

Now, it is also possible to optimize vehicle fronts for a collision involving two moving vehicles, i.e. not a wall crash (self-protection) but a collision between vehicles of different size (partner protection). The collision tolerance involved here is called compatibility. The design for the fronts of "compatible" vehicles would have to look as follows:

- The small car must share the deformation of the larger vehicle. This can be done by choosing different stiffness characteristics (soft, medium, hard) or a linear increase in the stiffness characteristic for the front of the larger car, at the same time taking advantage of what will normally be greater front length and also a stiffer design in the front of the smaller car.
- If these two vehicles—now designed for compatibility—collide, first of all the stiff front of the smaller vehicle crushes the soft section of the front of the larger vehicle. In the process, the kinetic energy of the small vehicle is absorbed by the large vehicle. After that there is an even deformation of both vehicles.

Now, however, there are drawbacks in the 30 mph impact test against the rigid barrier described earlier for both vehicles. The small vehicle has been given a stiffer front design; as a result, the entire possible deformation path is no longer deformed; the mean deceleration and, hence, the strains on the occupants are higher. The large vehicle "gives away" opportunities for intaking energy. And although the choice of different degrees of stiffness can deal with the impact of 30 mph against the rigid wall thanks to the longer front, a constant choice of stiffness and optimation of stiffness to cope with the barrier impact might have allowed the occupants to survive an impact involving a speed of perhaps 35 mph without serious injuries. So far, vehicle stiffnesses have not yet

---

[1] A double change of velocity normally means quadrupling the kinetic energy to be absorbed. However, this value is halved again, since the distribution of masses is 2:1 as indicated above.

been optimized for the protection of people. However, there are approaches to solutions, e.g. in [3].

Empirical Analyses

Data Base

In 1985, there were 77,009 accidents involving personal injuries between two cars in the Federal Republic of Germany. Out of these, 15,207 accidents with a total 28,757 casualties were accounted for by accident type "Collision with an oncoming vehicle." 686 of a total of 4,182 killed car occupants lost their lives in this accident type.

This analyses are based on data for accidents involving personal injuries and serious car damage for the State of North-Rhine/Westphalia, supplemented by automotive technology data available at the Federal Road Traffic Agency (Kraftfahrt-Bundesamt) [1]. Attention was paid in particular to the consequences of accidents for car drivers in accidents involving two passenger cars (station wagons excluded) with an car age of less than 10 years.

The risk of injury for car occupants depends very much on whether seat belts were used. The rate of seat belt use on front seats of cars averaged 60% until the introduction of fines in August 1984, since when, the rate has been over 90%. In order to rule out possible distortions owing to the different rates, this study is confined to accidents occurring between August 1984 and December 1988.

In order to target the problem of compatibility with the available data, the following remarks only concern accidents of type "Collision with an oncoming vehicle". By definition, therefore, the accidents to be considered here are collisions involving oncoming traffic without, e.g., one party intending to turn off to the left. In the period under review the accidents of this type in North-Rhine/Westphalia totalled 17,612.

Study Hypotheses

Compatibility problems always occur when large vehicles collide with smaller vehicles. The two main factors are:

- different vehicle structure optimized for self-protection
- different "mass aggressiveness" of vehicles of different weights.

This gives us the following two hypotheses:

Hypothesis 1: Differences in vehicle structure and "mass aggressiveness" mean that the consequences of an accident are less favourable for the occupants of the smaller and correspondingly more favourable for those in the larger vehicle.

Hypothesis 2: Where the vehicles have the same structure and "mass aggressiveness," this means that a head-on collision involving two small vehicles may be expected to have the same consequences as a head-on collision involving two large vehicles.

Characteristics for Assessing the Seriousness of Injuries

The central question concerns the extent to which the probability of serious consequences for the car occupants depends on vehicle size. Since considerable variations are possible in the number and seating position of co-driver and passengers, our study is confined only to drivers and to the consequences for them.

For this study, the characteristic to indicate the mean seriousness of injuries to drivers involved in head-on collisions between two cars is the share of fatalities and serious casualties among all drivers involved in accidents with personal injuries and serious material damage is chosen:

$$AS = \frac{\text{number of fatalities + seriously injured drivers}}{\text{number of drivers in AI and AD}}$$

AI = accidents with personal injuries
AD = accidents with serious material damage

With regard to this specific characteristic the statistically significant variable of whether the driver felt "guilty" or "not guilty" does not have to be taken into account in the statistical analysis (cf. [2]).

Classification by Weight Classes

For the purposes of the present analysis, the vehicle population is subdivided by curb weight into four weight classes and the distribution is shown in Table 1.

Class 1: car with an curb weight of 600 to 799 kg,
Class 2: car with an curb weight of 800 to 999 kg,
Class 3: car with an curb weight of 1,000 to 1,199 kg,
Class 4: car with an curb weight of 1,200 to 1,599 kg.

Table 1. Cars involved in headon collision between two cars in North-Rhine/Westphalia in the period 1 August 1984 to 31 December 1988, classified by curb weight (accidents with personal injuries and serious material damage)

	Cars Involved	
Curb weight (kg)	Number	%
600 to 799	3,076	8.9
800 to 999	14,037	40.6
1000 to 1199	9,795	28.3
1200 to 1599	7,683	22.2
Total	34,591	100.0
up to 599/1600	615	
and more not known	18	

Classification by Design Features

As stated above, stiffness and/or vehicle design, which vary from type to type, have considerable implications for the relative collision tolerance of the vehicles.

Accordingly, two groups of vehicles were formed, taking account of empty weight and other design features:

Group 1:	empty weight up to 999 kg;
"small"	traverse front engine;
	front-wheel drive
Group 2:	empty weight up to 1,400 to 1,799 kg;
"large"	longitudinally installed front engine;
	standard drive

To form the above two groups, the empty weight classifications used deviate from those considered in Section 3.4. This was necessary in order to obtain sufficiently large groups for study when two further vehicle design features are taken into account.

The data material available for this study contains 13,554 vehicles in Group 1 ("small") and 3,750 in Group 2 ("large"). 8,742 of the 13,554 vehicles in Group 1 (64%) concern the car models Ford Fiesta, Opel Kadett, VW Rabbit and VW Polo, while 76% of the vehicles in Group 2 (2,863 of 3,750 vehicles) concern the car models Mercedes Benz W123 and W124 and BMW in the 5, 6 and 7 series.

Other Determinants

Alongside the vehicle features "vehicle structure" and "mass aggressiveness," there are other important factors—e.g. velocity, age of occupants, etc.—which may have a more or less favourable impact on the consequences of the accident for the occupants.

One factor of special importance for the consequences as they affect the occupants involved in a head-on collision is the speed at which the vehicles collide. The data material available for the present analysis does not explicitly include this feature, although we do know that the permissible max. speed and the mean speeds actually driven "inside built-up areas" are definitely below the values "outside built-up areas without autobahns" (rural roads). Alternatively, therefore, the factor "speed" is considered as explanatory variable via the feature "locality."

Also included in the analysis as a further explanatory variable is "driver age," since the seriousness of injuries under the same circumstance is, greater in the case of elderly people On the other hand, accidents involving younger drivers tend to correlate with excessive speeding.

In a consideration of collision compatibility, vehicle age is important for two reasons:

- old vehicles tend to be heavier and stiffer, which leads to special problems when a "light new" vehicle collides with an "old heavy" vehicle;
- older vehicles have, normally a higher degree of corrosion than newer vehicles, so that the accident may have different consequences for the occupants.

This was the reason to include only accidents with passenger cars of less than 10 years age.

Variables Used in the Study

In line with the remarks contained in the previous sections, the analysis uses the following features as independent variables (for dependent variables, see above):

Curb weight class of the car under consideration (CAR1) or the other car (CAR2)

(1)	600	to	799 kg
(2)	800	to	999 kg
(3)	1,000	to	1,199 kg
(4)	1,200	to	1,599 kg

Alternatively:

Size and design of the car under consideration (CAR_A) or the other car (CAR_B)

(1) small
(2) large

Locality (L)

(1) inside built-up area
(2) outside built-up area without autobahn (rural roads)

Age of driver in car under consideration (A)

(1) under 25 years
(2) 25 to 59 years
(3) 60 years and older

The Statistical Analysis Method

The counting of the fatalities and serious casualties for car drivers involved in head-on car crashes according to two or more variables produces a multi-dimensional matrix. The more variables are considered and the more categories the variables have, the more difficult it is—without adequate analytical procedures—to identify the relevant structures and to distinguish essential influences from the inessential. This is specially true where the occupation of the cells in the multi-dimensional matrix shows considerable variation, i.e. if the matrix has cells with a high as well as cells with a very low occupation frequency.

Statistical procedures based on logit models enable essential determinants to be identified using a multi-dimensional matrix; distinctions can be made between significant and nonsignificant determinants. Non-significant determinants can be excluded from the analysis, i.e. unlike a "conventional" evaluation involving a splitting up into multidimensional matrices, the use of logit models allows parameters to be excluded wherever they are not statistically significant on the basis of empirical data [2].

Results

Influence of "Locality"

The variable "locality" has, as expected, a very great influence on the mean seriousness of injuries to drivers involved in head-on collisions between two cars.

The percentage of fatalities and serious casualties among drivers (relative to all drivers involved in accidents with personal injuries and serious material damage) is about three times higher in the case of head-on collisions between two cars on rural roads than in built-up areas.

The inference is that the high mean seriousness of injuries on rural roads is basically statistically independent of the curb weight of one's own car and of the curb weight of the other car. Thus, the variable "locality" acts as a constant factor on the mean seriousness of injuries; the relative increase in the percentage of fatalities and serious casualties among drivers is equally high for all "curb weight classes."

In view of the high explanatory value of the variable "locality" accounting for the percentage of serious consequences, this variable is further considered again in the model.

Influence of Driver Age

The independent variable "driver age" has only a comparatively slight influence on the mean seriousness of injuries from head-on collisions. Of the three categories of the main effect, only the third category "drivers aged 60 years and more" is significantly different from 0 ($\alpha < 0.05$) and has a positive sign. This means that the percentage of fatalities or serious casualties among "old" drivers involved in head-on collisions is higher than the percentage of young drivers or middle-aged drivers. The absolute amount of this estimated value is small, however, relative to the values of the other parameters in the model, especially the "locality" variable.

Since no interactive effects significantly different from 0 occur between the three categories of the feature "driver age" in the car under consideration and the other parameters contained in the model, the inference is that a higher mean seriousness of injuries can only be established for older drivers, regardless of locality and the weight of one's own car and the weight of the other car.

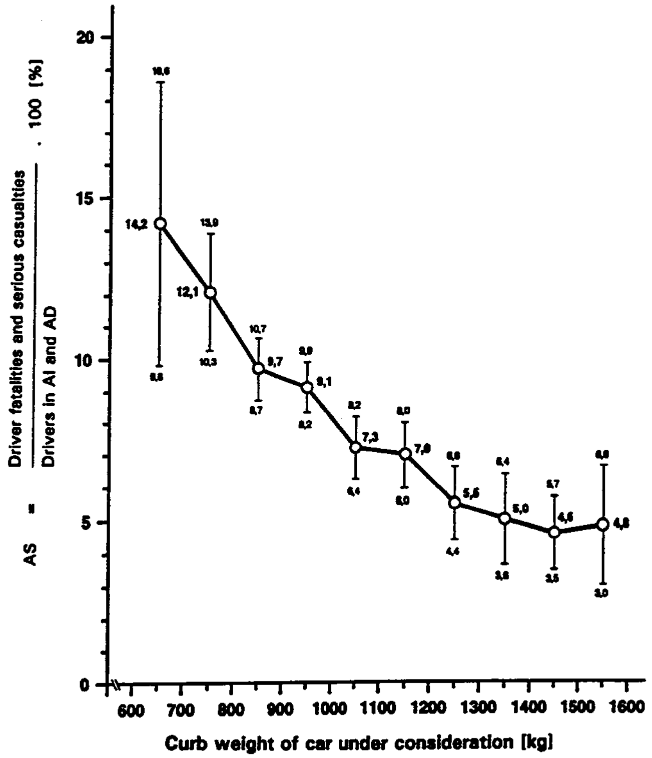
An additional study of the connection between car driver age and car weight has shown that the percentage of older drivers increases markedly with the curb weight. In order to avoid any distortions to the results from a correlation between these two variables, the analyses in the following Sections ignore drivers aged 60 and older.

As was already established, the same accident consequences can be expected for young and middle-aged drivers involved in head-on collisions between two cars. Thus, if we ignore older drivers, the feature "age of driver of car considered" need no longer be considered in the analysis.

Seriousness of Head-on Crashes Involving Two Cars as a Function of Weight

Before dealing with the question of the collision compatibility of cars in the following Sections, the present Section examines the mean seriousness of injuries to drivers involved in head-on crashes between two cars as a function of the weight of one's "own" car; the weight of the "other" car is left out of account in this first analysis.

Figure 1 shows a curve for the mean seriousness of injuries to drivers involved in head-on crashes between two cars that falls with the curb weight of the car. The seriousness of the consequences fall substantially with the rise in the weight of the car under consideration. The percentage of fatalities and serious casualties among drivers of cars with 600 kg curb weight is 14.2%; and that for drivers in cars with an curb weight of 1,500 kg is 4.8%.



BASt - U2 - 43/90

Figure 1. Seriousness of head-on crashes involving two cars on rural roads as function of the curb weight of the two cars (driver age up to 59 years)

Compatibility in a Consideration of Four Weight Classes

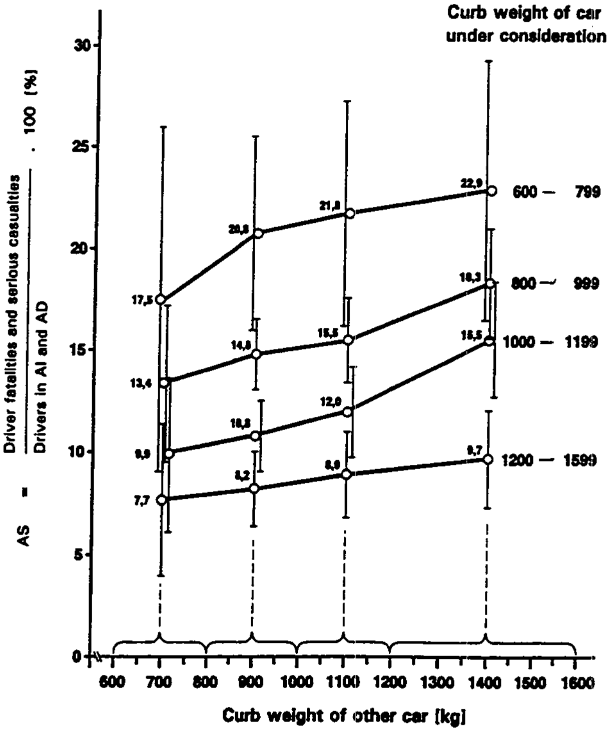
To describe the collision compatibility of cars, a model is estimated in what follows that takes as independent variables the feature "locality" and the car under consideration and/or the other car (each in four weight classes). The dependent variable considered is the percentage of fatalities and serious casualties among drivers relative to all drivers involved in accidents with personal injuries and serious material damage (AS).

Using this model, we can estimate expected values for the seriousness of accidents and the relevant confidence intervals for all covariable constellations. Fig. 2 shows the results for the rural road sector.

In the following the two hypotheses for the collision compatibility of cars involved in head-on collisions described above were tested (see Annex Table A1 and A2 and Figure 2):

Hypothesis 1 says that, in accidents involving cars of different weight, **different "mass aggressiveness"** can lead to more serious consequences of the accident for the occupants of the smaller and correspondingly less serious consequences for those in the larger vehicle. This hypothesis can only be maintained partly:

- Figure 2 makes it clear that seriousness of the consequences of the accident for the driver is related quite definitely to the curb weight of his own car. The consequences for drivers in cars with an curb weight of 600 to 799 kg are—regardless of the weight of the other car—some 2.5 times less favourable than for drivers of cars with an curb weight of 1,200 to 1,599 kg. On rural roads, for example, the expected value for the percentage of fatalities and serious casualties among drivers in cars with an curb weight of 600 to 799 kg in the case of head-on collisions with a car of 800 to 999 kg curb weight is 20.8%, with a car of 1,200 to 1,599 kg curb weight 22.9%; the corresponding expected values for drivers in cars with an curb weight of 1,200 to 1,599 kg, however, are only 8.2% (weight of other car 800 to 999 kg) and 9.7% (weight of other car 1,200 to 1,599 kg) resp.
- Within the various curb weight classes, however, hypothesis 1 can be confirmed in principle; it can be seen, e.g., that, in the case of drivers of cars with an curb weight of 800 to 999 kg involved in head-on collisions with a smaller car (600 to 799 kg weight), the consequences for the car with 800 to 999 kg curb weight are much less serious (13.4%) than in the case of a head-on collision with a heavier car (1,000 to 1,199 kg curb weight 15.5% and 1,200 to 1,599 kg curb weight 18.3%).



BASt - U2 - 43/90

Figure 2. Compatibility—expected values for the seriousness of accidents in head-on crashes involving two cars on rural roads, as function of the curb weight of both cars (driver age up to 59 years)

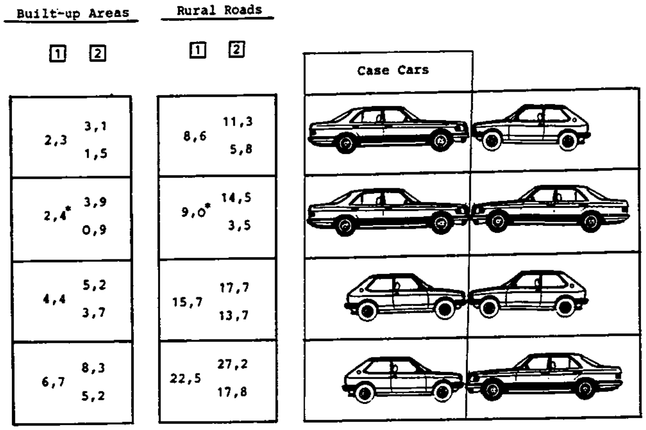
Hypothesis 2—equal "mass aggressiveness"—viz. that the consequences of a head-on collision between cars of equal weight classes are approx. the same for the occupants, cannot be confirmed. In fact, Fig. 2 shows that the seriousness of the consequences for the driver depends quite substantially on the curb weight of his own car. The values of the characteristic for the seriousness of injuries AS fall strikingly as the weight of the car under consideration increases. The expected value for the percentage of fatalities and serious casualties among drivers in head-on collisions involving two cars with an curb weight of 800 to 999 kg is 14.8%; in head-on collisions involving two cars with an curb weight of 1,200 to 1,599 kg, the figure is 9.7%.

Compatibility in a Consideration of Two Selected Vehicle Groups

To take account of these conditions, two vehicle groups ("small"/"large") were selected by size and design features, for the car under consideration and the other car—as independent variables and included in the multivariable analysis. The feature "locality" was considered as a further independent variable. The dependent variable is again the percentage of fatalities and serious casualties relative to all drivers involved in head-on crashes with personal injuries and serious material damage.

As stated above the consequences of head-on collisions are many times less favourable for drivers on country roads than they are inside builtup areas, **regardless** of the size and design of the vehicle. The accident severity (AS) for small and large cars is shown in Fig. 3. The hypotheses 1 and 2 for the collision compatibility of the cars can be checked again.

Overall, it can be said that the results obtained by classifying the vehicle populations into four empty weight classes for the car under consideration and the other car by postulating two vehicle groups based on masses and design features, were corroborated; in the case of head-on collisions involving a small and a large car, the mean seriousness of the injuries is some 2.5 times greater in the large car.



1 AS = Percentage of fatalities and serious casualties relative to all drivers involved in accidents with personal injuries and serious material damage
2 95 % confidence interval
* In this constellation, only 3 fatalities or seriously injured drivers were recorded

Figure 3. Expected value for seriousness of accidents involving car drivers in head-on crashes (accident type 4) between two cars *in built-up* and *on country roads* as a function of two selected vehicle groups (accident with personal injuries and material damage; driver age up to 59 years)

Summary, Discussion of the Results

Head-on crashes between cars are particularly serious. Where large and small vehicles collide, physical theory leads to expect compatibility problems. The main factors regarded as underlying the special collision intolerance of vehicles of different sizes are the different vehicle structures optimized for self-protection and the different "mass aggressiveness" of vehicles of different weights.

In 1985, there were 77,009 accidents involving personal injuries between two cars in the Federal Republic of Germany. Out of these, 15,207 accidents with a total 28,757 casualties were accounted for by accident type "Collision with an oncoming vehicle." 686 of a total of 4,182 killed car occupants lost their lives in this accident type.

The analysis undertaken in this report is based on the data for accidents involving personal injuries and serious material damage in the State of North-Rhine/Westphalia, supplemented by automotive data available at the Federal Road Traffic Agency. In order to rule out any distortions due to differences in rates of seat belt use, the study is confined to accidents occurring after August 1984. Since then, the rate of seat belt use in the Federal Republic has averaged well over 90%. The vehicle population was broken down by curb weight into four weight classes.

The assessment criterion in the statistical analysis was the mean seriousness of injuries to drivers involved in head-on collisions between two vehicles. The independent variables considered in addition to the features "curb weight class of the car under consideration" or "of the other car" were the features "locality" and "age of the driver of the car under consideration."

The statistical analysis was made using logit models, which enable the key determinants to be identified and their impact quantified within the scope of multidimensional analysis. As expected, the feature **"locality"** has a great impact on the mean seriousness of injuries to car drivers involved in collisions with oncoming cars; regardless of curb weight class of the vehicle, the consequences of accidents for drivers on rural roads are about three times less favourable than in the case of built-up areas.

The feature **"age of driver in the car under consideration"** has a comparatively slight impact on the mean seriousness of injuries to drivers involved in head-on collisions between two cars. In the case of older drivers, however, there is in fact a higher mean seriousness of injuries, regardless of locality and the curb weight of their own or the other car.

Study hypothesis 1, viz. that **different "mass aggressiveness"** in accidents involving cars of different weights produces more serious consequences for the driver of the smaller car—and correspondingly less serious consequences for the driver of the larger vehicle—were only confirmed with reservations.

Study hypothesis 2, viz. that **equal "mass aggressiveness"** produces approx. the same consequences for car occupants in head-on collisions involving cars of the same weight, was not confirmed.

In fact, the empirical analysis showed that the seriousness of the consequences for drivers was associated on average and quite significantly with the **curb weight** of the driver's own car. The mean seriousness of injuries is some 2.5 times as high for small cars or for cars with a weight between 600 and 799 kg—regardless of the weight of the other car—as it is for large cars or for cars with an curb weight between 1,200 and 1,599 kg.

The same results could be obtained by only looking to small cars (< 1000 kg) with traverse engine and large cars (> 1400 kg) with longitudinally installed engine.

Thus, there must be other factors operating to explain why safety is very much greater for the occupants of large vehicles than it is for small vehicles. One possible explanation is that the interior appointments of large—and hence more expensive—cars offer more scope or the use of safety-enhancing features. For example, the use of energy-absorbing materials in the interior (e.g. dashboard), the installation of safety steering wheels, etc. is easier to implement cost-wise for large cars than it is for small cars. Differences in car safety for different cars within each weight class cannot be made by means of the data base used for this study.

References

[1] Bock, O.; Brühning, E.; Dilling, J.; Ernst, G.; Miese, A.; Schmid, M.; 1989: Aufbereitung und Auswertung von Fahrzeug- und Unfalldaten zur Hebung der Verkehrssicherheit. Gemeinsamer Bericht der Bundesanstalt für StaBenwesen und des Kraftfahrt-Bundesamtes Herausgegeben im Auftrag des Bundesministers für Verkehr von der Bundesanstalt für StraBenwesen, Bereich Unfall-forschung, 1989, Heft 71.

[2] Bruhning, E.; Ernst, G.; 1988: Loglinear and Logit Modells in Accident Research. 9. IRCOBI Konferenz, Bergisch Gladbach. In: 1988 International IRCOBI Conference on the Biomechanics of Impacts, S. 35 - 46.

[3] Danner, M.; Appel, H.; Schimkat, H.; 1980: Entwicklung kompatibler Fahrzeuge. Abschlubericht des BMFI, 1980.

[4] Evans, L.; Wasielewski, P.; 1987: Serious or Fatal Driver Injury Rate vs. Car Mass in Head On Crashes of Similiar Mass. In: Accident Analysis and Prevention, Vol. 19, Nr. 2.

[5] Langwieder, K.; Schmelzing, W.; 1982: Kollisionen von Pkw unterschiedlicher Masse. BMFT Statusseminar. Münster 1982.

[6] Nygren, A.; Gustafsson, H.; Tingvall, C.; 1982: Injury Frequency and Injury Panorama among Drivers—A Comparison between Small and Big Cars and the Influence of Year Model and Production Start. 7. IRCOBI Konferenz, Koln 1982.

[7] William, Boehly, Lombardo (NHTSA); 1980: Safety Consequences of the Shift to Small Cars in the 1980' s. 8. ESV Konferenz, Wolfsburg 1980.

[8] Ernst,G. ,Bruhning,E., Glaeser,K.-P.,Schmid,M.; 1991 Safety in Small and Large Passenger Cars, IRCOBI Conf. Potsdam, Sept. 91.

Annex

Table A1: Expected value for seriousness of accidents involving car drivers in head-on crashes between two cars **inside built-up areas** as a function of four curb weight classes (Accidents with personal injuries and serious material damage;driver age up to 59 years)

Curb weight of considered CAR1	Curb weight of other CAR2							
	600 to 799 kg (1)		800 to 999 kg (2)		1000 to 1199 kg (3)		1200 to 1599 kg (4)	
	AS$^{1)}$	confidence-limits$^{2)}$	AS$^{1)}$	confidence-limits$^{2)}$	AS$^{1)}$	confidence-limits$^{2)}$	AS$^{1)}$	confidence-limits$^{2)}$
600 to 799 kg (1)	5.5$^{*)}$	8.2 2.8	6.7	8.3 5.1	7.1	8.9 5.3	7.5	9.6 5.4
800 to 999 kg (2)	4.1	5.2 2.9	4.5	5.1 3.9	4.8	5.5 4.1	5.8	6.7 4.8
1000 to 1199 kg (3)	2.9	4.0 1.8	3.2	3.7 2.6	3.6	4.3 2.9	4.8	5.7 3.9
1200 to 1599 kg (4)	2.2$^{*)}$	3.3 1.2	2.4	2.9 1.8	2.6	3.2 2.0	2.8	3.6 2.1

1) AS = percentage of fatalities and serious casualties relative to all drivers involved in accidents with personal injuries and serious physical damage

2) 95 % confidence interval

*) In the constellation, fewer than 10 fatalities or serious casualties were recorded

Table A2: Expected value for seriousness of accidents involving car drivers in head-on crashes between two cars **on rural roads** as a function of four curb weight (Accidents with personal injury and serious material damage; driver age up to 59 years)

Curb weight of considered CAR1	Curb weight of other CAR2							
	600 to 799 kg (1)		800 to 999 kg (2)		1000 to 1199 kg (3)		1200 to 1599 kg (4)	
	AS$^{1)}$	confidence-limits$^{2)}$	AS$^{1)}$	confidence-limits$^{2)}$	AS$^{1)}$	confidence-limits$^{2)}$	AS$^{1)}$	confidence-limits$^{2)}$
600 to 799 kg (1)	17.5	26.0 9.0	20.8	25.6 16.0	21.8	27.3 16.4	22.9	29.3 16.4
800 to 999 kg (2)	13.4	17.2 9.6	14.8	16.5 13.0	15.5	17.6 13.3	18.3	21.0 15.6
1000 to 1199 kg (3)	9.9	13.6 6.3	10.8	12.5 9.0	12.0	14.2 9.9	15.5	18.3 12.7
1200 to 1599 kg (4)	7.7	11.4 4.0	8.2	10.0 6.4	8.9	11.0 6.8	9.7	12.1 7.2

1) AS = percentage of fatalities and serious casualties relative to all drivers involved in accidents with personal injuries and serious physical damage

2) 95 % confidence interval

S1-O-14

Survey of Car-To-Fixed-Obstacle Fatal Crashes

Claude Henry, Serge Koltchakian,
Gérard Faverjon, Jean Yves Le Coz
Laboratory of Accident Research and
Biomechanics
Associated with Peugeot SA/Renault SA
Alain Patel, Claude Got
Orthopaedic Research Institute

Abstract

The main factor of over-risk related to road infrastructure is fixed roadside obstacles. Due to their high stiffness, they represent a major danger in the event of loss of car control.

In France, on the road network outside of urban areas, about one third of the car fatalities recorded in 1990 were in crashes against fixed objects, and involved about 1600 fatalities. As far as trees alone are concerned, it should be emphasized that 900 fatalities are related to this kind of obstacle, mostly for lines of trees along the roadside.

Impact characteristics will be given for primary safety factors (circumstances, road conditions, driver state, etc.) and also for secondary safety aspects (impact types, violence of impacts, intrusion frequency, etc.).

Expected benefits (saved lives) from road infrastructure improvements by using guardrails, principally in front of trees, are studied on the basis of extensive and well-documented fatal crash police records established by the police force network over 6 months for all of France.

Introduction

As a joint initiative of the Orthopaedic Research Institute of Garches Hospital and the Laboratory of Accident Research and Biomechanics Associated with Peugeot SA/Renault SA, it was undertaken to collect the police records of fatal crashes occurring in France on the entire road network, over one year from 1st March 1990 to 28 February 1991.

The present study is devoted to the analysis of fatal crashes of passenger car occupants against fixed obstacles, occurring over six months on the network monitored by the National Police Force.

Of the 6295 deceases of passenger car occupants counted in France in 1990, the National Police Force [1] recorded 5014 (80% of all motorist fatalities), of which 2618 occurred between 1st March and the 31st August 1990. At present, more than 90% of the crash reports concerning these victims have been transmitted to us, and for 2374 of the 2618 fatalities, we have been able to break down the victims according to the type of crash [Table 1].

Table 1. Breakdown of Motorist Fatalities According to the Nature of the Accident in France, from the 1st March to the 31st August 1990, on the National Police Network*

NATURE OF THE ACCIDENT	MOTORIST FATALITIES	
	NUMBER	%
CAR-TO-CAR	666	28.1
CAR AGAINST A UTILITY VEHICLE	453	19.1
CAR AGAINST OTHER VEHICLE	41	1.7
CAR TO FIXED OBSTACLE	741	31.2
- ..... of which trees	413	17.4
- ..... of which other fixed obstacles	328	13.8
ROLLOVER, OVERTURNING OF CAR	411	17.3
OTHERS (submersion, fall into gully, etc.)	62	2.6
TOTAL	2374	100.0

*Road network located outside of urban areas, consisting of the network in the open countryside and the network passing through small and medium-size towns.

Crashes against fixed obstacles and crashes "with no obstacle" represent more than half of all fatalities. Fixed obstacles alone are the cause of close on one third of deceases (31.2%).

Out of 100 fatalities against fixed obstacles, the obstacle is a tree in 56% of cases, whereas walls and poles alone represent more than half of the remaining 44% of fatalities.

By comparison, impacts against fixed obstacles on the entire road network in the U.S.A. caused 36.6% of the 25,046 motorist fatalities in 1989 [2], with the obstacle being a tree for only a quarter of these deceases.

An exhaustive study of fixed obstacles requires a good assessment of impact conditions. This obviously requires that the crash reports be sufficiently well documented with photographs of the vehicles and the environment. Accordingly, we had to exclude from the basic sample, consisting of 413 fatalities in crashes against trees and 328 fatalities in crashes against other fixed obstacles, a small number of victims for which the files were insufficiently documented. The sample adopted consists of 691 fatalities, involved in 582 fatal crashes against fixed obstacles, with trees representing 57% of deceases [Table 2].

Table 2. Fatal Accidents Against Fixed Obstacles: Breakdown of Crashes and Casualties Against Trees or Other Fixed Obstacles in the Basic Sample

OBSTACLES	FATAL CRASHES	FATALITIES	SEVERE INJURIES	LIGHT INJURIES	UNHARMED	SEVERITY UNKNOWN	TOTAL NUMBER OF OCCUPANTS
TREES	323	391	121	61	18	3	594
OTHER FIXED OBSTACLES	259	300	109	72	23	2	506
TOTAL	582	691	230	133	41	5	1100

Part one of this study is devoted to analysis of the main data (characteristics of the locations, obstacles impacted, types of impacts, driver-related data, crash conditions for motorist fatalities).

Part two contains, on the one hand, an evaluation of the number of fatalities which could have been prevented with 100% wearing of the seat belt (or another appropriate restraining system), and on the other hand an a priori evaluation of the potential safety benefits from protecting the obstacles, especially trees.

Main Characteristics of Fatal Crashes Against Fixed Obstacles

The results mentioned in part one of this study are based either on the observations of the national police force, or on crash research analysis carried out by our specialists at the laboratory.

With respect to the characteristics of locations, the following points should be noted.

- Close on 80% of crashes against fixed obstacles occurred outside of urban areas. The network of departmental roads represents 58% of all crashes, and the main highways 32%. Out of 100 crashes, the day/night breakdown is as follows: 47% by day and 53% by night [Table 3].

Table 3. Fatal Crashes Against Fixed Obstacles: Types of Road Networks, Road Categories and Luminosity

A - Impacts against trees (N = 323)

NETWORK	ROAD CATEGORY	LUMINOSITY				TOTAL
		DAY (143)	NIGHT (156)	DAWN/ DUSK (22)	UNKNOWN (2)	
IN TOWN (N = 33)	- National Highway	9	6	2	-	17
	- Departmental road	3	11	1	-	15
	- Others	1	-	-	-	1
OUT OF TOWN (N = 290)	- National Highway	48	47	6	1	102
	- Departmental road	77	85	10	1	173
	- Others	5	7	3	-	15

B - Impacts against other fixed obstacles (N = 259)

NETWORK	ROAD CATEGORY	LUMINOSITY				TOTAL
		DAY (112)	NIGHT (129)	DAWN/ DUSK (16)	UNKNOWN (2)	
IN TOWN (N = 84)	- National Highway	7	10	1	-	18
	- Departmental Road	14	36	2	-	52
	- Others	6	7	1	-	14
OUT OF TOWN (N = 175)	- National Highway	24	17	5	1	47
	- Departmental Road	45	50	4	1	100
	- Others	16	9	3	-	28

- Trees represent more than half (55.5%) of the obstacles impacted, followed by walls (13.6%), poles and embankments/ditches + pipes located in the ditches. The 2.4% of impacts against guardrails is far below the proportion observed in the U.S.A. [2], where this figure is close on 10% [Table 4].

Table 4. Breakdown of Fatal Crashes Against Fixed Obstacles According to Type of Obstacle

MAIN OBSTACLE	FATAL CRASHES	
	NUMBER	%
TREE	323	55.5
- Ø < 0.40 m	108	
- Ø 0.40 to 0.60 m	120	
- Ø > 0.60 m	95	
WALL, BUILDING	79	13.6
ELECTRICITY OR TELEPHONE POLE	60	10.3
DUCT (in ditch)	30	5.2
EMBANKMENT, DITCH	28	4.8
BRIDGE RAIL	21	3.6
GUARDRAIL	14	2.4
LAMP POST	7	1.2
OTHERS	20	3.4
TOTAL	582	100 %

- Crashes occur in the straights in 43% of cases, as against 54% in curves (including entry and exit), mostly in left-hand curves. In 17% of crashes, road adhesion was degraded (wet surface, snow, etc., or deformed roadway, loose gravel, etc.). We specify that climatic conditions were particularly mild during the period over which the cases were selected. In 52% of cases, the obstacle is located on the left road shoulder relative to the car's direction of travel [Table 5].

Table 5. Position, in Relation to the Initial Direction of Car Travel, of the Fixed Obstacle Impacted as a Function of the Road Layout and the Condition of the Roadway

A - Impacts against trees (N = 322*)

ROAD LAYOUT	DRY ROADWAY, IN GOOD CONDITION (N = 265)		WET ROADWAY, SNOW... AND/OR IN BAD CONDITION (N = 57)	
	On Right Shoulder (N = 120)	On Left Shoulder (N = 145)	On Right Shoulder (N = 21)	On Left Shoulder (N = 36)
- Straight section (165)	64	76	9	16
- Entry/Exit/In left curve (82)	41	31	5	5
- Entry/Exit/In right curve (72)	14	37	6	15
- Others (3)	1	1	1	-

B - Impacts against other fixed obstacles (N = 258*)

ROAD LAYOUT	DRY ROADWAY, IN GOOD CONDITION (N = 214)		WET ROADWAY, SNOW... AND/OR IN BAD CONDITION (N = 44)	
	On Right Shoulder (N = 112)	On Left Shoulder (N = 102)	On Right Shoulder (N = 23)	On Left Shoulder (N = 21)
- Straight section (87)	41	35	8	3
- Entry/Exit/In left curve (96)	53	31	6	6
- Entry/Exit/In right curve (65)	14	31	8	12
- Others (10)	4	5	1	-

* Undetermined in 1 case

- When the obstacle is a tree, the tree is isolated in only 10% of cases, while in two thirds of the cases it is located in a plantation bordering the road. Large plantations such as clumps of trees and forests represent close on one quarter of crash cases. In the case of trees lining the road, the average spacing between 2 trees is less than or equal to 10 metres in 55% of cases, between 10 and 20 metres in 40% of cases, and greater than 20 metres in 5% of cases. The tree is located at a distance less than or equal to 1 metre from the edge of the roadway in one third of cases (45% for rows of trees only), and more than 3 metres from the roadway in close on one case in four [Table 6].

Table 6. Distance Between Impacted Obstacle and the Edge of the Roadway

	DISTANCE (in metres) BETWEEN THE OBSTACLE AND THE (left or right) EDGE OF THE ROADWAY					
	⩽ 1.0	1.1-2.0	2.1-3.0	3.1-4.0	> 4.0	TOTAL
FATAL CRASHES AGAINST TREES						
ALL CRASHES of which...	109 (33.7)	95 (29.4)	43 (13.3)	28 (8.7)	48 (14.9)	323 (100 %)
- Isolated tree	10	10	7	3	3	33 (10.2 %)
- Row	95	77	25	9	7	213 (65.9 %)
- Clump	3	7	5	8	17	40 (12.4 %)
- Forest	1	1	6	8	21	37 (11.5 %)
FATAL CRASHES AGAINST OTHER FIXED OBSTACLES*						
ALL CRASHES	43 (16.7)	63 (24.5)	58 (22.6)	25 (9.7)	68 (26.5)	257 (100 %)

* Distance unknown in 2 cases

Analysis of the 582 fatal crash reports shows that frontal impact is the most frequent configuration, representing more than 50% of cases, both for impacts against trees and impacts against other fixed obstacles [Table 7]. Side impacts represent 31% of crashes (all fixed obstacles combined) and crashes of an "unclassifiable" type (car impacting an obstacle during a rollover or overturning) represent close on 15% of crashes.

By means of the photographs enclosed with the police reports, we established, for all frontal and side impacts, a distribution of overlaps (areas of main deformation) of the front (or side) with the obstacle. A fairly precise evaluation of the E.E.S. (Equivalent Energy Speed) was made for close on 80% of frontal impacts, while a more difficult (and therefore more approximate) evaluation was made for about two thirds of side impacts.

The following aspects are noteworthy.

In Frontal Impact, the impacts with the greatest offset (1/4 overlap type with deformations affecting the front wheel and the side of the passenger compartment, and of 1/3 overlap type in which a longitudinal member was subjected to loading) represent 30% of all impacts. Impacts in which the deformations affect (at most) half of the car concern 61% of impacts against trees and 44% of impacts against other fixed obstacles. Finally, impacts of the "centred" type concern less than one quarter of impacts against trees [Table 8].

Table 7. Breakdown of Fatal Crashes Against Fixed Obstacles According to Type of Impact

	TYPES OF IMPACT	ALL IMPACTS	
		Number	%
FATAL CRASHES AGAINST TREES	Frontal	163	(50.5)
	Side	108	(33.4)
	Unclassifiable	49	(15.2)
	Others	3	(0.9)
	TOTAL	323	100 %
FATAL CRASHES AGAINST OTHER FIXED OBSTACLES	Frontal	144	(55.6)
	Side	71	(27.4)
	Unclassifiable	38	(14.7)
	Others	6	(2.3)
	TOTAL	259	100 %

The E.E.S. distribution shows that the impacts, against trees especially, are extremely severe: the E.E.S. was evaluated at more than 55 km/h for close on three quarters of cars impacting a tree, as against 40% for impacts against other fixed obstacles [Table 9].

Table 8. Frontal Impacts—Areas of Overlap of the Car Front with the Obstacle

OVERLAP	FATAL CRASHES			
	AGAINST TREES		AGAINST OTHER FIXED OBSTACLES	
	Number	%	Number	%
1/4	16	9.8	23	16.0
1/3	34	20.9	19	13.2
1/2	50	30.7	22	15.3
2/3	19	11.6	18	12.5
Distributed	7	4.3	53	36.8
Centred	37	22.7	9	6.2
TOTAL	163	100 %	144	100 %

In Side Impact, impacts centred on the passenger compartment occur in 40% of cases, and impacts affecting all or part of the passenger compartment in more than 90% of cases [Table 10]. These impacts are extremely severe, as testified by the proportions of cars cut in two:

Table 9. Evaluation of E.E.S. (Equivalent Energy Speed) in Frontal Impact

EQUIVALENT ENERGY SPEED (km/h)	FATAL CRASHES AGAINST:			
	TREES		OTHER FIXED OBSTACLES	
≤ 35	2	1.3	15	11.4
36-45	12	7.9	32	24.2
46-55	26	17.2	33	25.0
56-65	73	48.3	38	28.8
66-75	34	22.5	11	8.3
> 75	4	2.6	3	2.3
SUB-TOTAL	151	100 %	132	100 %
Undetermined	12	-	12	-
TOTAL	163	-	144	-

Table 10. Side Impacts—Areas of Overlap of the Car Side with the Obstacle

OVERLAP	FATAL CRASHES			
	AGAINST TREES		AGAINST OTHER FIXED OBSTACLES	
	Number	%	Number	%
Front	7	6.5	6	8.4
Front + Passeng. Compart.	48	44.5	18	25.4
Passenger Compart. (only)	40	37.0	30	42.3
Passeng. Compart. + Rear	8	7.4	5	7.0
Rear	1	0.9	1	1.4
Whole car	4	3.7	11	15.5
TOTAL	108	100 %	71	100 %

- 18% in impacts against trees;
- 6% in impacts against other fixed obstacles.

For those impacts where it was possible to evaluate the E.E.S., this value is greater than 35 km/h in close on 80% of cases [Table 11].

Table 11. Evaluation of E.E.S. (Equivalent Energy Speed) in Side Impact

EQUIVALENT ENERGY SPEED (km/h)	FATAL CRASHES AGAINST:			
	TREES		OTHER FIXED OBSTACLES	
≤ 25	3	4.4	5	9.6
26-35	11	16.2	9	17.3
36-45	22	32.4	25	48.1
46-55	21	30.8	11	21.2
56-65	11	16.2	2	3.8
SUB-TOTAL	68	100 %	52	100 %
Undetermined	40 cars (of which 19 cut in two)		19 cars (of which 6 cut in two)	
TOTAL	108	-	71	-

Data Relating to Drivers Involved in Fatal Crashes against Fixed Obstacles

The driver is alone on board the vehicle in more than half of the cases (53%), and accompanied by a single passenger in 24% of cases.

The age of the vehicles on board which they are travelling is less than 3 years in 25% of cases, while in 50% of cases the cars first came onto the road between 1982 and 1987. Vehicles prior to 1975 represent only 3.5% of the cars involved.

The percentage of small sporting vehicles in the selected sample is 10.5% when the obstacle is a tree and 12.4% for other fixed obstacles.

For drivers (males and females) involved in fatal crashes against fixed obstacles, those aged under 26 represent almost half of all the drivers of the sample. For this same age group, the percentage of drivers involved in bodily injuries occurring in 1990 on the National Police network represents only 28% of cases. If we consider only drivers of male gender, the percentage of those involved in fatal crashes against fixed obstacles is twice as high as the figure for all bodily injuries in 1990 (National Police network). This "over-involvement" is even more marked for drivers of male gender aged under 21: 15.1% of the sample as against 6.6% of all bodily injuries [Table 12].

In traffic, approximately 5% of the drivers have had their driving license for one year or less. The drivers in the sample have had their driving license for less than or equal to 2 years in 28% of cases, and less than or equal to 1 year in 18% of cases. 4% of the drivers were using the vehicle without a license or had their license suspended [Table 13].

Table 12. Breakdown (by %) of Car Drivers by Age and Gender: 1) In Fatal Crashes Against All Fixed Obstacles 2) In All Accidents Involving Bodily Injury

	DRIVER AGE GROUP							TOTAL
	≤ 20	21/25	26/35	36/45	46/55	56/65	> 65	
FATAL CRASHES AGAINST ALL FIXED OBSTACLES								
Male	15.1	28.3	16.0	11.0	6.2	3.4	4.5	84.5
Female	1.6	2.9	4.5	2.8	1.5	0.7	1.5	15.5
TOTAL	16.7	31.2	20.5	13.8	7.7	4.1	6.0	100 %
ALL ACCIDENTS INVOLVING BODILY INJURY OCCURRING IN 1990 IN FRANCE*								
Male	6.6	15.1	17.9	13.6	8.3	6.4	5.9	73.8
Female	1.8	4.6	7.5	6.1	3.1	1.9	1.2	26.2
TOTAL	8.4	19.7	25.4	19.7	11.4	8.3	7.1	100 %

* National Police Network

Table 13. No. of Years Driving License Held by Drivers Involved in Fatal Crashes Against All Fixed Obstacles

BREAKDOWN OF DRIVERS BY No. OF YEARS DRIVING LICENCE HELD							TOTAL
≤ 1 YEAR	2 YEARS	3 YEARS	4 YEARS	5 YEARS AND +	OTHERS (no licence, licence suspended)	UNDETERMINED	
90 15.5 %	47 8.1 %	37 6.4 %	23 3.9 %	282 48.4 %	19 3.3 %	84 14.4 %	582 100 %

Fatal crashes occurred during the weekend in 45.7% of cases, when travelling to or from a dance or a party in 17.9% [Table 14].

Table 14. Fatal Crashes Against All Fixed Obstacles: Reasons for Trip According to Time of the Week

TYPES OF TRIP (outward or return)	MONDAY TO FRIDAY	SATURDAY AND SUNDAY	TOTAL
ALL TRIPS of which...	316 (54.3 %)	266 (45.7 %)	582 (100 %)
- Professional motive	62	14	76
- Outing or personal motive	74	50	124
- Gathering of family or with friends	27	31	58
- Week-end, holidays	16	21	37
- Danse, party	32	72	104
- Others	5	2	7
- Undetermined	100	76	176

In France, for all bodily injuries, the Police Force checks the alcohol absorption of the drivers involved.

In the sample, a number of cases were unable to be documented (impossible to take a blood sample, result unknown to date, etc.). For the other cases, or 295 fatal crashes, it appears that 45.8% of the drivers have an alcohol level above the legal limit (in France, equivalent to 0.8 g of alcohol per litre of blood), of which 15% have more than 2 g of alcohol per litre of blood [Table 15].

Table 15. Fatal Crashes Against All Fixed Obstacles: Results of Driver Alcohol Tests

ALCHOHOL LEVEL TEST CONDITIONS	NUMBER OF CASES	BLOOD SAMPLE (OR BREATHALYZER) LEVEL					
		0	0.02/0.80	0.81/1.20	1.21/2.00	> 2.00	Unknown
No test	4* (0.7 %)						
Blood test or breath test practised:							
- Negative	54 (9.3 %)						
- Positive (no blood-test result)	4 (0.7 %)						
Breathalyzer test	8 (1.4 %)	1	1	2	3	1	
Blood test	367 (63.0 %)	60	44	20	63	42	138
Blood test impossible	145 (24.9 %)						
TOTAL	582 (100 %)	61	45	22	66	43	138

* Including 2 hit-and-run drivers, caught later

Fatal Crashes Against Fixed Obstacles: Crash Conditions for the 691 Motorist Fatalities in the Sample

Front-seat occupants represent 86% of fatalities for all impacts together, and rear-seat occupants 14% of fatalities. The youngest occupants (≤age 20) are over-represented (26% of fatalities as against only 17% of all motorist fatalities on the national network in 1990). Conversely, persons aged over 50 represent only 14% of deceases, as against 24% in the overall evaluation [Table 16].

Table 16. Breakdown of Motorist Fatalities by Age Group and Position Occupied in the Basic Sample

AGE	DRIVERS	FRONT PASSENGERS	REAR PASSENGERS	TOTAL
FATAL CRASHES AGAINST TREES				
≤ 10	-	-	7	7
11-20	38	29	32	99
21-30	105	33	13	151
31-50	73	9	3	85
51-60	21	3	1	25
> 60	15	8	1	24
TOTAL	252 (64.5)	82 (21.0)	57 (14.5)	391 (100 %)
FATAL CRASHES AGAINST OTHER FIXED OBSTACLES				
≤ 10	-	1	11	12
11-20	22	21	18	61
21-30	69	30	6	105
31-50	58	9	2	69
51-60	9	5	-	14
> 60	27	9	1	37
TOTAL	187 (62.3)	75 (25.0)	38 (12.7)	300 (100 %)

The breakdown of fatalities in all positions according to types of impacts and obstacles [Table 17] shows that frontal impact is the cause of the highest percentage of occupant fatalities (52%), before side impacts (31%) and "unclassifiable" impacts (16%).

Motorist Fatalities in Frontal Impact

The breakdown of fatalities by types of obstacles according to the position occupied, the velocity change (delta-V) of the occupant and the level of intrusion sustained by the occupant is given in Tables 18 and 19. The proportion of fatalities ejected completely from the car is 7% in impacts against trees, and 20% in impacts against other fixed obstacles. For the unejected fatalities, the problem for the analyst at the Laboratory is to determine whether the seat belt (or possibly another restraining system, such as a child's seat for example) was worn at the time of the impact. In some cases, by examining the crash report it is possible to conclude as to whether or not a restraining system was used. In other cases (chiefly impacts in which the fatality is the victim of a critical intrusion), the absence of reliable information in the report inevitably results in a significant number of cases where it is undetermined whether the seat belt was worn or not.

Table 17. Breakdown of Fatalities by Type of Impact

	FRONTAL	SIDE	UNCLASSIFIABLE	OTHERS	TOTAL
AGAINST TREES	192 (49.1)	130 (33.3)	65 (16.6)	4 (1.0)	391 (100 %)
AGAINST OTHER FIXED OBSTACLES	164 (54.7)	85 (28.3)	45 (15.0)	6 (2.0)	300 (100 %)
TOTAL	356 (51.5)	215 (31.1)	110 (15.9)	10 (1.5)	691 (100 %)

Table 18. Fatalities in Frontal Impact Against Trees—Description of Impact Conditions

SEVERITY (Delta-V) OF IMPACTS (km/h)	LEVEL OF INTRUSION ON OCCUPANT*	UNEJECTED FATALITIES			EJECTED FATALITIES	TOTAL
		RESTRAINED OCCUPANTS	UNRESTRAINED OCCUPANTS	UNDETERMINED (Restrained or unrestrained)		
FRONT-SEAT OCCUPANTS (N = 178)						
≤ 40	A	2	2	2	1	7
41-50	A	-	8	3	-	11
	B	-	-	1	-	1
51-60	A	3	9	10	-	22
	B	3	4	10	-	17
	C	3	-	2	-	5
	Undetermined	-	1	1	-	2
61-70	A	1	5	6	3	15
	B	3	6	13	-	22
	C	9	7	18	2	36
> 70	A	-	1	-	-	1
	C	2	3	1	1	7
Undetermined	A	1	2	1	2	6
	B	2	4	3	-	9
	C	-	2	5	2	9
	Undetermined	-	1	6	1	8
REAR-SEAT OCCUPANTS (N = 14)						
51-60	A	-	4	-	-	4
61-70	A	-	5	3	1	9
Undetermined	A	-	-	1	-	1
TOTAL		29 (15.1 %)	64 (33.3 %)	86 (44.8 %)	13 (6.8 %)	192 (100 %)

* - 3 degrees of intrusion :
A ---> from 0 to 30% }
B ---> from 30 to 50% } reduction in free space in front of the occupant
C ---> above 50% }

- Intrusion undetermined = intrusion on occupant but unquantifiable

In Impact against Trees, evaluation of the delta-V (the delta-V is equal to the E.E.S., except for cases in which the fixed obstacle has dissipated a large amount of energy and cases in which the car swipes the side of the obstacle, in other words when the vehicle comes completely to a stop at a distance greater than 10 m beyond the point of impact without any major change in its trajectory) was possible for 159 of the 192 fatalities. The evaluation shows that 88% of the fatalities sustained a delta-V greater than 50 km/h, and 57% a delta-V greater than 60 km/h.

Table 19. Fatalities in Frontal Impact Against Other Fixed Obstacles—Description of Impact Conditions

SEVERITY (Delta-V) OF IMPACTS (km/h)	LEVEL OF INTRUSION ON OCCUPANT*	UNEJECTED FATALITIES			EJECTED FATALITIES	TOTAL
		RESTRAINED OCCUPANTS	UNRESTRAINED OCCUPANTS	UNDETERMINED (Restrained or unrestrained)		
FRONT-SEAT OCCUPANTS (N = 151)						
≤ 40	A	2	11	2	3	18
41-50	A	3	17	3	2	25
	B	-	2	-	-	2
51-60	A	1	11	3	1	16
	B	2	3	1	-	6
	C	2	1	-	-	3
	Undetermined	-	1	-	-	1
61-70	A	1	3	1	-	5
	B	3	1	1	1	6
	C	3	-	2	-	5
> 70	A	-	1	1	-	2
	B	1	-	2	-	3
	C	1	1	1	-	3
Undetermined	A	3	8	4	16	31
	B	1	3	3	1	8
	C	1	2	6	1	10
	Undetermined	1	1	3	2	7
REAR-SEAT OCCUPANTS (N = 13)						
≤ 40	A	-	1	-	-	1
41-50	A	2 (child seats)	1	-	1	4
51-60	A	-	-	-	2	2
> 70	A	1 (child seat)	1	-	-	2
Undetermined	A	-	1	-	3	4
TOTAL		28 (17.1 %)	70 (42.7 %)	33 (20.1 %)	33 (20.1%)	164 (100 %)

* - 3 degrees of intrusion :
A ---> from 0 to 30% }
B ---> from 30 to 50% } reduction in free space in front of occupant
C ---> above 50% }

- Intrusion undetermined = intrusion on occupant but unquantifiable

By comparison with the results obtained close on ten years ago by processing fatal motorist crashes occurring on the national network in the 2nd quarter of 1980 [3], one observes a sharp increase in the delta-V, since 68% of fatalities had sustained a delta-V greater than 50 km/h, and 43% a delta-V greater than 60 km/h. A delta-V of approximately 58 km/h covered 50% of fatalities, as against 62 km/h nowadays.

Intrusion in the passenger compartment, which is estimated from photographs of the car, is quantified as a percentage of reduction of the free space in front of the occupant in question. Three degrees of intrusion will be considered here:

- reduction ≤30% (zero or moderate intrusion);
- reduction of 30 to 50% (severe intrusion);
- reduction of 50 to 100% (critical intrusion).

Overall, one observes that 40% of fatalities (76/192) sustained no intrusion or that the reduction of space was small or moderate, and that 55% of fatalities sustained a severe intrusion (49 fatalities) or a critical intrusion (57 fatalities). The remaining 10 fatalities (5% of cases) also sustained intrusion of the passenger compartment, but the photographs enclosed with the files did not allow us to make an adequate evaluation.

In Impact against Other Fixed Obstacles, the delta-V was able to be evaluated for 104 of the 164 fatalities. As a general rule, the severity of the impacts, in terms of speed of impact, is less than that observed in impacts against trees:

- 52% of fatalities sustained a delta-V greater than 50 km/h;
- 25% of fatalities sustained a delta-V greater than 60 km/h.

Accordingly, cases of major intrusion are less frequent and two thirds (110/164) of deceases occurred in impacts in which the reduction of space available for effective restraining by the seat belt was zero or limited. 28% of fatalities sustained a severe intrusion (25 fatalities) or a critical intrusion (21 fatalities), while the 8 remaining fatalities (5% of cases) also sustained an intrusion of the passenger compartment which could not be quantified on the basis of the data in the files.

Motorist Fatalities in Side Impact

The breakdown of fatalities by types of obstacles according to their position in the car in relation to the impacted zone, the velocity change (delta-V) of the car and the degree of intrusion sustained by each victim is given in Tables 20 and 21.

Table 20. Fatalities in Side Impact Against Trees—Description of Impact Conditions

SEVERITY (Delta-V) OF IMPACTS (km/h)	LEVEL OF INTRUSION ON OCCUPANT*	UNEJECTED FATALITIES			EJECTED FATALITIES	TOTAL
		RESTRAINED OCCUPANTS	UNRESTRAINED OCCUPANTS	UNDETERMINED (Restrained or unrestrained)		
NEAR-SIDE OCCUPANTS WITH INTRUSION (N = 75)						
21-30	A	-	1	-	-	1
	B	-	-	1	-	1
31-40	A	1	-	1	-	2
	B	2	1	5	1	9
	C	-	1	1	-	2
41-50	A	1	-	1	-	2
	B	1	-	1	1	3
	C	2	2	6	1	11
	Undetermined	-	-	1	-	1
> 50	A	-	-	1	-	1
	C	4	2	7	-	13
Undetermined	A	1	2	2	5	10
	B and C	3	-	2	1	6
	Undetermined	2	2	7	2	13
NEAR-SIDE OCCUPANTS WITH NO INTRUSION (N = 6)						
≤ 20	A	-	1	-	-	1
31-40	A	-	-	-	2	2
41-50	A	-	-	-	1	1
Undetermined	A	-	-	-	2	2
FAR-SIDE OCCUPANTS (N = 43)						
21-30	A	-	1	-	-	1
31-40	A	-	1	-	1	2
41-50	A	3	5	2	2	12
> 50	A or B or C	3	1	8	2	14
Undetermined	A or B or C	-	3	5	6	14
REAR-SEAT OCCUPANTS, POSITIONS UNDETERMINED (N = 6)						
31-40	Undetermined	-	2	-	1	3
41-50	Undetermined	-	1	-	-	1
> 50	Undetermined	-	1	-	-	1
Undetermined	Undetermined	-	-	-	1	1
TOTAL		23 (17.7 %)	27 (20.8 %)	51 (39.2 %)	29 (22.3 %)	130 (100 %)

* - 3 degrees of intrusion :
A ---> from 0 to 30% }
B ---> from 30 to 50% } reduction in passenger space at right angle to occupant
C ---> above 50% }

- Intrusion undetermined = intrusion on occupant but unquantifiable

Table 21. Fatalities in Side Impact Against Other Fixed Obstacles—Description of Impact Conditions

SEVERITY (Delta-V) OF IMPACTS (km/h)	LEVEL OF INTRUSION ON OCCUPANT*	UNEJECTED FATALITIES			EJECTED FATALITIES	TOTAL
		RESTRAINED OCCUPANTS	UNRESTRAINED OCCUPANTS	UNDETERMINED (Restrained or unrestrained)		
NEAR-SIDE OCCUPANTS WITH INTRUSION (N = 50)						
21-30	A	-	2	1	-	3
	B	-	3	-	-	3
31-40	A	-	5	1	-	6
	B	-	-	2	-	2
	C	1	-	1	-	2
41-50	A	2	-	-	-	2
	B	2	1	-	-	3
	C	3	2	2	-	7
	Undetermined	1	-	-	-	1
> 50	B	-	1	-	-	1
	C	1	-	2	-	3
Undetermined	A	3	-	1	2	6
	B	2	2	-	1	5
	C	1	-	1	-	2
	Undetermined	-	-	3	1	4
NEAR-SIDE OCCUPANTS WITH NO INTRUSION (N = 4)						
Undetermined	A	-	2	1	1	4
FAR-SIDE OCCUPANTS (N = 29)						
31-40	A	2	4	1	3	10
41-50	A or B or C	2	1	1	2	6
> 50	A or B or C	1	2	1	-	4
Undetermined	A or B or C	2	4	2	1	9
REAR-SEAT OCCUPANTS, POSITIONS UNDETERMINED (N = 2)						
Undetermined	Undetermined	-	2	-	-	2
TOTAL		23 (27.1 %)	31 (36.5 %)	20 (23.5 %)	11 (12.9 %)	85 (100 %)

* - 3 degrees of intrusion :
A ---> from 0 to 30% }
B ---> from 30 to 50% } reduction in passenger space at right angle to occupant
C ---> above 50%

- Intrusion undetermined = intrusion on occupant but unquantifiable

The proportion of ejected occupants among the fatalities is 22% in impacts against trees and 13% in impacts against other fixed obstacles. Apart from the fact that these ejections generally occur in impacts of high violence, it should be specified that 9 of the 29 cases of ejection (31%) in impacts against trees occurred on board cars which were cut in two, and in 2 cases out of 11 (18%) in impacts against other fixed obstacles.

As for frontal impact, the lack of reliable information in the crash report results in a significant number of "unknowns" concerning the use of a restraining system by unejected occupants.

In Impact Against Trees, the occupants killed are near-side occupants who sustain a direct intrusion in 58% of cases. For the far-side occupants killed (one third of fatalities), it is frequent for penetration of the body side panel to reach or exceed the median plane of the car in impacts with a car delta-V greater than 45 km/h.

A rough evaluation of the car delta-V was able to be performed for 84 of the 130 fatalities, in all vehicle occupancy configurations. It shows that in more than two cases out of three, the impacts occur at a speed greater than 40 km/h.

In Impact Against Other Fixed Obstacles, the proportion of near-side fatalities "with intrusion" and of far-side fatalities is of the same order as in impact against trees: 59% and 34% of all fatalities respectively.

For cases in which the velocity change of the car was able to be evaluated (this concerns 53 of the 85 fatalities), one observes that the impacts occur at a speed greater than 40 km/h in one case out of two.

Motorist Fatalities in "Unclassifiable" Impacts

110 occupants (in impact against trees and other fixed obstacles) were killed in impacts in which the car impacted the obstacle during an overturning or a roll-over. Since the impacts generally occur on all or part of the car's roof panel, it is not possible to estimate the speeds. However, it is probable that these impacts occur at speeds close to those observed in side impact.

The proportion of fatalities that sustained complete ejection is 15% (16/110), while the proportion of fatalities which, according to the analysts, used a restraining system, is 23% of all unejected fatalities (22/94).

Motorist Fatalities in Other Impacts (Rear Impact, Side Swipe)

Such cases represent 1.4% of all fatalities.

Fatalities in Crashes Against Fixed Obstacles: Prognostic Concerning the Effectiveness of the Seat Belt

If the seat belt (or an appropriate restraining system) had been worn by all deceased occupants, the proportion of avoidable fatalities would have been 29% for all fatal impacts against fixed obstacles and 21% for fatal impacts against trees alone.

The number of fatalities which would probably be prevented, in each impact configuration, has been calculated taking into account, in particular:

- the violence of the impacts (delta-V);
- the level of intrusion on the occupant;
- the age of the occupants.

The evaluations made by the specialists at the Laboratory show that approximately 40% of fatalities in frontal impact (against all fixed obstacles) could have been prevented if the seat belt had been worn in all positions, as against 16% in side impact and in impacts of an "unclassifiable" nature.

In what follows, the gains which would result from 100% wearing of the seat belt are evaluated in terms of the proportion of fatalities prevented, for each type of obstacle and impact.

Probable Effectiveness of the Seat Belt

1. *In Frontal Impact*: The proportion of preventable fatalities in impact against trees would be approximately 32% as against 49% in impact against other fixed obstacles. For all impacts against fixed obstacles, the proportion of fatalities prevented would be 40% [Tables 22 and 23].

Table 22. Proportion Fatalities in Frontal Impact Using or Not Using a Restraining System as per APR

OBSTACLES	RESTRAINING SYSTEM USED			
	YES	NO	UNDETERMINED	TOTAL
TREES	29 (15.1)	73 (38.0)	90 (46.9)	192 (100 %)
OTHER FIXED OBSTACLES	28 (17.1)	103 (62.8)	33 (20.1)	164 (100 %)
TOTAL	57 (16.0)	176 (49.4)	123 (34.6)	356 (100 %)

Table 23. Fatalities in Frontal Impact: Probable Effectiveness of a Restraining System for Unrestrained Fatalities and Cases Where Seat-Belt Wearing is Undetermined

OBSTACLES	PREVENTABLE FATALITIES	REMAINING FATALITIES	UNDETERMINED	TOTAL
TREES	62 (38.0)	93 (57.1)	8 (4.9)	163 (100 %)
OTHER FIXED OBSTACLES	81 (59.6)	45 (33.1)	10 (7.3)	136 (100 %)
TOTAL	143 (47.8)	138 (46.2)	18 (6.0)	299 (100 %)

2. *In Side Impact*: In impact against trees, the proportion of preventable fatalities would be approximately 12% as against 21% in impact against other fixed obstacles. For all types of impact, this proportion would be 16% [Tables 24 and 25].

Table 24. Proportion of Fatalities in Side Impact Using or Not Using a Restraining System as per APR

OBSTACLES	RESTRAINING SYSTEM USED			
	YES	NO	UNDETERMINED	TOTAL
TREES	23 (17.7)	51 (39.2)	56 (43.1)	130 (100 %)
OTHER FIXED OBSTACLES	24 (28.2)	41 (48.2)	20 (23.5)	85 (100 %)
TOTAL	47 (21.8)	92 (42.8)	76 (35.3)	215 (100 %)

Table 25. Fatalities in Side Impact: Probable Effectiveness of a Restraining System for Unrestrained Fatalities and Cases Where Seat-Belt Wearing is Undetermined

OBSTACLES	PREVENTABLE FATALITIES	REMAINING FATALITIES	UNDETERMINED	TOTAL
TREES	16 (15.0)	80 (74.8)	11 (10.3)	107 (100 %)
OTHER FIXED OBSTACLES	18 (29.5)	41 (67.2)	2 (3.3)	61 (100 %)
TOTAL	34 (20.2)	121 (72.0)	13 (7.7)	168 (100 %)

3. *In Impacts of an "Unclassifiable" Nature*: The proportion of preventable fatalities in impact against trees would be approximately 6%, as against 31% in impact against other fixed obstacles. For all types of impact, this proportion would be 16% [Tables 26 and 27].

Table 26. Proportion of Fatalities in Impacts of an "Unclassifiable" Nature Using or Not Using a Restraining System as per APR

OBSTACLES	RESTRAINING SYSTEM USED			
	YES	NO	UNDETERMINED	TOTAL
TREES	11 (16.9)	28 (43.1)	26 (40.0)	65 (100 %)
OTHER FIXED OBSTACLES	12 (26.7)	20 (44.4)	13 (28.9)	45 (100 %)
TOTAL	23 (20.9)	48 (43.6)	39 (35.5)	110 (100 %)

Table 27. Fatalities in Impacts of an "Unclassifiable" Nature: Probable Effectiveness of a Restraining System for Unrestrained Fatalities and Fatalities for Which Seat-Belt Wearing is Undetermined

OBSTACLES	PREVENTABLE FATALITIES	REMAINING FATALITIES	UNDETERMINED	TOTAL
TREES	4 (7.4)	48 (88.9)	2 (3.7)	54 (100 %)
OTHER FIXED OBSTACLES	14 (42.4)	17 (51.5)	2 (6.1)	33 (100 %)
TOTAL	18 (20.7)	65 (74.7)	4 (4.6)	87 (100 %)

4. *In Other Impacts*: The 10 fatalities in rear impact or in side swipe were not restrained occupants. The use of a restraining system would probably have made it possible to prevent the decease of 5 of them, including 1 in an impact against a tree.

In sum, out of all fatal impacts against fixed obstacles, it is probable that approximately 200 of the 691 motorist fatalities (29%) would have been prevented by 100% wearing of the seat belt (or the use of a restraining system).

The proportion of lives saved is high (39%) in impact against other fixed obstacles, where 117 of the 300 fatalities could have been prevented, and less in impact against trees, since (only) 83 of the 391 fatalities (21%) would have benefited from this safety measure.

Applied to the 5014 motorist fatalities which occurred on the National Police network in 1990, 100% wearing of the seat belt (or the use of an appropriate restraining system) for impacts against fixed obstacles only would probably have made it possible to prevent between 400 and 500 fatalities (185 fatalities against trees and 270 against other fixed obstacles).

Fatalities in Crashes Against Fixed Obstacles: Prognostic Concerning the Effectiveness of Road Infrastructure Improvement by Isolating Trees

While the setting up of a guardrail appears rather unrealistic for most impacts against fixed obstacles other than trees (obstacles which are isolated, or even remote from the roadway, dwelling houses, etc.), the isolation of trees can be considered chiefly in the case of repeated obstacles such as rows of trees planted alongside the roads.

Concerning the protection of motorists (and trees), we have considered it "inconceivable" to set up a guardrail in close on one crash case out of two.

The same is true is most cases where:

- the setting up of a guardrail is incompatible with the environment (exits from houses for example, when going through small and medium-size towns in particular);
- the tree is isolated;
- the tree is located more than 4 metres from the roadway (mainly clump type plantations or forests);
- the roadway is very narrow (communal lanes).

Where the setting up of a guardrail seemed to us realistic, we considered its "probable effectiveness," taking into account chiefly:

- the impact angle according to the traces of braking or skidding noted on the roadway and/or wheel marks left on the road shoulder and/or, failing that, the location of impact traces observed on the bark of the tree;
- the speed of impact (estimate of the Equivalent Energy Speed) of the car against the tree when evaluation was possible.

The guardrail is regarded as effective if, after absorbing energy, it can prevent impact against the tree by guiding the car back onto the roadway or contribute to reducing the consequences of the impact.

The isolation of a tree by a flexible metallic guardrail implies that a distance equal to the system's pocket of deformation be available in front of the obstacle. Accordingly, plantations closest to the road and the most dangerous can be protected satisfactorily by a "conventional" guardrail.

Research on a product which could be used at a small distance from the obstacles and would be capable of restraining the cars in safe conditions (in particular, preventing the car from rebounding at a large angle in the event of impacts) was undertaken several years ago.

By adapting a device designed to reinforce the sliding surface and allow the attachment of a "support" at a right angle to the tree [Figure 1], one can reduce the distance at which the device is set up to 0.60 m, or even 0.40 m, from the tree. Various impact tests were performed on the device set up at the level of the tree; the results were good [4].

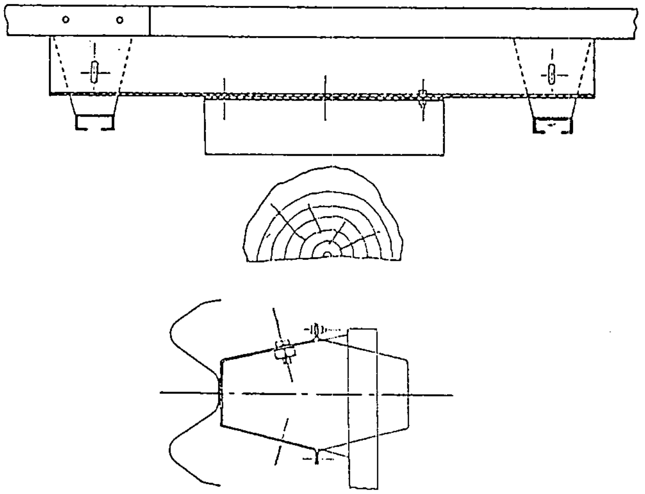


Figure 1. Setting Up a Guardrail: Mounting of Adaptor When the Obstacle is Located at a Right Angle to the Support

In the case of plantations lining the road, we have considered using this "specialized" guardrail in most cases in which it could be set up 0.50 m from the tree.

The gains which would be obtained by realistic setting up of guardrails along roads lined with trees, clumps of trees or forests in the open countryside (mainly departmental roads and national highways) are evaluated at 50% (196/391) in terms of preventable fatalities, assuming, of course, that the seat belt (or another means of protection) is worn by each of the fatalities of the reference sample [Table 28].

Table 28. Summary of Probable Effectiveness (as per APR) of a Guardrail in Fatal Impacts Against Fixed Obstacles

TYPES OF IMPACT	EFFECTIVE	INEFFECTIVE	UNDETERMINED	INCONCEIVABLE	NOT APPLICABLE (impact against guardrail)	TOTAL
FATALITIES IN FATAL ACCIDENTS AGAINST TREES						
Frontal	114 (105)	5 (5)	3 (3)	70 (29)	-	192 (142)
Side	61 (58)	2 (2)	8 (8)	59 (23)	-	130 (91)
Unclassifiable	18 (11)	4 (4)	1 (1)	42 (1)	-	65 (17)
Others	3 (3)	-	-	1	-	4 (3)
Total	196 (177) 50.1 %	11 (11) 2.8 %	12 (12) 3.1 %	172 (53) 44.0 %	- -	391 (253) 100 %
FATALITIES IN FATAL CRASHES AGAINST OTHER FIXED OBSTACLES						
Frontal	4	-	-	159	1	164
Side	3	-	1	76	5	85
Unclassifiable	1	-	-	36	8	45
Others	-	-	-	6	-	6
Total	8 2.7 %	- -	1 0.3 %	277 92.3 %	14 4.7 %	300 100 %

(N.B.: The values in brackets refer to fatalities occurring against plantations lining the road)

Note that of the 196 fatalities preventable by isolating trees, wearing of the seat belt (or the use of a restraining system) would have undoubtedly, by itself, made it possible to prevent 44 fatalities, or less than one quarter of these victims.

The isolation of in-line plantations only would probably have made it possible to prevent 45% of the 900 or so fatalities in crashes against trees counted in 1990 on the National Police network, or approximately 400 preventable fatalities.

Knowing, moreover, that the proportions of motorist fatalities in the open countryside in impact against trees and in rollover (which generally occur after leaving the roadway) are identical (17 to 18% of all fatalities), it is probable that these measures would be beneficial for a certain number of motorist fatalities in rollover. The effects of this measure are still of course hard to calculate.

In the long term, over 20 years for example, the widespread setting up of guardrails in "high risk" areas should make it possible to prevent close on 8000 fatalities, or the equivalent of 80% of the fatalities in France each year, for all categories of users taken together.

Conclusions

On the network supervised by the National Police (5014 motorist fatalities in 1990), impacts against trees and other fixed obstacles represent 900 and 700 fatalities respectively.

Fatal crashes against fixed obstacles occur generally:

- outside of towns (80% of cases);
- on departmental roads (58% of cases);
- at night (53% of cases).

Plantations lining the road represent two thirds of fatal crashes against trees, while walls and poles, by themselves, represent more than half of the other fixed obstacles.

In 53% of cases, the driver is alone on board the car. The frequency of involvement of drivers of male gender aged 25 or under (43%) is twice that observed for all bodily injuries. The proportion of drivers who have had their driving license for 1 year (at most) and of those driving without a license is 22%. Almost half (46%) of the drivers on whom the alcohol test was performed and the results were known, had an alcohol level exceeding the legal rate.

For all fixed obstacles combined, frontal impact is the cause of the highest percentage of occupant fatalities (52%), before side impacts (31%) and impacts of an "unclassifiable" nature in which the car impacted the obstacle during an overturning or a rollover (16%).

In frontal impact against trees, more than half of the fatalities (restrained and unrestrained occupants) for which the violence of impact was able to be estimated sustained a delta-V greater than 60 km/h, which obviously resulted in extensive intrusion of the passenger compartment. Frontal impacts against other fixed obstacles are, in general, of lower violence, since a quarter of fatalities are involved in impacts of severity greater than 60 km/h delta-V.

Side impacts against fixed obstacles are extremely severe: the car delta-V is estimated at more than 40 km/h in more than 50% of cases where it was able to be evaluated, and close on one car out of five in impact against trees is cut in two. In side impact against trees or other fixed obstacles, the fatalities are near-side occupants and they sustain a direct intrusion by the obstacle in close on 60% of cases. One third of fatalities are far-side occupants and these fatalities frequently occur in impacts in which the penetration of the car reaches or exceeds the centreline.

With 15% of fatalities, impacts of an "unclassifiable" nature are far from insignificant.

100% wearing of the seat belt (or the use of another means of protection) would probably have made it possible to prevent 29% of fatalities against fixed obstacles (21% in impact against trees). It is in frontal impact that the percentage of preventable fatalities seems greatest: 49% in impact against other fixed obstacles, 32% in impact against trees.

Over one year, the effects of this safety measure, applied in full, would have made it possible to prevent between 400 and 500 fatalities, including approximately 200 in impacts against trees.

The gains which would result from realistic setting up of guardrails along departmental roads and national highways lined with trees are evaluated at 45% of all fatalities in crashes against trees, or approximately 400 preventable fatalities over one year.

Acknowledgements

We should like to thank the Police Forces for kindly providing us with a copy of fatal crash police reports. Without their cooperation, this study would have been impossible.

References

1. Gendarmerie Nationale (National Police), 1990: annual road accident statistics.
2. Fatal Accident Reporting System, 1989: A review of information on Fatal Traffic Crashes in the United States.
3. J.Y. Foret-Bruno, F. Hartemann et al.: "Principales caracteristiques des accidents mortels de voitures particulieres survenus en FRANCE au cours du 2eme trimestre de 1980." Unpublished Report of the Laboratory of Physiology and Biomechanics associated with PEUGEOT SA/RENAULT
4. General Review of Roads and Aerodromes (January 1984): "Quels dispositifs de retenue pour demain"—J.C. Dupuis, French Road Safety and Traffic Board.

S1-W-16

Patterns and Causes of Serious Injury Amongst Car Occupants

Peter L Harms
Private Consultant
R J Tunbridge
Transport and Road Research Laboratory

Abstract

This Paper reports on a sample of nearly 3700 accident-involved cars with 4491 injured occupants. These were selected from a comprehensive crash-injury investigation which has been underway in the UK since 1983. Detailed injury mechanisms quantify injury sources from this very large sample and enables a perspective view to be taken on future direction of remedial measures. The results show that the majority of impacts were to the front of the vehicle and involved the offside part of the front more often than the nearside. Approximately three quarters of the front occupants were known to be restrained, while most of the rear seat passengers were unrestrained. As expected, the unrestrained passenger sustained a greater level of overall injury than the restrained, this difference being more pronounced in side impacts. In absolute numbers, most injuries occurred to the cranium and limbs with the steering wheel being responsible for most head/face and trunk injuries to the driver. Most of the other injuries to all occupants occurred when they contacted adjacent, internal structures in the direction of impact. The seat belt webbing featured highly in trunk injuries and although these are seen as a lesser evil than injuries sustained by the unrestrained. A proportion of upper body injuries were caused by contact with another vehicle or external structure and it is reasoned that attention should be given to reducing injuries from intrusion in side impacts. The results indicate that all occupants should be restrained. Means such as persuasion or enforcement should be used to make restraint use effective. Consideration must also be given reducing entrapment, particularly of the lower limbs, in order to improve the clinical outcome of casualties who may have other injuries.

Introduction

Analyses presented in this Paper derive from an ongoing study from which new information is added to the main computerised database on a regular basis. The present work on car accident injury mechanisms, known as the Cooperative Crash Injury Study (CCIS), commenced in 1983 and this Paper uses data gathered from that time up to mid-1989. The study methodology has previously been described by Mackay et al [1], Otubushin and Galer [2], and with database aspects more recently being described by Renouf [3]. The data is subject to a number of validation checks and the full data "released" for analyses only when these are satisfactory. Therefore the database operates on a process of continuous growth. Each release will contain more data than its predecessor, a large database being required to analyse certain variables that are not very common. The new data will of course be gathered during the time that vehicle designs are changing. As the database grows in size, more refined and detailed analyses can take place. This could include comparisons between model types in the same impact configuration. The effects of relevant legislative changes such as the new rear seatbelt law will hopefully be investigated in future presentations. However there is always the danger that vehicle design changes and the introduction of new legislation will make some aspects of the earlier data obsolete. Time series analyses must be treated with some caution as changes over an extended period will mean that a particular analysis may not always be comparing "like with like."

Given some restrictions on observing and therefore assigning injury causes in modern vehicles, *probable* contacts are considered, relying on the expertise and experience of the investigators. A high standard of investigation and audit is required. The Paper attempts to address the question of where problem areas lie in relation to injury causation.

Cars that are less than 6 years old at the time of the accident and have been damaged sufficiently to be towed from the scene form the basis of selection for investigation. These are known as "case" vehicles for the purposes of the study. The sample is further stratified by injury severity (as assessed by the police), based on the highest injury level in the selected vehicle. The tow-away criteria is not applied when there is a fatality in the "case" vehicle. Therefore the accidents are sampled on vehicle age, damage, police injury severity and injury outcome. This sampling basis has relevance when weighting the data in order to relate sample size and certain parameters to the number of car accidents in a given catchment area and eventually to the national accident scene. Application of weighting factors to the database is in hand but will not be applied in this Paper.

The sample used in the following analyses initially comprised 3695 vehicles and 6220 occupants of which 4491 were injured. Injury severity was assessed using the 1985 Abbreviated Injury Scale [4]. The parameters considered were occupant age, injury severity/body region, seating position, impact direction, restraint use and injury mechanisms.

Impact Characteristics and Restraint Use

Impact Characteristics

A vehicle can have more than one impact in an accident and the data set records up to three in severity order. Only the direction of the most severe impact is considered in these analyses, using the Collision Deformity Classification (CDC) system [5] which allocates direction of impact using the twelve clock points. There are further gradations in this system related to the side and part of the side impacted, height and also extent of the impact zone and some of these will be considered. Accidents involving a right-angled impact plus or minus one clock point related to the struck "side" of the vehicle have been chosen. Therefore a frontal impact is 11, 12 or 1 o'clock to the vehicle's front structure. Similarly an offside impact is 2, 3, or 4 o'clock to the right-hand side and 8, 9 and 10 o'clock to the left-hand side of the "case" vehicle. It is appreciated that vehicle collisions are rarely straightforward as there is often an element of rebound and/or spin following the initial impact which could affect occupant contact and possibly injury outcome. However, the simplified approach described above enables most of the relevant accidents to be categorised. The sample size using the above classification is given in Table 1 where it will be seen that the majority of impacts were frontal.

Table 1. Principal Direction of Impact

	Frontal	Nearside	Offside	Rear	All Others*	TOTAL
N.	2131	301	347	204	712	3695
(%)	(57.7)	(8.1)	(9.4)	(5.5)	(19.3)	(100)

(* Includes swipes, rollovers, some multiple impacts and unclassified)

The CDC system indicates the location of principal impact to the exterior of the relevant vehicle body side, dividing the front into thirds and the side according to the main components. The latter are the engine/bonnet (front), the passenger compartment and the luggage area (back). The impact distribution using these categories is shown in Tables 2 and 3.

Table 2. Vehicle Body Location of Principal Impacts, Frontal Collisions

Body Region	LH 1/3	Centre 1/3	RH 1/3	LH+Centre	RH+Centre	Full Width
N. (%)	291 (13.7)	95 (4.5)	440 (20.6)	228 (10.7)	383 (18.0)	694 (32.6)

Table 3. Vehicle Body Location of Principal Impacts, Side Collisions

Body Region	Front	Pass Comp	Back	Pass+Front	Pass+Back	Full Length
Nearside						
N. (%)	77 (25.6)	89 (29.6)	10 (3.3)	78 (25.9)	36 (12)	11 (3.7)
Offside						
N. (%).	88 (25.4)	114 (32.9)	7 (2.0	87 (25.1)	29 (8.4)	22 (6.3)
Combined						
N. (%)	165 (25.4)	203 (31.3)	17 (2.6)	165 (25.4)	65 (10.0)	33 (5.1)

Taking all impacts to the front, it will be seen that there is a bias towards the offside of the vehicle. In side impacts, the majority (72%) involved the passenger compartment, either exclusively or in combination with other parts of the vehicle.

Restraint Use and Occupant Age

Four classifications of restraint use are considered in the study. When there is clear visual/mechanical evidence on the restraint itself and/or clinical evidence such as body contusions and, in some cases, rib or pelvic fractures along the line of the belt webbing, the restraint is considered "Used." In addition, unless it is judged that there is likely to be personal sensitivity in relation to severe or fatal injuries, questionnaires are sent to every adult occupant in the case vehicle requesting, amongst other information, whether a restraint was worn at the time of the accident. If the answer is in the affirmative but there is no clear visual and/or clinical evidence to the contrary, this category is classified as "Used-Unproven." In some cases there is positive evidence that the restraint was *not* used which forms the third category. The final category of "Use Not Known" indicates there is no clear evidence either way and no questionnaire responses have been received - despite reminders. Restraint use for the sample related to seating positions for all impact directions is given in Table 4.

Table 4. Restraint Use Relative to Seating Position

Restraint Use Seat Position	Used plus Used-Unproven	Not Used	Use NK	TOTAL
Drivers N.	2769	249	667	3685
" (%)	(75)	(7)	(18)	(100)

FS Passengers N.	1104	89	230	1423
" (%)	(78)	(6)	(16)	(100)

RS Passengers N.	57	993	29	1079
" (%)	(5)	(92)	(3)	(100)

Seating Pos NK N.	1	21	11	33
TOTAL	3931	1352	937	6220

It should be noted that the restraint-use situation for the *total* sample since the study commenced in 1983 is shown and indicates a very low wearing rate for rear seat occupants. Since April 1988 all new vehicles are obliged by law to have rear restraints fitted but some vehicles had them fitted before that date, including child restraints. During the period covered by this analysis, legislation was enacted covering compulsory belt wearing for rear seat child occupants and an analysis of the 1988 data shows a marginal improvement in wearing rate for this category of occupant. Restraint use related to age for all seating positions is given in Table 5.

It will be noted that the highest percentage in the "Not Used" category relate to the young and elderly. Legislation enacted in the UK in Sept 1989 requires that children under 14 years of age are restrained when seated in the rear and when belts are available. This law has recently been extended to adults and it is hoped that the full legislation will have a positive effect in reducing the number of rear seat casualties.

General Injury Distribution

Injury Patterns and Comparisons

Casualties can be compared on a restraint-use basis for different seating positions using the Maximum AIS (MAIS) as an injury severity indicator (Table 6). Where restrained occupants are considered in the analyses, The USED and USED-UNPROVEN categories have been combined and the NOT KNOWN category discounted as it is reasoned that this approach would give an acceptable representation of the situation. It must be accepted that the sample selection is biassed towards serious and fatal injuries which is bound to reduce any differences between restrained and unrestrained occupants.

Table 6. Injury Comparisons—All Impact Directions

Restraint Use/ Seating Position	MAIS 2-6 N. (%)	MAIS 3-6 N. (%)	MAIS 1-6 N. (%)
Restrained Drivers	917 (43)	377 (18)	2117 (100)
Unrestrained "	118 (61)	55 (28)	194 (100)
Ratio Unrestr%/Restr%	1.4:1	1.6:1	
Restrained FSPS	382 (36)	156 (15)	1048 (100)
Unrestrained FSPS	46 (66)	24 (34)	70 (100)
Ratio Unrestr%/Restr%	1.8:1	2.2:1	
Restrained RSPS	44 (14)	11 (3)	306 (100)
Unrestrained RSPS	252 (33)	92 (12)	756 (100)
Ratio Unrestr%/Restr%	2.4:1	4.0:1	
TOTAL			4491

The effect of restraint use on overall injury severity can be seen in all groups, particularly amongst the higher levels (MAIS 3-6) and also with the rear seat passengers. However the ratio is less pronounced amongst drivers and this is worth exploring further for all seating positions in relation to impact direction (Table 7).

For purposes of definition, a driver in an *offside* impact and a front seat passenger in a *nearside* impact are considered as having been on the "struck side." The data shows that there is also an increase in injuries sustained by restrained FSOs in struck-side impacts compared to frontal impacts; 1.3:1 (53/42) for drivers and 1.2:1 (42/35) for passengers. There is also a

Table 5. Age Related to Restraint Use (Percentage per Age Band)

Age / Restraint Use	0-4	5-9	10-1	17-24	25-34	35-44	45-54	55-59	60-64	65-69	70-74	GE 75	NK	TOTAL
Used plus Used-Unproven	26	19	31	62	70	77	74	74	75	74	66	67	47	[3931]
Not Used	70	77	63	26	18	11	13	14	14	16	19	25	19	[1352]
Use NK	4	4	6	12	12	13	12	13	12	10	15	8	34	[936]
TOTAL (N)	105	95	215	1495	1166	809	559	280	235	135	83	110	933	[6220]

comparative increase of 1.7:1 (47/27) between frontal and nearside impact-related injuries for unrestrained RSPs.

Table 7. AIS 2-6 Injuries relative to Seating Position and Impact Direction

(Excluding surface injuries but showing (%) of TOTAL injuries per sub-set)

Impact Direction	Restrained Drivers	Restrained FS Pass	Unrestrained Drivers	Unrestrained FS Pass	Unrestrained RS Pass
Frontal	526	206	68	27	120
(%) of sub-set	(42)	(35)	(51)	(61)	(27)
Nearside	84	57 #	9	5 #	42
(%) of sub-set	(43)	(42)	(*)	(*)	(47)
Offside	114 #	25	17 #	-	23
(%) of sub-set	(53)	(26)	(*)	-	(31)

(*) Numbers too low to express as percentages
(#) Indicates casualty sitting on Struck side (see text)

If the more serious injuries of MAIS 3-6 are considered, the ratios become 1.2:1 (50/41) for restrained drivers and 1.7:1 (69/40) for front passengers (Table 8).

Table 8. MAIS Comparison for Different Impact Directions

Percentages for severe Injuries (MAIS 3-6)

Impact Direction	Restrained Drivers	Restrained FSPs	Unrestrained Drivers	Unrestrained FSPs	Unrestrained RSPS
Frontal	41	40	68	44	51
Offside	50	37	-	-	-
Nearside	50	69	-	-	38

Using the five AIS body regions, the distribution of serious injuries AIS 2-6 (excluding external) related to seating position, restraint use and impact direction is given in Table 9.

Table 9. Distribution by Body Region of Casualties with AIS 2-6 Injuries

(Related to Impact Direction and excluding Surface Injuries)

Body Region/ Seat Pos	Head/ Neck	Face	Chest/ Up Back	Abdo/ Lo Back	Pelvis/ Limbs	Casualties per Group
Frontal						
Restr. DVRS	252	85	199	68	280	526
Unrestr. DVRS	27	10	23	14	41	68
Restr. FSPS	76	12	86	31	107	205
Unrestr. FSPS	12	4	6	1	16	27
Unrestr. RSPS	54	19	24	20	68	120
Nearside						
Restr. DVRS	51	6	27	21	32	84
Unrestr. DVRS	8	2	4	2	1	9
Restr. FSPS	29	3	32	19	37	57
Unrestr. FSPS	2	2	4	2	2	5
Unrestr. RSPS	26	4	7	3	28	42
Offside						
Restr. DVRS	59	8	45	32	63	114
Unrestr. DVRS	13	-	11	8	11	17
Restr. FSPS	13	1	7	2	13	25
Unrestr. FSPS	-	-	-	-	-	-
Unrestr. RSPS	16	3	5	3	14	23
TOTAL	638	159	480	226	713	1322
(%)	(48)	(12)	(36)	(17)	(54)	(100)

The data shows that head and limb injuries predominate and this will be explored in subsequent Sections. Suffice to say at this stage that many of the head injuries were relatively brief periods of unconsciousness and a distribution of limb injuries sometimes shows relatively smaller numbers per individual limb region. Many casualties sustained more than one injury (Table 10).

Table 10. AIS 2-6 Injuries/Occupant Group Relative to Impact Direction

Impact Dir./ Injury Groups	Restrained Drivers	Restrained FS Pass	Unrestrained Drivers	Unrestrained FS Pass	Unrestrained RS Pass
Frontal	N. (%)	N. (%)	N. (%)	N. (%)	N. (%)
One Injury	302 (57)	127 (62)	40 (58)	15 (56)	77 (64)
Two Injuries	134 (25)	59 (29)	13 (19)	11 (41)	25 (21)
>2 Injuries	90 (17)	20 (10)	15 (22)	1 (4)	18 (15)
Sample size	526 (100)	206 (100)	68 (100)	27 (100)	120 (100)
Nearside			(*)	(*)	
One Injury	53 (63)	23 (40)	3 -	2 -	24 (57)
Two Injuries	14 (17)	15 (26)	4 -	1 -	12 (29)
>2 Injuries	17 (20)	19 (33)	2 -	2 -	6 (14)
Sample size	84 (100)	57 (100)	9 -	5 -	42 (100)
Offside			(*)		(*)
One Injury	61 (54)	16 (64)	5 -	- -	10 -
Two Injuries	23 (20)	7 (28)	4 -	- -	9 -
>2 Injuries	30 (26)	2 (8)	8 -	- -	4 -
Sample size	114 (100)	27 (100)	17 -	- -	23 -

(*) Numbers too small for meaningful percentages

These figures show relatively more multiple injuries in side impacts than in frontal. This is discussed further in the next Section.

Overall Injury Severity related to Impact Direction

Based on the restraint-use information given in Table 2, and considering only injuries in the AIS 2-6 range, analyses will be presented by seating position and principal impact direction for restrained drivers and front seat passengers. Unrestrained front seat occupants will also be considered where appropriate and, since they predominate within their group, data on unrestrained rear seat passengers will also be presented. Impact configurations, seat occupancy or restraint-use data not producing sufficiently large numbers for any meaningful analyses will not be reported.

Tables 11, 12 and 13 show the maximum injury distribution for different seating positions and principal impact directions. The Not Known category has not been reported.

Table 11. MAIS 2-6 Distribution, Injured Occupants in Frontal Impacts

Injury Severity	Restrained Drivers N. (%)	Restrained FS Pass N. (%)	Unrestrained Drivers N. (%)	Unrestrained FS Pass N. (%)	Unrestrained RS Pass N. (%)
MAIS 2	308 (59)	125 (61)	32 (47)	15 (56)	69 (53)
MAIS 3	117 (22)	49 (24)	14 (21)	7 (26)	34 (26)
MAIS 4	31 (6)	8 (4)	8 (12)	1 (4)	6 (5)
MAIS 5	43 (8)	16 (8)	7 (10)	2 (7)	16 (12)
MAIS 6	27 (5)	8 (4)	7 (10)	2 (7)	6 (5)
TOTAL	526 (100)	206 (100)	68 (100)	27 (100)	131 (100)
of which Fatal	81 (15)	27 (13)	16 (24)	5 (19)	21 (16)

Table 12. MAIS 2-6 Distribution, Injured Occupants in Nearside Impacts

Injury Severity	Restrained Drivers N. (%)	Restrained FS Pass N. (%)	Unrestrained Drivers N. (*)	Unrestrained FS Pass N. (*)	Unrestrained RS Pass N. (%)
MAIS 2	42 (50)	22 (39)	4	1	26 (62)
MAIS 3	15 (18)	11 (19)	1	1	10 (24)
MAIS 4	8 (10)	10 (18)	1	1	3 (7)
MAIS 5	12 (14)	4 (7)	2	1	2 (5)
MAIS 6	7 (8)	10 (18)	1	1	1 (2)
TOTAL	84 (100)	57 (100)	9	5	42 (100)
of which Fatal	18 (21)	18 (32)	4	3	5 (12)

* Numbers too small for meaningful percentages

Table 13. MAIS 2-6 Distribution, Injured Occupants in Offside Impacts

Injury Severity	Restrained Drivers N. (%)	Restrained FS Pass N. (%)	Unrestrained Drivers N. (*)	Unrestrained RS Pass N. (*)
MAIS 2	54 (48)	15 (60)	4	12
MAIS 3	33 (29)	6 (24)	4	4
MAIS 4	9 (8)	- -	2	2
MAIS 5	8 (7)	3 (12)	2	4
MAIS 6	9 (8)	1 (4)	5	1
TOTAL	114 (100)	25 (100)	15	23
- of which - Fatal	18 (16)	4 (16)	8	4

* Numbers too small for meaningful percentages

Although not tabulated, on average, half the injuries sustained in all impact directions were of MAIS 1 severity.

It is well established that injury outcome is largely speed dependent; detailed analyses have not been considered in this Paper but will doubtless be presented in future. The key variable of velocity change on impact (Delta-v) is computed from detailed crush measurements from the case vehicle and known constants. There are some invalidating conditions attached to this method and therefore Delta-v figures cannot always be produced. However some were available for the accident sample analysed although it will be appreciated that sample size diminishes with increasing impact speed. Table 14 shows the variation of mean Delta-v related to Maximum Injury Severity for restrained front occupants in frontal collisions.

Table 14. Variation of Maximum Injury Severity with Mean Delta-v

Restrained FSOs in Frontal Impacts

MAIS	2	3	4	5	6
Drivers					
Sample size	137	55	17	10	7
Mean DV km/h	42.2	48.6	57.4	56.1	58.3
F.S. Pass.					
Sample size	47	21	5	8	-
Mean DV km/h	38.6	44.8	53.2	66.1	-

The scale of injury severity increases with mean Delta-v. This is more pronounced for front seat passengers than for drivers, although accident sampling and missing Delta-v values in the data set may influence trends.

Injuries and Probable Causes

Several points must be borne in mind when ascribing contact zones giving rise to injuries: Injuries and mechanisms are not mutually exclusive ie, there can be more than one injury from a single source and also several sources can be responsible for one initial injury with the possibility of also aggravating that injury. Alternative sources can also be responsible and an earlier method of coding used in the study did not enable all possibilities to be taken into account. Some injuries arise from direct blows and others can be induced from contact with another body region. Non-contact, deceleration type injuries are also a possibility. Rebound injuries also occur, particularly with restrained occupants in side impacts. There is sometimes a degree of uncertainty in assigning injury causes so probability must be considered. With these limitations in mind, *principal* causes of injury have been used in the analyses and will be presented by impact direction, seating position, restraint use and AIS body region. Restrained and unrestrained occupants injury details will be compared where appropriate.

Frontal Impacts

Drivers

There were 526 restrained and 68 unrestrained drivers involved in frontal impacts with injuries AIS 2-6. These figures will be used in subsequent analyses and presented for different body regions. For ease of presentation, the bony pelvis has been included with lower limbs.

Limb Injuries (Including Bony Pelvis). As mentioned earlier 3.2 and indicated in Table 9, limb injuries predominate. For the restrained drivers, 280 casualties (53%) had limb injuries of AIS 2 or 3 with one AIS 4 (pelvic crush). However the picture is more complex in that these injuries were to different limbs and limb regions throughout the sub-set, there being 521 individual limb injuries amongst the 280 casualties with such injuries. They were frequently concomitant with serious injuries to other body regions in the same driver casualty.

For unrestrained drivers, there were 41 (60%) with limb injuries. Of these there was a total of 72 separate injuries to different limb regions and the same remarks apply as for the restrained sub-set. The injury distribution for both groups is given in Table 15 and a further distribution by limb region in Table 16.

Table 15. Drivers in Frontal impacts

AIS 2-6 Injury Distribution,
Limb and Pelvic Injuries

AIS	Restrained		Unrestrained	
2	159	(57%)	21	(51%)
3	120	(43%)	20	(49%)
4	1	(<1%)	-	-
TOTAL	280	(100%)	41	(100%)

Injuries to the right side of the body predominates by a considerable amount for both groups, which is not entirely surprising as data in Table 2 indicated an impact bias towards the front, right-hand side of the vehicle in frontal impacts. The highest number of individual limb injuries occurred to the arms.

Probable injury causes for lower limbs are presented in Tables 17 for *restrained* drivers.

Table 16. Drivers in Frontal Impacts

Distribution of AIS 2-6 Limb Injuries by Limb Region

	Pelvis*	Hip	Thigh	Knee	Lo/leg	Foot	Should	Arm	TOT
Restrained									
Left Side	(24)	7	8	15	28	38	13	55	164 (24)
Right Side		21	58	20	37	73	35	89	333
TOTAL	24	28	66	35	65	111	48	144	521
Unrestrained									
Left Side	(2)	5	5	7	2	3	5	2	29 (2)
Right Side		3	9	1	2	5	8	13	41
TOTAL	2	8	14	8	4	8	13	15	72

(*) Pelvic injuries are not assigned Left or Right in the coding.

Table 17. Restrained Drivers in Frontal Impacts

Probable Causes of AIS 2-6 Lower Limb Injuries

Lower Limb Region Injury Source	Pelvis	Hip	Thigh	Knee	Lo. Leg	Ankle /foot	TOTAL
A Pillar			4				4
Fascia Face/controls		2	6	4			12
Lower fascia/parcel shelf	3	10	22	19	8	1	63
Column/cladding/brackets	3	3	9	5	5		25
Centre Console/Tray	1				2		3
Pedals/brackets		2	6	2	17	54	81
Front Firewall		3	5		2	1	11
Steering Wheel			2				2
Gen. Footwell Intrusion	3	5	5		20	45	78
Other Vehicle/Ext Object	3		3		3	1	10
Door/Handles	4		1	4	1		10
Other Cause	6	2	1		5	4	18
Source Not Known	0		2	1	2	4	9
TOTAL	23	27	66	35	65	106	326

It is recognised that lower limbs are sometimes subjected to indirect loads which give rise to injury. An example is contact to the knee or lower leg which, in addition to injuring the contacted region, may also induce a posterior dislocation to the hip or cause a femoral fracture on the same side. Although indirect or induced injuries are noted in the database, they have not been highlighted in this particular analysis. Therefore it is possible that a femoral injury may be ascribed to say, general footwell intrusion. For ease of presentation, left and right injuries will be combined where appropriate. It should also be recognised that limb injuries are not mutually exclusive since there could be one upper limb and possibly two lower limb injuries on the same side of a single casualty. In addition these limb injuries could also be concomitant with injuries to other body regions.

Although different lower limb regions are injured by a variety of contact sources, fascia, foot pedals and their brackets and also generalised footwell intrusion are the main causes. It is confirmed that there are more contacts occurring on the right side, particularly in the footwell region.

The probable causes of upper limb injuries are shown in Table 18. The driver is usually holding, if not gripping, the steering wheel during the impact phase and therefore may sustain wrist injuries due to physical bracing. The arm can also be freely moving and can therefore strike parts of the car interior, sustain an injury but leave no identifiable contact. Therefore there can be a degree of uncertainty in ascribing injury causes so it is not surprising that there is a very high proportion of "Source Not Known" in the data.

Table 18. Restrained Drivers in Frontal Impacts

Probable Causes of AIS 2-6 Upper Limb Injuries

\ Upper Limb Region	LEFT		RIGHT		TOTAL
Injury Source \	Shoulder	Arm	Shoulder	Arm	
Door Pillars		2		14	16
Fascia/Controls		8	1	3	12
Steering Wheel	7	13	5	10	35
Seat Belt Webbing			21	1	22
Door/Handles				11	11
Other Vehicle/Ext Object	4	6	3	16	29
Limb Bracing		3		4	7
Other Cause	2	2	1	3	8
Source Not Known		21	4	27	52
TOTAL	13	55	35	89	192

The steering wheel rates highly as an injury source for both left and right arms with the A Pillar as a further source for right arm injuries. Right shoulder injuries often occur in the higher energy impacts where some level of injury would be expected due to the restraining influence of the belt webbing. The upper parts of the body, including the limbs, are sometimes exposed to other vehicles and external objects during the impact, causing contact via the broken, glazed areas where there is minimal protection to the vehicle occupant, as illustrated in the data. Examples are severe collisions with trucks or other unyielding objects giving rise to passenger compartment intrusion.

Abdominal/Lower Back Injuries. Fifty-six (11%) of the restrained drivers sustained an internal abdominal injury. Thirteen (2.5%) also sustained a lower back injury, mainly skeletal, of which only one coincided with an abdominal injury. Fourteen (21%) of the unrestrained drivers sustained abdominal injuries and there were no recorded lower back injuries. A distribution of AIS injury levels for both groups is given in Table 19 and probable causes of injury in Table 20, related to the total sub-set of 526 restrained drivers of which 68 sustained injuries to these body regions. This method of computation will be used for other Tables where appropriate.

Table 19. Drivers in Frontal Impacts

AIS 2-6 Distribution, Abdomen and Lower Back

AIS/ /Restraint Use	2	3	4	5	TOTAL
Restrained	16	19	10	23	68
Unrestrained	1	-	6	7	14

Table 20. Drivers in Frontal Impacts

Probable Causes of AIS 2-6 Abdominal and Lower Back Injuries

Restraint Use/Body Region	Restrained				Unrestrained
	Abdomen			Lo. Back	Abdomen
Probable Injury Source	N.	(%)	(%)	N. (")	N. (*)
S/Wheel Rim &/or Spokes	20	(4)	(29)	-	8
• Other/Part NK	4	(1)	(6)	-	4
Seatbelt Webbing	13	(2)	(19)	-	-
Other Vehicle/Object	9	(2)	(13)	-	-
Decel.-No Contact	2	(<1)	(3)	3	-
Other Cause	3	(<1)	(4)	4	-
Not Known	5	(1)	(7)	6	2
Baseline for (%)		526	68		

* Numbers too low for meaningful percentages

It will be seen that the steering wheel components, particularly the rim, and also seatbelt webbing, were responsible for the highest percentage of abdominal injuries amongst restrained drivers. It will also be noted from Table 20 that a high proportion (76%) of the injuries were AIS 3-6. For the relative few unrestrained drivers, again the steering wheel gave rise to most of the abdominal injuries. No overall conclusions can be reached for the few lower back injuries.

Chest/Upper Back Injuries. Of the restrained drivers, 199 (38%) sustained a chest or upper back injury. Of these, 127 (66%) were skeletal rib and/or sternum fractures and mainly AIS 2, 18 (9%) were internal and 46 (24%) were combined. There were only 13 (3%) with upper back injuries, 12 of these coinciding with chest injuries. Twenty-three (34%) of the *unrestrained* drivers sustained a chest injury. Of these, 3 had only skeletal injuries, a further three had only internal injuries but the majority (17) had combined injuries, mainly of a serious nature. There was only one upper back injury, concomitant with a serious chest injury. The AIS distribution is given in Table 21.

Table 21. Drivers in Frontal Impacts

AIS 2-6 Distribution, Chest/Up. Back Injuries

AIS/ /Restraint Use	2	3	4	5	6	TOTAL
Restrained	116	32	30	12	9	199
Unrestrained	3	3	7	3	7	23

Probable sources of injury are given in Table 22 where it will again be seen that the principal cause of chest injury to the restrained driver is the steering wheel and/or seat belt webbing, these injuries being mainly a simple fracture of one or two ribs and/or the sternum of AIS 2 severity. Conversely the unrestrained driver sustained far more serious chest injuries, including a higher proportion of internal trauma from striking the steering wheel. The numbers of upper back injuries were too low for a meaningful analysis.

Table 22. Drivers in Frontal Impacts

Probable Causes of AIS 2-6 Chest and Upper Back Injuries

Restraint Use/Body Region	Restrained				Unrestrained
	Chest			Up. Back	Chest
Probable Injury Source	N.	(%)	(%)	N. (*)	N. (*)
Steering wheel Rim	20	(4)	(10)		
S/Wheel Rim &/or Spokes	17	(3)	(9)	-	13
" Hub	8	(2)	(4)	-	2
" Part NK	22	(4)	(11)	-	6
Seatbelt Webbing	104	(20)	(52)	-	-
Other Vehicle/Object	16	(3)	(8)	2	-
Other Cause	4	(1)	(2)	7	2
Not Known	4	(1)	(2)	4	-
Baseline for (%)		526	199		

* Figures too low for meaningful percentages

Head, Face and Neck Injuries. Many of the injuries sustained in this group are not mutually exclusive. Of the restrained drivers, 279 (53%) sustained a skeletal or internal injury to the head, face or neck ≥ AIS 2. The corresponding figure for the unrestrained drivers was 33 (49%). The injury severity distribution is shown in Table 23, many of the face and neck injuries being concomitant with head injuries, as shown in Table 24. In addition, there were a number of head injuries caused by a facial contact, which only resulted in an AIS 1 or 2 surface injury to the face. The former were usually brief periods of unconsciousness and possibly some other head involvement.

Table 23. Drivers in Frontal Impacts

AIS 2-6 Head, Face and Neck Injury Severity Distribution

	Restrained			Unrestrained		
AIS	Head	Face	Neck	Head	Face	Neck
2	162	55	9	15	6	-
3	24	24	8	6	4	-
4	17	7	-	4	-	-
5	22	-	2	-	-	-
6	18	-	5	2	-	2
NK	-	5	-	1	-	-
TOTAL	243	91	24	28	10	2

Table 24. Drivers in Frontal Impacts

AIS 2-6 Head, Face and Neck Injuries

	Only			Face+ Head	Face+ Neck	Head+ Neck	Head, Face + Neck	TOTAL
	Head	Face	Neck					
Restrained	175	27	5	53	1	15	3	279
Unrestrained	21	6	-	4	-	2	-	33

Most of the head injuries were of AIS 2 severity and the facial injuries were mainly simple fractures. Probable injury causes are shown in Table 25.

Table 25. Drivers in Frontal Impacts

Probable Causes of AIS 2-6 Head, Face and Neck Injuries

Belt Status/Head Region	Restrained			Unrestrained		
Probable Injury Cause	Head	Face	Neck	Head	Face	Neck
Roof/Sun Roof	9	2	-	1	-	-
Front Header/Visor	5	1	1	3	-	-
Windscreen	4	3	1	9	3	-
A Pillar	21	8	3	3	-	-
Fascia	4	-	-	-	-	-
Steering Wheel Rim	36	14	3	1	2	-
St. Wheel Rim & Spokes	14	9	1	1	3	-
Steering Wheel Hub	31	22	2	1	-	-
St. Wheel, Part NK	28	9	1	-	-	-
Side Glass/Door	3	-	-	-	-	-
Bonnet-Own Car	9	2	-	-	-	-
Other Veh./Ext. Object	29	13	2	2	-	2
Decel. No Contact	18	-	7	1	-	-
Other Cause	8	3	1	4	1	-
Cause NK	23	5	2	2	1	-
TOTAL	243	91	24	28	10	2

The highest cause of facial and head injury to restrained drivers is due to steering wheel contact. A further number of injuries were caused by contact with the A Pillar and intruding objects, including other vehicles—the latter via the broken, glazed areas of the casualty's vehicle. A number of head and neck injuries were judged to be of a non-contact nature but nevertheless caused brief periods of unconsciousness and severe neck lesions.

Although head/face/neck injury numbers of the *unrestrained* driver were small, commensurate with the smaller sample size, the highest proportion were judged to be due to windscreen contact. It is well documented from earlier, pre-seat belt wearing days that head/face contact with the windscreen was common in severe frontal impacts, often causing severe, lacerative facial injuries and underlying head trauma to the occupants.

Front Seat Passengers (FSPs)

There were 206 restrained and 27 unrestrained front seat passengers involved in frontal impacts with injuries ≥ AIS 2 and again these figures will be used in subsequent analyses. There were proportionally less injuries per casualty and the corresponding figures will be presented for different body regions.

Limb Injuries (Including Bony Pelvis). As in the case of driver casualties and also indicated in Table 9, limb injuries still predominate. Of the restrained FSP casualties, 107 (52%) had limb injuries of AIS 2 or 3. However the picture is again complex as these injuries were to different limb regions throughout the sub-set, often in more than one limb, there being 158 individual limb injuries in the sub-set. As before, such injuries were frequently concomitant with serious injuries to other body regions in the same casualty.

Sixteen of the unrestrained FSPs sustained limb injuries. Of these there was a total of 20 separate injuries to different limb regions and the same remarks apply as for the restrained sub-set. The injury distribution for both groups is given in Table 26 and a further distribution by limb region in Table 27.

Table 26. FSPs in Frontal Impacts

AIS 2+ Distribution, Limb and Pelvic Injuries

AIS	Restrained	Unrestrained
2	73	12
3	35	4
TOTAL	107	16

Table 27. FSPs in Frontal Impacts

Distribution of AIS 2-6 Limb Injuries

	Pelvis	Hip	Thigh	Knee	Lo/leg	Foot	Should	Arm	TOTAL
Restrained	4	4	25	5	23	24	19	54	158
Unrestrained	4	1	1	6	2	1	3	2	20

There is little difference in the injury distribution between the Left and Right sides of the body with the exception of more Left shoulder injuries amongst the restrained sub-set. The probable causes of lower limb injury are shown in Table 28. Due to the small numbers amongst unrestrained FSPs, only those results for the restrained sub-set will be presented. As with the restrained drivers, different lower limb regions are injured by a variety of contacts, the lower fascia/parcel shelf and also generalised footwell intrusion being the main causes.

Unlike the restrained driver, who is in proximity to, and may also be gripping the steering wheel (see previous discussion), the upper limbs of the FSP are usually totally free to move during the impact phase. They can strike a variety of interior structures, principally the fascia and also the adjacent door, particularly if intrusion is involved. As with the drivers, there are also a number of cases where the injury source is not known. Predictably, the left shoulder sustained most injury, mainly of AIS 2 severity, from the restraining effects of the seat belt webbing (Table 29).

Table 28. Restrained FSPs in Frontal Impacts

Probable Causes of AIS 2-6 Lower Limb Injuries

Lower Limb Region Injury Source	Pelvis	Hip	Thigh	Knee	Lo. Leg	Ankle /foot	TOTAL
Fascia Face/controls		1	1		2	2	6
Lower fascia/parcel shelf		1	10	2	5	3	21
A Pillar			3				3
Front Firewall			3			3	6
Gen. Footwell Intrusion			1		8	11	20
Other Vehicle/Ext Object			3		2		5
Other Cause	2		1	1	5	3	10
Source Not Known	2	2	3	2	1	2	12
TOTAL	4	4	25	5	23	24	85

Table 29. Restrained FSPs in Frontal Impacts

Probable Causes of AIS 2-6 Upper Limb Injuries

\ Upper Limb Region	LEFT		RIGHT		TOTAL
Injury Source \	Shoulder	Arm	Shoulder	Arm	
Fascia		10	1	8	19
Seat Belt Webbing	12		2		14
Door/Handles		9			9
Other Vehicle/Ext Object		4			4
Other	2	1	2	5	10
Source Not Known		7		10	17
TOTAL	14	31	5	23	73

Abdominal/Lower Back Injuries. Twenty-one (10%) of the restrained FSPs sustained an internal abdominal injury. There were 10 (5%) who also sustained a lower back injury, mainly skeletal, none of which appeared to coincide with an abdominal injury. Only one of the 27 unrestrained FSPs in frontal impacts sustained an abdominal injury and there were no recorded lower back injuries. Therefore only the restrained sub-set will be presented in the analyses. A distribution of AIS levels for the abdomen and lower back injuries is given in Table 30 and probable causes of injury in Table 31.

Table 30. Restrained FSPs in Frontal Impacts

AIS 2-6 Injury Distribution,
Abdomen and Lower Back

AIS	2	3	4	5	TOTAL
N.	11	7	7	6	31

Although the numbers are small, it will be seen that a high proportion of the injuries were severe (AIS 3-6). Injury causes are distributed but it can be seen that the seat belt webbing was responsible for more than the

Table 31. Restrained FSPs in Frontal impacts

Probable Causes of AIS 2-6
Abdominal and Lower Back Injuries

Body Region/ Probable Injury Source	Abdomen	Lo. Back
Fascia	2	-
Other Occupant	1	7
Seatbelt Webbing	9	-
Other Vehicle/Object	4	-
Other Cause	2	1
Not Known	3	2
TOTAL	21	10

other mechanisms. Injury mechanisms for lower back injuries are always difficult to determine but contact with other occupants was judged to be responsible for most. It is interesting to note that, for restrained *drivers* in frontal impacts, the current data show that only one back injury was caused by occupant contact (Table 20). Although injury numbers are too small for full analysis, one possibility is that the rear seat passenger, having entered the car from the nearside for safety, may have remained sitting on that side and therefore would have contacted the front passenger rather than the driver in the impact. The CCIS data shows that more restrained occupants sit on the nearside than the offside.

Chest/Upper Back Injuries. Eighty-six (42%) of the restrained FSPs sustained a chest or upper back injury. Of these, 52 (60%) had rib and/or sternum fractures only. A further thirty (35%) had internal chest injuries, principally of a serious nature but 23 of these also had a concomitant skeletal chest injury. There were only four upper back injuries, none of which coincided with a chest injury. Six (22%) of the *unrestrained* FSPs had a chest injury, this number being too small for any meaningful analysis. The AIS distribution for the former group is shown in Table 32 and probable causes of injury in Table 33.

Table 32. Restrained FSPs in Frontal Impacts

AIS 2-6 Injury Distribution,
Chest/Upper Back Injuries

AIS	2	3	4	5	6	TOTAL
N.	51	19	5	10	1	86

Table 33. Restrained FSPs in Frontal Impacts

Probable Causes of AIS 2-6
Chest and Upper Back Injuries

Body Region/ Probable Injury Source	Chest N.	Up. Back N.
Fascia	3	-
Seatbelt Webbing	66	-
Other Vehicle/Ext.Obj.	6	-
Decel. No Contact	1	1
Other Occupant	3	-
Other Cause	1	1
Not Known	2	2
TOTAL	82	4

It can be seen that the principal cause of chest injury is the seat belt webbing. As mentioned, these are mainly simple rib/sternum fractures, 46 (70%) of which were only AIS 2 severity. As in the case of the driver casualty, the next highest injury cause was due to external objects/vehicles intruding via the broken, glazed areas. Although the numbers of chest/upper back injuries amongst the unrestrained sub-set was too low for a meaningful analysis, it is worth noting that, of these six casualties, four died from their overall injuries.

Head, Face and Neck Injuries. As with the driver sub-set, many of the injuries in this group are not mutually exclusive per casualty. Of the restrained FSPs, 83 (40%) sustained a skeletal or internal injury to the head, face or neck of AIS 2-6 severity. The corresponding figure for the same body regions in the case of the unrestrained FSPs was 15 (56%). As with the drivers, a number of the face and neck injuries were concomitant with head injuries, as shown in Table 34.

Table 34. FSPs in Frontal Impacts

AIS 2-6 Head, Face and Neck Injuries

Body Region/ Restraint Use	Head only	Face only	Neck only	Face & Head	Head & Neck	Head,Face & Neck
Restrained	54	7	11	5	6	-
Unrestrained	8	3	-	2	1	1

In addition to the figures shown in the table, there were a number of head injuries caused by a facial contact, although this only resulted in an AIS 1 or 2 surface injury to the face. It will be remembered that surface injuries have been excluded in this Paper. However, such impacts were usually sufficient to cause a period of unconsciousness and possibly some other head trauma. Therefore, and as previously stated, assigning injury causes to the head/face region is not as straightforward as for other body regions and injury severity distribution is presented in Table 35.

The highest proportion of head injuries were AIS 2/ brief periods of unconsciousness and simple fractures of the face.

Table 35. FSPs in Frontal Impacts

AIS 2-6 Head, Face and Neck Injury Distribution

	Restrained			Unrestrained		
AIS	Head	Face	Neck	Head	Face	Neck
2	41	7	8	8	1	-
3	8	4	5	1	3	1
4	6	1	1	1	-	-
5	5	-	1	1	-	-
6	5	-	2	-	-	1
TOTAL	65	12	17	11	4	2

Probable injury causes are presented in Table 36 with a reminder that figures/mechanisms are, in general, not mutually exclusive.

Table 36. Restrained FSPs in Frontal Impacts

Probable Causes of AIS 2-6 Head, Face and Neck Injuries

Belt Status/Head Region	Restrained			Unrestrained		
Probable Injury Cause	Head	Face	Neck	Head	Face	Neck
Front Header/Visor	2	-	1	2	-	-
Windscreen	4	2	-	1	1	-
A Pillar	2	-	-	2	-	-
Fascia	17	4	2	2	2	2
Steering Wheel	3	2	-	-	-	-
Bonnet-Own Car	2	-	-	-	-	-
Other Veh./Ext. Object	10	2	1	1	-	-
Decel. No Contact	8	-	9	2	-	-
Other Cause	3	1	1	-	-	-
Cause NK	14	1	3	1	1	-
TOTAL	65	12	17	11	4	2

Not surprisingly, it will be seen that the main cause of facial and head injury to restrained FSPs is due to contact with the interior structures ahead of the occupant and the data identifies the contact zones. The fascia and also other vehicle/external objects making contact via the glazed areas featured highly for this group. Although absolute numbers are small, it is worth noting that a higher proportion of head/neck lesions amongst the restrained sub-set were judged to be due to deceleration without any physical contact to the cranium when compared to the unrestrained group. This is due to the head/neck jerking forward whilst the trunk is restrained by the seat belt giving the classic, violent forward flexion followed by hyperextension as the head is thrown back.

Unrestrained Rear Seat Passengers (RSPs)

Reference to earlier Sections and Tables indicated that restrained RSPs were in the minority and therefore analyses will concentrate on the *unrestrained* sub-set of which there were 120 casualties with AIS 2-6 injuries involved in frontal collisions. Due to the distribution of rear seating positions and a proportion where this was not known, seating positions have been combined in the analyses. Although it is appreciated that full injury mechanisms cannot be explored in this way, a general indication will be given for frontal impacts only.

Limb Injuries (Including Bony Pelvis). Of the 120 casualties in this sub-set, 68 sustained limb injuries (57%). However some were multiple, there being a total of 103 such injuries of AIS 2 or 3 in this sub-set and distributed amongst different limb regions as shown in Table 37.

Table 37. Unrestrained RSPs in Frontal Impacts

Distribution of AIS 2-6 Limb Injuries

Pelvis	Hip	Thigh	Knee	Lo/leg	Foot	Should	Arm	TOTAL
6	5	22	1	14	2	9	46	103

Almost half the limb injuries were to the arms, mostly on the left. This difference is not necessarily significant as much depends upon seating position prior to impact. The causes of limb injuries have not been tabulated because it was reasoned that the majority were due to contact with the front seat but contact marks are frequently difficult to either observe or differentiate from in-use scuff marks on the seat material.

Abdominal/Lower Back Injuries. There were only 20 casualties (17%) in the subset who sustained injuries to these body regions and hence the injury causes have not been tabulated. Of these, 12 were caused by striking the rear of the front seat, most of the others by contacting different internal structures and three related to ejection from the vehicle. The AIS severity distribution is given in Table 38 and shows that such injuries were severe and often fatal.

Table 38. Unrestrained RSPs in Frontal Impacts

AIS 2-6 Injury Distribution,
Abdomen and Lower Back

AIS	2	3	4	5	TOTAL
N.	3	4	4	9	20

Chest/Upper Back Injuries. There were 24 injuries in this category (20%) and the AIS severity distribution is given in Table 39. As with the abdomen, it will be seen that many of these injuries are severe. Probable injury causes are shown in Table 40 where it is seen that striking the front seat is the most common cause of chest injury in this sub-set. Again there was a proportion of "Not Known's."

Table 39. Unrestrained RSPs in Frontal Impacts

AIS 2-6 Injury Distribution, Chest and Upper Back

AIS	2	3	4	5	6	TOTAL
N.	3	7	3	9	2	24

Table 40. Unrestrained RSPs in Frontal Impacts

Probable AIS 2-6 Injury Causes, Chest and Upper Back

Cause	Door/B Pillar	Other Seat	Ejection	Other	NK	TOTAL
N.	3	9	3	3	6	24

Head, Face and Neck Injuries. Sixty-eight (57%) sustained a head, face or neck injury of AIS 2-6 and Table 41 gives the AIS distribution of the 88 separate injuries. This shows a high proportion in the AIS 2 category which, as previously mentioned, usually signifies short periods of unconsciousness. There is also a significant number of severe head injuries as indicated by the higher scores. As with the other occupant casualties, a head injury is sometimes concomitant with a face and/or neck injury (Table 42).

Table 41. Unrestrained RSPs in Frontal Impacts

AIS 2-6 Injury Distribution, Head, Face and Neck

AIS	2	3	4	5	6	TOTAL
Head	30	16	6	7	3	62
Face	11	7	1	-	-	19
Neck	2	3	-	-	2	7

Table 42. Unrestrained RSPs in Frontal Impacts

AIS 2-6 Head, Face and Neck Injuries

Body Region	Head only	Face only	Neck only	Face & Head	Head & Neck	Head, Face & Neck
N.	43	4	2	14	4	1

Probable causes of injury are given in Table 43 which shows the majority occurring in the roof/header rail area. Again there is a high proportion of "Not Known's" and some due to ejection of the unrestrained occupant from the vehicle following impact.

Table 43. Unrestrained RSPs in Frontal Impacts

Probable AIS 2-6 Injury Causes,
Head, Face and Neck

Probable Cause	Head	Face	Neck
Roof/Header Rails	10	2	1
Fascia Area	6	2	-
Pillars/Door	5	1	2
Front Seat/Headrest	8	3	-
Rear Seat	2	1	-
Ejection	5	2	-
Other Vehicle	2	1	-
Other Cause	4	2	2
Cause NK	20	5	2
TOTAL	62	19	7

Side Impacts

Although the highest proportion of accident impacts are to the vehicle front (Table 1), there is concern amongst accident researchers and vehicle designers regarding the vulnerability of occupants in side impacts. This is mainly due to the close proximity of the adjacent door and that the vehicle is often supported by the struck or striking object during the impact phase, causing the occupant to contact an unyielding structure. This is in some contrast to the relatively greater protection offered by the vehicle front structure in frontal impacts. The passenger compartment itself is involved in most side impacts (Table 3) and injury mechanisms will be explored in a similar way to the analyses for frontal impacts but considering the impact direction relative to the occupant's seating position. Therefore a driver involved in an offside impact would be considered sitting on the "struck-side" and any front seat passenger on the "non-struck side." For a nearside impact, the converse would apply. Using this principle, data on Drivers and FSPs will be combined as Front Seat Occupants (FSOs).

Front Seat Occupants (FSOs) in Struck-side Impacts

As indicated, data for restrained front seat occupants involved in "struck-side" impacts have been combined ie, drivers involved in an offside and a front passenger involved in a nearside impact. There were 171 injured, restrained FSOs (114 drivers and 57 FSPs) and also 22 unrestrained FSOs in struck-side impacts and again these figures will be used in subsequent analyses and be presented for different body regions.

Limb Injuries (Including Bony Pelvis). One hundred casualties (59%) in the restrained subset sustained a limb injury. As in the previous analyses, a proportion sustained injuries to more than one limb region, there being 206 individual limb injuries amongst these casualties. Thirteen (59%) of the unrestrained FSO casualties sustained a limb injury. However, when broken down into individual limb regions, the numbers for the latter group would be too small for meaningful analysis and have therefore not been reported. However it is worth noting that, *of* the 22, over half died of multiple injuries. A distribution by individual limb region for the restrained FSO sub-set is given in Table 44. Since offside and nearside impacts are being combined, it is necessary to differentiate between the left and right limbs in relation to the impact. They have been designated "adjacent" (nearest the *struck* side) and "remote" for the converse.

Table 44. Restrained FSOs in Struck-side Impacts

Distribution of AIS 2-6 Limb Injuries

	Pelvis*	Hip	Thigh	Lo/leg	Foot	Should	Arm	TOTAL
Remote	(46)	4	11	8	6	4	9	42 (46)
Adjacent		20	24	16	8	27	23	108
TOTAL	(46)*	24	35	24	14	31	32	206

* Pelvic Injuries are not assigned Left/Right in the coding

Not surprisingly, as struck-side impacts are being considered, there were more injuries to the adjacent side of the body compared to the remote by a factor of approximately 3:1 overall - or more if pelvic injuries can be attributed to struck-side impacts. Probable injury causes are presented in Tables 45 and 46.

Table 45. Restrained FSOs in Struck-side Impacts

Probable Causes of AIS 2-6 Lower Limb Injuries

Limb Region Injury Source	Bony Pelvis	Hip	Thigh	Lower Leg	Ankle /foot	TOTAL *
		Adjacent Limbs				
Adjacent Door/Pillar	25	16	14	6	2	38
Other Vehicle/Ext. Object	20	2	6	7		17
Gen. Footwell Intrusion				3	5	8
Pedals/bracketry		2				2
Other Cause	1		2		1	3
TOTAL	46	20	24	16	8	68
		Remote Limbs				
Adjacent Door/Pillars		3	1	1	1	6
Other Vehicle/Ext. Object			6			6
Gen. Footwell Intrusion			2	7	4	13
Other Cause		1			1	2
Cause NK			2			2
TOTAL	46	4	11	8	6	29

* Excluding pelvic injuries which are not coded Left or Right side

Table 46. Restrained FSOs in Struck-side Impacts

Probable Causes of AIS 2-6 Upper Limb Injuries.

Limb Region Injury Source	Remote Limbs		Adjacent Limbs		TOTAL
	Should	Arm/hand	Should	Arm/hand	
Door/Pillars	2	1	20	15	38
Other Vehicle/Ext.Object			4	6	10
Other Cause	2		3		6
Cause NK		4		2	6
TOTAL	4	6	27	23	70

It is not surprising to observe that adjacent door/pillars are the principal cause of limb injury. The other important thing to note is that, at the moment of impact and for part of the accident phase, the door can remain loaded by (usually) the striking vehicle or an unyielding structure thereby offering a stiffer structure against which the occupants sustain their injuries. Therefore the injury cause is more related to this solid structure, particularly if it intrudes into the passenger compartment. This will also apply to some other body region injuries.

The data also shows that some injuries are caused by a structure not normally adjacent to the body region in question. There is often violent occupant movement (particularly limbs) during the impact phase coupled with some vehicle spin and also passenger compartment intrusion. Therefore the occupant limb positions are often very different from those of the normal riding mode.

Abdominal/Lower Back Injuries. Fifty-one (30%) of the restrained FSO casualties sustained an injury to the abdomen and/or lower back (principally the former). The severity distribution is shown in Table 47 and probable injury cause in Table 48. There were only 10 unrestrained FSOs in this group, this number being too small for a meaningful analysis.

Table 47. Restrained FSOs in Struck-side Impacts

AIS 2-6 Injury Severity Distribution, Abdomen and Lower Back

AIS	2	3	4	5	TOTAL
N.	13	16	12	10	51

Table 48. Restrained FSOs In Struck-side Impacts

Probable AIS 2-6 Injury Causes, Abdomen and Lower Back

Probable Cause	Adjacent door /pillar	Door handles	Seatbelt Webbing	Other Veh. Ext. Object	Other Cause	TOTAL
N.	23	2	5	17	4	51

The abdomen lacks skeletal protection and the data shows the level of serious injury sustained. Again the adjacent door was the principal cause with other vehicle/external objects also featuring highly.

Chest/Upper back Injuries. Seventy-seven (45%) of the restrained FSOs sustained an injury to the chest and/or upper back (principally the former). The severity distribution is shown in Table 49 and the probable causes in Table 50. As before, the few unrestrained casualties with injuries to this body region have not been reported.

Table 49. Restrained FSOs in Struck-side Impacts

AIS 2-6 Injury Severity Distribution, Chest and Upper Back

AIS	2	3	4	5	6	TOTAL
N.	24	19	14	10	10	77

Table 50. Restrained FSOs In Struck-side Impacts

Probable AIS 2-6 Injury Causes, Chest and Upper Back

CAUSE	Adjacent door /pillars	Other Occ.	Other Seat	Seat Belt	Other Veh. Ext. Object	Other Cause	Cause NK	TOTAL
N.	25	5	4	8	21	7	2	77

Table 49 indicates the seriousness of the injuries in this group, including a proportion of fatals. The causal pattern is the same as for abdominal injuries, namely the adjacent door and external impacts from other vehicles and objects. A smaller proportion of the chest injuries were attributed to the restraining effect of the seatbelt webbing. Interaction between the casualty and the adjacent seat and/or occupant also featured.

Head, Face and Neck Injuries. Ninety-one (53%) of the restrained occupant casualties in this group sustained injuries to the head, face or neck, mainly the former and the injury distribution is shown in Table 51.

Table 51. FSOs in Struck-side Impacts

AIS 2-6 Head, Face and Neck Injury Distribution

	Restrained			Unrestrained*	
AIS	Head	Face	Neck	Head	Neck
2	52	8	2	4	1
3	15	3	5	2	2
4	8	-	-	5	-
5	4	-	-	-	-
6	9	-	3	2	1
TOTAL	88	11	10	13	4

* Drivers only

However, some coincided with other cranium injuries (Table 52) and, as before, most head injuries were of AIS 2 severity/brief periods of unconsciousness.

Table 52. FSOs in Struck-side Impacts

AIS 2-6 Head, Face and Neck Injuries

Body Region/ Restraint Use	Head only	Face only	Neck only	Face & Head	Head & Neck	Head, Face & Neck
Restrained	66	3	1	7	8	1
Unrestrained*	10	-	-	-	3	-

* Drivers only

In a smaller sample of injured unrestrained drivers, 13 out of 17 sustained a head or neck injury. Half of these died from multiple injuries, including the head and/or neck region.

It will be seen that head injuries predominate, the highest proportion being AIS 2/brief periods of unconsciousness. Probable causes of these injuries are presented in Table 53 with a reminder that figures/ mechanisms for this particular body region are not mutually exclusive.

The most common cause of injury in this group was contact with another vehicle/external object, usually via the broken glazed area. There was also a significant number of contacts with the adjacent door/pillars and

Table 53. Restrained FSOs in Struck-side Impacts

Probable AIS 2-6 Injury Causes, Head, Face and Neck

Probable Cause	Restrained			Unrestrained*
	Head	Face	Neck	Head/Neck
Roof/Side header	7	1	-	2
Adjacent door/Pillars	17	1	-	2
Side Glass	12	2	-	1
Other Occupant	2	-	1	-
Other Veh./Ext. object	24	6	4	6
Decel. No contact	10	-	4	-
Other Cause	4	-	-	1
Cause NK	12	1	1	1
TOTAL	88	11	10	13

* Drivers only

side glass. A lesser percentage of head and neck injuries were due to deceleration without noticeable head contact.

Restrained Front Seat Occupants in Non-struck Side Impacts

As with the struck-side analyses, data on restrained FSOs have been combined. Therefore *drivers* involved in *nearside* and *front passengers* in *offside* impacts have been considered of which there were a total of 109 casualties (84 drivers and 25 FSPs). There were only 9 unrestrained drivers in this impact category and, when their injury patterns were further broken down into individual limb regions, the final figures were insufficient for meaningful analysis.

Limb Injuries (Including Bony Pelvis). Forty-six (42%) of a sub-set (32 drivers and 14 FSPs) sustained limb injuries ≥ AIS 2. The distribution is given in Table 54 and again it is necessary to define limb side in relation to the side of the vehicle that has been impacted. Using the previous convention, a driver's Left leg in a nearside impact is classified as "Adjacent" whilst the Right leg in the same impact would be classified as "Remote." For a front seat passenger in an offside impact the converse would apply for the Right and Left limbs. This convention is not totally accurate as say, an *adjacent* limb would strictly be more in the middle of the car at the time of impact. However the same terminology has been used for consistency.

Table 54. Restrained FSOs in Non-struck Side Impacts

Distribution of AIS 2-6 Limb Injuries

Limb side	Pelvis*	Hip	Thigh	Lower Leg	Foot/ ankle	Shoulder	Arm	TOTAL
Adjacent		1	-	1	3	5	9	19
	(9)							(9)
Remote		2	4	1	1	6	11	25

* Pelvic injuries are not assigned Left/Right in the coding.

Most injuries occurred to the upper limbs and, as the individual numbers are small, probable causes have not been tabulated. Most of the driver's pelvic injuries were due to the transmission tunnel and were probably indirect arising out of contact with one of the lower limbs. Upper limb injuries were judged to be due to contact with the other occupant or door with a number of Not Known's.

Abdomen/Lower Back Injuries. Twenty-three (21%) sustained abdomen and/or lower back injuries. The severity distribution is given in Table 55 and shows a high proportion of AIS 3-6 injuries (18/23).

Table 56 shows the distribution of probable injury causes, the largest classification being due to the effects of another vehicle/external object. Again some of these injuries can be in the rebound category.

Chest/Upper Back Injuries. There were 34 casualties with injuries to this body region (31% of sub-set) and Table 57 again shows that over half were severe (AIS 3-6). All sustained rib fractures, the majority being simple at AIS 2 level. Table 58 shows that the causal pattern is not dissimilar to that for the abdomen but with more interactive-type injury mechanisms.

Table 55. Restrained FSOs in Non-struck Side Impacts

AIS 2-6 Injury Severity Distribution, Abdomen and Lower Back

AIS	2	3	4	5	TOTAL
N.	5	8	7	3	23

Table 56. Restrained FSOs in Non-struck Side Impacts

Probable AIS 2-6 Injury Causes, Abdomen and Lower Back

Cause	Door	Other Occupant	Seatbelt	Other Veh. Ext.Object	Other Cause	Cause NK	TOTAL
N.	3	2	3	7	4	4	23

Table 57. Restrained FSOs in Non-struck Side Impacts

AIS 2-6 Injury Severity Distribution, Chest and Upper Back

AIS	2	3	4	5	6	TOTAL
N.	14	8	5	2	5	34

Table 58. Restrained FSOs in Non-struck Side Impacts

Probable AIS 2-6 Injury Causes, Chest and Upper Back

Cause	Door	Other Occ.	Other seat	Seat belt	Other Veh. Ext.Object	Other Cause	Cause NK	TOTAL
N.	5	5	5	5	9	2	3	34

Head, Face and Neck Injuries. There were 64 injuries to the head and 7 to the face, a total of 71. All but 2 of the latter were concomitant with other head injuries. Table 59 shows, as before, that the majority were AIS 2 and, since they were in the majority, only head injury causes are presented in Table 60.

Table 59. Restrained FSOs in Non-struck Side Impacts

AIS 2-6 Injury Severity Distribution, Head, Face and Neck

AIS	2	3	4	5	6	TOTAL
Head	28	11	6	12	7	64
Face	5	2	-	-	-	7

Although not specifically presented, it can be reasoned that many of the door/pillar assigned contacts could be either rebound injuries or the result of gross intrusion towards the non-struck side of the vehicle.

Table 60. Restrained FSOs in Non-struck Side Impacts

Probable Causes of AIS 2-6 Head Injury

Doors/ Pillars	Steering Wheel	Side Glass	Other Veh./ Ext. Object	Decel. No Contact	Other Cause	Cause NK	TOTAL
16	2	3	18	3	7	15	64

As in the case of struck-side collisions, intrusion into the occupant space of other vehicle/external objects also featured highly—as well as a proportion in the "Not Known" category.

Discussion and Concluding Remarks

It is no surprise that the data show the majority of impacts are to the vehicle front with the highest proportion offset to the right. In a previous CCIS investigation by Ashton et al [6] it was found that such impacts are largely the result of offset head-on collisions on unrestricted roads.

The data also show that, in terms of total numbers, head and limb injuries predominate. Although the latter are not life-threatening when taken in isolation, they often coincide with sometimes serious injuries to other body regions.

In a proportion of cases, lower leg injuries occur when there is entrapment of the casualty in the vehicle and there are also a higher percentage of multiple injuries in side impact collisions. If the door itself is grossly distorted and jammed following impact, rescue is invariably delayed, despite the sophisticated cutting equipment carried by emergency vehicles. If there are life-threatening injuries present, such a delay could compromise eventual clinical recovery of the patient, despite improvements in roadside medical care. Therefore these points must be borne in mind when considering vehicle design improvements, particularly in side impact protection.

The analyses clearly show that lower fascia contact, footwell intrusion and foot pedal entrapment are the principal causes of lower leg injuries amongst drivers. Instances have been found where, although the fascia surface is compliant, it is sometimes supported by an aggressive structure. Therefore the above injury-causing structures warrant further consideration, particularly in relation to the frontal impact situations previously mentioned.

The results show yet again that steering wheel contact is responsible for the majority of restrained drivers' facial contact in frontal impacts, producing as it does concomitant and often serious head injuries. It is accepted that initiatives have been taken on producing an occupant-friendly steering wheel assembly, more recently reported by White et al [8]. The data analysed in this report has not differentiated between wheel types. Implementation of these improved designs must remain a priority item.

Many of the head injuries recorded in the data are brief periods of unconsciousness caused by the head either striking the internal structure or external structures/other vehicles. Non-contact head injuries are also recorded, producing a similar clinical outcome. Although these periods are brief, they should not be dismissed lightly as latent head trauma, epilepsy and recurring headaches are a possibility following unconsciousness.

The steering wheel and seatbelt webbing, often in combination, are again the principal causes of chest and abdomen injuries for the restrained driver in frontal impacts. It has long been accepted that seatbelt-related injuries are the lesser "penalty" of wearing restraints when compared to the more serious and fatal injuries sustained by those who still choose not to wear their seat belts. The majority of the recorded chest injuries were AIS 2, usually one or two simple rib fractures and an increase in this type of injury following the introduction of the 1983 seatbelt legislation was predicted by Rutherford et al [7] who also indicated a likely reduction in overall injuries. However the *elderly* population are more susceptible to skeletal fractures and it is predicted that half the population will be over 55 years of age by the year 2000 with many of them drivers. Therefore the question of (particularly rib) fracture causation and possibly underlying soft tissue damage must be addressed.

The Sections on side impact collisions discuss the relative vulnerability of occupants when compared to frontal impacts. The data quantify the relative injury severity and it is no surprise that contact *with* the door is the principal cause of side-impact chest, pelvis and upper leg injuries. It has also been shown that striking/struck objects often remain in contact with the "case" vehicle door during the impact phase. This tends to produce an unyielding structure against which most injuries occur.

A considerable number of head and chest injuries were sustained due to contact with another vehicle/structure, usually intruding via the glazed areas, particularly in side impacts. Although the fitting of laminated side glass may go some way to reducing a *few* of these injuries, attention will possibly have to be focused on door/sill strengths to partially prevent intrusion of these outside, full height structures. It is appreciated that concern over injuries sustained in side impacts and potential solutions is receiving worldwide attention. However frontal collisions are still in the majority so a combined approach to frontal and side impact protection must remain a goal.

For the restrained front seat passenger in frontal impacts, the intruding lower fascia was the cause of the majority of thigh injuries. A proportion of trunk injuries were also caused by this mechanism but the majority, particularly to the chest, were caused by the restraining effect of the seat belt webbing. Again, many of these were simple rib fractures of AIS 2 severity with the same remarks applying as for the restrained driver. These and footwell intrusion for injuries to the lower legs have already been mentioned.

The difficulties of assigning injury causes to the (sometimes) flailing upper limbs have been discussed. However there is a dominant involvement of the steering wheel in the case of the driver and seatbelt webbing-related shoulder injuries for both restrained FSOs.

Many of the rear seat casualties in the sample were unrestrained and the earlier data identified a high proportion of the young and elderly. All modern cars now have rear restraints fitted and legislation has been introduced for compulsory wearing by all occupants seated in the rear where a restraint is available. This legislation is important as the data from this and other studies clearly show that unrestrained vehicle occupants sustain greater levels of serious and fatal injury in accidents. What the data *also* show is that most of the contacts for unrestrained RSPs in frontal impacts are to the front seats. Not only can this produce injury to the RSP, but also loads the front seat and therefore its occupant. Although this is not brought out in the analysis, such loading can either cause primary injuries to the FSOs or aggravate any previously sustained by them in the impact. Ejection of unrestrained rear seat occupants from the vehicle following impact has also been recorded, usually with serious or fatal consequences.

The wearing of available restraints for *all* occupants is vital as there seems little point in striving for meaningful improvements to restraint systems if they are not going to be worn. Enforcement should take a higher profile.

Acknowledgements

The work described in this Paper forms part of the programme of the Transport and Road Research Laboratory, commissioned by the Vehicle Standards and Engineering Division of the Department of Transport, and the Paper is published by permission of the Director.

Collection of the data depends on the voluntary cooperation of many individuals and agencies without which the project would not be possible. Gratitude is therefore expressed to the following:

The Chief Constables and their staff in the geographical areas covered by the study.

The Hospital Consultants and their staff, particularly the medical secretaries in the participating hospitals.

H M Coroners, Procurators Fiscal and their officers.

The management and staff, both scientific and administrative, of the Accident Research Units at Loughborough and Birmingham.

Co-Sponsors Ford, Rover Group and more recently, Nissan Cars.

Staff at the DTp's Vehicle Inspectorate's Headquarters at Bristol and particularly the many Vehicle Examiners in participating Regions.

The authors would like to acknowledge the efforts of Martin Renouf and Jeff Meades who have developed and managed the comprehensive, computerised database used in the study.

References

1. MACKAY G M, M D GALER, S J ASHTON and P D THOMAS. The Methodology of In-Depth Studies of Car Crashes in Great Britain. SAE Paper 850556. Detroit, 1985.
2. GALER MARGARET M, G M MACKAY, S CLARKE and S J ASHTON. The Causes of Injury in Car Accidents - an Overview of a Major Study currently underway in Britain. Proceedings of the 10th International Conference on Experimental Safety Vehicles. Oxford, July 1985.
3. RENOUF M. A Car Accident Injury Database: Overview and Analyses of Entrapment and Ejection. Transport and Road Research Laboratory Report RR 320, Transport and Road Research Laboratory, Crowthorne, England, 1991.
4. The Abbreviated Injury Scale, 1985 Revision. Association for the Advancement of Automotive Medicine, Des Plaines Il, 60018, USA.
5. Collision Deformation Classification. Report of the Automotive Safety Committee. SAE Report J224, March 1980.
6. ASHTON S J, P D THOMAS, P L HARMS, G M MACKAY and M D GALER. The Effects of Mandatory Seatbelt Use in Great Britain. Proceedings of the 10th International Conference on Experimental Safety Vehicles. Oxford, July 1985.
7. RUTHERFORD W H, A GREENFIELD H R M HAYES and J K NELSON. The Medical Effects of Seat Belt Legislation in the United Kingdom. DHSS Report No. 13, HMSO, London, 1985.
8. WHITE M, K CLEMO and S PENOYRE. Safer Steering wheels to reduce face bone fractures. Proceedings of the 12th International Conference on Experimental Safety Vehicles. Göteborg, Sweden, 1989.

S1-W-17

The Use of Crash Injury Research Data by the Vehicle Inspectorate to Identify Secondary Safety Concerns

Alan Bowker
Department of Transport

Abstract

This paper briefly details the current arrangements in Britain for examining road vehicle crashes and the causes of injury to vehicle occupants. The use of this data by the Department of Transport's Vehicle Inspectorate to examine vehicle secondary safety performance is described. In addition to providing research data for consideration by vehicle manufacturers when formulating new model designs, this accident data has been analysed with some success in order to identify what design or manufacturing related features of current models could be usefully improved.

Corrective action by the vehicle manufacturer within the current model lifespan will assist in reducing the number or severity of occupant injuries attributed to that model. The earlier in the model lifespan that any design related concerns can be identified and corrected, the greater will be the total saving in occupant injuries. Some examples of the type of analyses which can be undertaken using this data is described.

Introduction

Vehicle accidents are investigated in the UK by the Vehicle Inspectorate for a variety of reasons. These include the provision of expert vehicle examination information to support the police or to provide crashed vehicle data to research bodies such as the Department's Transport and Road Research Laboratory (TRRL). A prime objective for VI however, is the identification of vehicle design or manufacturing defects which may have contributed to the cause of the accident or to the severity of the injuries received by the vehicle occupants or other road users. Through analysis of accident data which is primarily collected for research purposes, early additional benefits in occupant protection and injury reduction can be gained through the introduction of countermeasures into current vehicle designs.

Two main computer databases containing specific vehicle and occupant information on UK road accidents are available to the Vehicle Inspectorate, one database focuses mainly on Primary Safety (Accident Causation) and has data accumulating at a rate of approximately 2000 accident/vehicle inspections per year on all vehicle types.

The second database focuses on Secondary Safety (Injury Reduction) and has data accumulating at a rate of approximately 700 accidents/vehicle inspections per year mainly involving cars and more recently, light goods vehicles and minibuses. It is this latter database which is briefly described and analysed for the purposes of this paper.

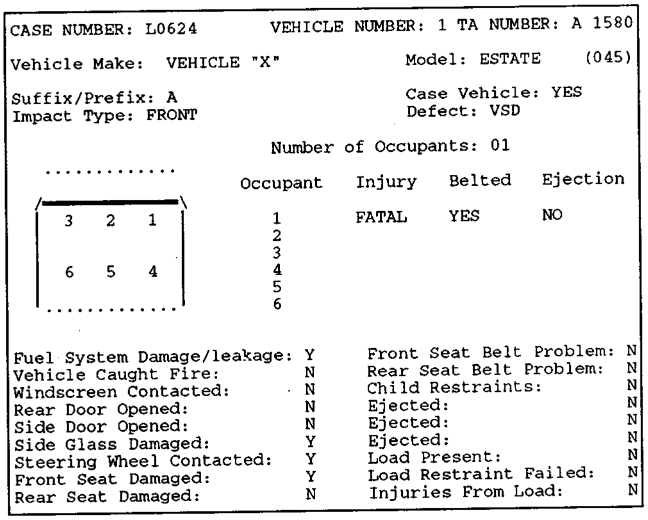
The UK Co-operative Crash Injury Study (CCIS) providing the information for this database was established in the early 1980's and the methodology and organization of the study was reported in detail by G M Mackay et al in a 1985 SAE paper [1]. The study was originally established to investigate the mechanisms of occupant injuries in car accidents and to provide basic research data to assess the effectiveness of the injury reducing features of current EEC/ECE Directives and vehicle safety regulations. The Department's Transport and Road Research Laboratory (TRRL) stores all the data on the vehicle examinations and occupant injuries on its mainframe computer database. This database contains details of 3707 vehicles involved in 3344 accidents, and occupant casualties. This data is medical data on the 6236 analysed by TRRL, Birmingham University and Loughborough's Institute for Consumer Ergonomics for vehicle safety research purposes. An overview of the study with typical analysis was published by M Galer et al in the proceedings of the 10th ESV conference [2].

Crash Investigations by Vehicle Inspectorate Staff

Data for the CCIS database is collected in a uniform manner by accident researchers from the two universities and by the seven teams of Vehicle Inspectors from VI. The accidents are selected at random in accordance with agreed stratified sampling techniques in each of the 7 study areas. In addition to collecting data for research purposes, the vehicle examiners are trained to detect any secondary safety concerns such as design or manufacturing defects in the vehicle systems inspected. Such concerns are reported separately to VI headquarters on a vehicle safety defect report. Components such as seatbelts which have broken in light to medium frontal impacts will be photographed before being removed from the vehicle. All such vehicle or component defects are then investigated by VI in conjunction with the manufacturer to establish the cause of the concern and whether a significant number of vehicles may be similarly affected. If this is the case vehicle recall action is the likely outcome.

Identifying Secondary Safety Concerns

In order to review interesting cases both from an occupant injury point of view and to examine possible vehicle concerns, meetings are arranged at four monthly intervals in which representatives from the University and VI accident investigation teams present recent "cases of interest" for wider discussion amongst their accident research colleagues. Often at these meetings vehicle concerns are identified in which it is felt that some action could be taken to mitigate the injuries received by occupants in future similar crashes. Potential as well as actual vehicle injury concerns are also discussed as part of the "cases of interest" session. For example a frontal impact accident in which the bonnet retaining hinges lost their integrity allowing the edge of the bonnet to penetrate the windscreen with potential or actual injuries would be discussed. Accident Investigators would discuss the case in question and reflect on any similar cases that they may have seen. Where accident cases identify a vehicle design concern or manufacturing concern which should be corrected these are noted and subsequently the whole accident database is checked for similar concerns. Figure 1 shows the data fields currently extracted by VI from the much larger data set of vehicle and occupant data. Although the number of search fields is relatively small some useful data analysis can be carried out. In the vast majority of cases the vehicle safety concern is not of sufficient seriousness to justify formal vehicle recall action under the terms of the UK code of practice which details action to be taken when identifying a significant safety defect. However in these cases it may be considered that some action could be taken by the vehicle manufacturer to improve for the future, an occupant's chances of avoiding injury from the concern identified. In the case identified above concerning bonnet integrity, the manufacturer would be invited to examine the related cases and consider whether a more robust design or manufacturing arrangement may prevent a recurrence. Invariably when such modifications are implemented at an early stage within the life of the model concerned, real injury savings often result from modification of the vehicle or the manufacturing methods used to produce it.



CASE NUMBER: L0624 VEHICLE NUMBER: 1 TA NUMBER: A 1580

Vehicle Make: VEHICLE "X" Model: ESTATE (045)

Suffix/Prefix: A
Impact Type: FRONT

Case Vehicle: YES
Defect: VSD

Number of Occupants: 01

Occupant	Injury	Belted	Ejection
1	FATAL	YES	NO
2			
3			
4			
5			
6			

Fuel System Damage/leakage:	Y	Front Seat Belt Problem:	N
Vehicle Caught Fire:	N	Rear Seat Belt Problem:	N
Windscreen Contacted:	N	Child Restraints:	N
Rear Door Opened:	N	Ejected:	N
Side Door Opened:	N	Ejected:	N
Side Glass Damaged:	Y	Ejected:	N
Steering Wheel Contacted:	Y	Load Present:	N
Front Seat Damaged:	Y	Load Restraint Failed:	N
Rear Seat Damaged:	N	Injuries From Load:	N

Figure 1. Shortform Data Coding Sheet

Typical Database Analysis

Two types of analysis of the database looking for vehicle concerns are carried out, one involves the search for similar cases in order to identify repeating concerns. The second is where an analysis of a more often observed concern needs to be compared to other manufacturers vehicles with similar style and weight classification. Examples of both types of analysis are detailed below to illustrate how real safety improvements can be achieved.

Case 1

Several cases of severe knee or compound lower leg fractures were observed from medium energy frontal accidents in a popular European hatchback model. These accidents were all in the range 40-70 kph delta V range and none of the drivers received fatal injuries. However, a common injury to each was the AIS 2 or 3 lower leg injuries caused by a brake pedal bracket assembly which was forced through the heater ducting and facia cladding as a result of the impact forces and the rotational effect caused by the driver when applying heavy braking to the pedal prior to impact. The injuries received were typically open Tibea or Fibula fractures just below the knee caused by the forward edge of the pressed bracket which peeled back when contact with the lower leg bone was made. Accident investigators at the case review meetings confirmed that no other model types they were examining produced similar and consistent injuries which would have resulted in such debilitating injuries. Research carried out in Sweden by Folksam on small car crashes also involving this model did not reveal an above average incidence of leg injury. However, it was subsequently discovered that the left hand drive version of the pedal bracket was a different shape and protruded towards the drivers knee by 20 mm less than on the RHD version. Similarly crash test using instrumented dummies to measure femur loads also did not reveal this concern possibly because the forces applied to the brake pedal in panic braking were not being reproduced in the dummy tests and only LHD versions were tested. So we had a situation where UK real world accident research data was showing a specific vehicle concern which was not evident from extensive crash test by the manufacturer or from Swedish insurance data involving only LHD variants of the vehicle.

The vehicle fascia design was modified by the manufacturer as a result of the concern. A crash pad involving a shaped steel plate was riveted to the reverse side of the fascia moulding around the underside of the steering column. This was designed to spread the load of the pedal bracket against the knee and prevent its protrusion beyond the fascia cladding. To date we have not observed similar severe leg injuries arising from the modified vehicle. Although this model is about to be superseded and the new model uses the same pedal bracket assemblies as the old one, the bulkhead design is significantly stiffer reducing the rearward movement effect of the bracket in an impact. The manufacturer has advised that this, combined with the new models use of a seat buckle activated pre-tensioning device should minimise the problem in future similar accidents.

Case 2

Accident Investigators were seeing a higher than expected frequency of concern involving seat belt buckle casings which shattered as a result of the intrusion caused by side impacts to a popular UK model of small hatchback car. The result of the side structure intrusion occasionally also caused the seat squab hinge to jam the seat belt release mechanism as a result of the upward movement of the seat/floor pan caused by side structure intrusion. Data on about 15 cases of the concern had to be collected before a sufficiently robust case for action could be put to the vehicle manufacturer. This concern, because it was side impact related, was not addressed by any current or proposed regulation but was evident on about 9% of the side impact cases involving the model concerned.

A major redesign of the vehicle structure was required to overcome the problem, this involved improvements to the seat slides, floor pan and associated brackets which were strengthened. A substantial cross brace was added to significantly improve the side impact stiffness of the vehicle and a modified metal strap type of seat belt stalk was introduced to further reduce seat to buckle casing clashes. These modifications significantly reduced the possibility of entrapment as a result of seat belt casing damage and consequential damage to the release mechanism.

The previous two cases examined specific concerns with a model in which accident investigators and vehicle examiners considered that a problem existed with the vehicle design or construction which should be corrected. Often injuries and vehicle damage concerns need to be examined statistically in order to make comparisons of secondary safety system performance between different manufacturers models. Ideally a large database of information involving the models to be compared is required. Variables such as direction of force at impact or impact severity (measured as delta V using crash 3 computer programme) can be used to refine the comparison of models in addition to the obvious one of comparing vehicles in the same weight/body classification. The following 3 cases illustrate how comparisons can reveal the models which have the poorest secondary safety performance.

Case 3

In this example the accident investigators and vehicle examiners were reviewing cases in which steering wheel hub covers were becoming displaced in impacts and the concern was that the exposed hub nut or sharp edges of the hub cover were causing excessive facial injuries. A database analysis was carried out in which the model concerned was the focus of attention. By examining frontal impact accidents with belted drivers in which face/head injury through contact with the steering wheel was observed it was possible to see how the model in question compared with others. Care was taken to ensure that the vehicles used for comparison were in the same weight/body classification as the subject vehicle and that a sufficient number of accident records were available for comparison.

Table 1 shows the results of this comparison and it was observed that from more than 300 accidents involving Model A the highest percentage of facial injuries at 15% was observed. The majority were AIS 1 (minor) injuries believed to be caused mainly from the hard finish two spoke steering wheel fitted to 73% of the Model A variants. The manufacturer had already taken steps to improve the product by fitting a "soft" feel wheel as standard. There are indications that this wheel is demonstrating useful injury reductions over the standard "hard" steering wheel. The manufacturer concerned was one of the sponsors for the CCIS work and was clearly aware of the concern and took appropriate action at an early stage. This example demonstrates the usefulness of manufacturers getting early injury information from a large number of accident cases involving their models.

Table 1. Frontal Impact Accidents—Belted Driver with Head/Face Contact on the Steering Wheel

Model	Accidents with face/ head injuries from steering wheel (%)	Injury Severity		
		AIS 1 (%)	AIS 2 (%)	AIS 3+ (%)
Model A	15	11	3	1
Model B	13	10	2	1
Model C	9	5	4	0
Model D	9	3	6	0
Model E	6	6	0	0
Model F	6	3	3	0

Case 4

This investigation commenced with a single case of a seat belt stalk which pulled out of the floor pan complete with fixing nut and space in a frontal (12 O'clock) 80% overlap accident with another vehicle. The delta V for the subject vehicle was estimated at 67 kph using crash 3 and the drivers weight was 80 kgs. There was no rear occupant loading of the front seat. The manufacturer of the vehicle provided information on 15 barrier impact tests carried out on vehicles equipped with dummies at the standard impact speed of 48 kph and provided seat belt anchorage test results from 5 production bodyshells. All results showed no failures and this single accident failure although very unusual was considered an isolated incident.

However a second similar incident involving the model in a 12 O'clock impact with a heavy goods vehicle also produced a similar failure where the seat belt stalk complete with anchor bolt spacer and fixing nut pulled through the floor pan. In this case the drivers weight was 87 kg. The delta V at impact was computed at 46 kph using the crash 3 computer programme, although the manufacturers estimate was about 54 kph with the crush profile being fairly evenly distributed across the front of the vehicle.

The manufacturer again suggested that the higher than average weight of the driver was largely the cause of the failure. We carried out a database analysis of our database to identify any related cases. Peer group vehicles similar to the subject vehicle were also examined for the purposes of comparison. The search criteria used was 11, 12 or 1 O'clock front impacts with damage to the seat belt mounting points observed. These were split into inboard, B pillar swivel and lower outboard anchorage damage. For each case the impact delta V, weight of occupant and any loading of the front seat belt from rear occupants or luggage was recorded. The results are shown in Table 2. The summary table shows the results for models of similar size and weight to the subject vehicle (Model A).

Table 2. Inboard Anchorage Concerns—Summary Table

Vehicle Model	Number in Sample	Inboard Anchor		B Pillar Swivel		Lower Out-board Anchor	
		Damaged	Fail	Damaged	Fail	Damaged	Fail
Model A	60	2	2	1	0	0	0
Model B	162	6	0	8	1	1	0
Model C	551	3	0	10	0	6	0
Model D	119	0	0	0	0	2	0

The summary table shows that anchor point damage was relatively infrequent compared to each model sample size. Damage in some cases was due to direct contact with an intruding vehicle and in other instances by the severity of the accident. In some cases additional rear loading was imposed on the seat belt system. Model A had the worst record of inboard anchorage problems with 2 suffering distortion damage and two suffering complete loss of integrity, this was despite having the smallest sample size of the models examined.

The manufacturers type approval and conformity test data showed that the original anchorage design exceeded the 27kn ECE R14 Regulation minimum load requirements by about 33%. However the later introduction of a thicker pile carpet into the model range meant that a much deeper spacer between the seat belt stalk and the floorpan was required. This imposed additional bending loads on the anchorage reducing the margin of acceptance to just 7% to 10% above the minimum type approval requirements. This slim margin was sufficient to cause anchorage failures in real world accidents, a phenomenon practically unknown on our accidents database. Corrective action taken by the manufacturer was to revert back to the original smaller spacer on the inboard anchorage.

It was interesting to note on observing a typical manufacturers anchorage test to destruction on a production vehicle that the floorpan deformation in the real world accidents prior to failure was neglible whereas the pull test in the laboratory produced quite significant floor pan deformation. This was as a result of the relatively slow load onset rate for type approval tests compared with the real accident situation. These differences may also explain why no test failures were observed in the laboratory and this case illustrates the need for real world accident data to identify any cases of marginal design performance.

Case 5

With about 3% of vehicle accidents a year in the UK resulting in fire, the possibility of doing a useful make/model analysis using a database growing at 700 accident cases per year would produce some unsound statistics even for the most popular models on the database. However, when we consider that the potential for a fire is significantly increased once the vehicles fuel system integrity is breached some useful analysis by make and model can be carried out fuel system disruption as a potential design concern.

Our primary safety accidents database had indicated a possible high fire risk concern with one particular model and at about the same time accident researchers and vehicle examiners were highlighting several examples of unexpected fuel system damage with the same model at our regular case review meetings.

Table 3. Fuel System Disruption

Model	No: Impacted	No Suffering Damage/Leakage	As %
Model F	55	22	40
Model G	72	4	5.5
Model H	41	5	12
Model I	63	4	6
Model J	76	6	8

A database analysis involving frontal impacts in which underbonnet fuel system damage and leakage was observed was undertaken in order to examine if the subject model was at variance with other popular models on the database. Vehicles from the same size and weight class and from smaller weight classes with good representation on the database were chosen for comparison. Table 4 shows the results of the analysis. The subject model (Model F) clearly suffers from a high incidence of fuel system disruption in frontal accidents with 40% of the sample of seriously damaged vehicles suffering loss of fuel system integrity. The next worst model was Model H with just 12% showing disruption but even this vehicle was clearly significantly better than the subject vehicle. The vehicle manufacturer took several measures to improve the situation having identified from the accident case notes the reasons for the concern. New engine mountings to provide greater levels of mount integrity in moderate to severe crashes were introduced and fuel hose lengths were increased to reduce the possibility of them pulling off when stretched due to engine movement. The clamps used to secure the hoses also were subject to research for a better design. One interesting fact to emerge from the analysis was that the fuel system disruption for the vehicle model which proceeded the subject model was significantly better with just 8% showing damage and leakage. In this case the design had taken a retrograde step in terms of its potential for fuel system disruption and fire following collision. A cross check using UK Home Office fire data for crash and collision using peer group vehicles for comparison and taking account of the model populations on the road also confirmed that the subject model was at least three times more likely to catch fire than average. Although this data was unable to specify the likely reasons for the fires the data did support the potential fire concern identified from the CCIS accident database.

Table 4. Fuel System Disruption—Later Manufactured Vehicles

Model	No: Impacted	No: Suffering Damage/Leakage	As %
Model F	80	23	28.8
Model G	90	7	7.8
Model H	72	13	18.0
Model I	100	7	7.0
Model J	122	13	10.7

Monitoring the Effectiveness of Countermeasures

The above case histories show how vehicle secondary safety concerns in crashes can be revealed from this study. The nature of the indepth recording of vehicle damage information on the hard copy enables an accurate assessment of the cause of many vehicle concerns. When countermeasures are introduced by the manufacturer, their effectiveness can also be monitored by a study which is continuous in its nature. Thus if we take Case 5 in the above section as an example it is possible to analyse a further data set involving more recently manufactured vehicles which have been modified to improve their performance. Table 1 shows the results of such an exercise using the same models for comparison as the earlier analysis. This shows that the fuel system damage and leakage concerns relating to model "F" fell from 40% of the population involved in frontal impacts to around 28%. Thus a feedback loop on the effectiveness of countermeasures is established and the performance of new models or system designs can be compared with earlier versions using real accident data.

Concluding Remarks

The case studies show how it is possible even with a limited sub set of data from a high quality accident database to identify vehicle safety concerns. The earlier in a models life that the concern can be identified and corrected the greater the injury saving potential. With models having lifespans of 6 years or more it is even possible to verify the effectiveness of the countermeasure in correcting the concern. Other accident studies in other countries in which manufacturers examine their own vehicles involved in crashes can provide useful data on specific concerns but these studies will have difficulty in drawing any conclusions on how their model compares with other manufacturers equivalent vehicles. The CCIS study enables these comparisons to be made and will concentrate the design efforts for improvement in areas where clear evidence indicates poor or marginal performance. The benefits to manufacturers in accessing real accident data are clear and vehicle occupants will also benefit from the resulting safer designs.

References

1. MacKay, G M, M D Galer, S J Ashton and P D Thomas "The methodology of indepth car crashes in Britain", SAE paper 850856, 1985.
2. Otubushin, Gater et al, "Crashed Vehicle Examination Techniques". SAE paper 860372, 1986.
3. Gustafsson H, Hagg et al, "Folksam car model safety rating 1989-90" Stockholm 1989.
4. Galer M, S Clark, G M MacKay and S J Ashton, "The causes of injury in car accidents—An overview of a major study currently underway in Britain." 10th ESV Conference.

S1-W-19

Air Bags in Crashes: Clinical Studies from Field Investigations

Donald F. Huelke, Ph.D.
University of Michigan
Transportation Research Institute
J. Vernon Roberts
National Highway Traffic Safety
Administration

Jamie L. Moore
University of Michigan
Transportation Research Institute

Abstract

This paper documents field investigations of "air bag" crashes. A full range of crashes are presented including

fatalities, to high speed impact with survival, and minor injury crashes. Also detailed are the UMTRI and NHTSA investigative alert systems. Most occupants sustained minor injuries. Those not wearing the 3-point restraint had more minor injuries, and the occurrence of higher level injuries (AIS >2) was found more often in the non-belted.

Introduction

The true test of any automotive safety device is in the real-world of motor vehicle crashes. Like all of the other safety features before it, the air bag was well tested in the laboratory, in simulated crashes, and in full scale barrier crashes. These engineering testing procedures showed the air bag to be an effective occupant injury countermeasure in certain crashes before the air bags were made available to the driving public. However, through investigation of real-world crashes in the various impact environments does the true effectiveness of the air bag, in terms of injury mitigation, become apparent. This is a report of a series of air bag deployments in passenger car crashes and the injuries of the drivers.

At the University of Michigan an "early alert" system was developed for notification of air bag deployments. In that the research was sponsored by Chrysler Corporation, Nissan Motor Company, Ltd., and Ford Motor Corporation, letters were sent to dealerships, private body repair shops, as well as selected salvage lots, to notify them of the investigative program and to alert UMTRI personnel of any air bag deployments via an 800 toll-free telephone number. Additionally, a "Wanted" poster was also enclosed to draw their attention to the program (Fig. 1). A similar "Wanted" poster was distributed by the Michigan State Police Accident Investigation Unit to all of the Michigan State Police Posts.

Contacts were also made with the Michigan Sheriff's Departments. All police agencies in the area of the University of Michigan were also alerted and several insurance companies cooperated with us by providing information on air bag equipped cars in crashes. As our toll free number became distributed throughout the country, we received numerous calls from drivers or occupants who were involved in air bag collisions. To date over 1,300 calls have been received of air bag crash deployments.

For years NHTSA has sponsored crash investigation teams throughout the continental United States. Most recently these five teams were alerted through the Accident Investigation Division of NHTSA to investigate air bag deployments in their respective geographic area. NHTSA also has a 800 toll-free telephone number as part of their early alert notification system. In addition, some General Service Administration (GSA) cars were also part of the government air bag fleet and all drivers were told to notify NHTSA in case of a crash involving air bag deployment.

WANTED!

CRASHES INVOLVING ANY CARS WITH:

• AIR BAGS •
• AUTOMATIC SEAT BELTS •
• REAR SHOULDER BELTS (WORN) •

FOR: A scientific research program — on the effectiveness of automobile restraint systems — at The University of Michigan Transportation Research Institute, Dr. Don Huelke.

ANYTIME
CALL: 1-800-423-7507

Please provide:
- your name, telephone number
- time and date of call
- police report number
- brief details about the crash (damage, injury)
- when best to return a call to you

If possible, quickly estimate damages.
DO NOT HESITATE TO CALL !

Figure 1. "Wanted" Poster

The NHTSA has also developed and utilized a system for notification of air bag events of interest. Most typically these events involve a crash where the air bag deployed. This system incorporates the voluntary participation of air bag vehicle manufacturers, insurance companies, police agencies, crash investigators, and private owners. The NHTSA teams investigate about 50 cases per year as part of the agency's Special Investigations program.

Results

It should be indicated at the onset that the air bag is not the polio vaccine for traffic medicine. Two cases exemplify this point.

Case 1 (UM-2805-90) The impact in this collision was so severe that the crash was totally un-survivable for the driver.

This 1990 Ford Taurus was traveling westbound on a 4-lane divided limited-access highway when the driver lost control, crossed the center grassy median, entered the eastbound lanes and was struck by a 1986 White Semi Tractor-Trailer. There was extensive damage to the front and left side of the Taurus (Fig. 2). The 22 year old male driver was wearing the 3-point restraint. The air bag deployed. On impact he continued forward and to the left where his neck contacted the intruding driver's door. He sustained a deep laceration to the anterior left neck with partial decapitation. Also, he sustained a fractured left femur, an open fracture of the left tibia and fibula and multiple lacerations and abrasions about the body. No autopsy was performed thus the existence of any internal injuries are not known. (MAIS 6).

Case 2 (NHTSA NC-90-18) This is a fatal crash involving an air bag equipped 1989 Chrysler LeBaron. The LeBaron crossed the centerline and struck a 1984 Buick LeSabre head-on (Fig. 3). Extreme intrusion prevented survival of the lap-shoulder belted 19 year old

Figure 2

female driver. The driver of the LeSabre and a rear seat passenger also were killed. (MAIS 6).

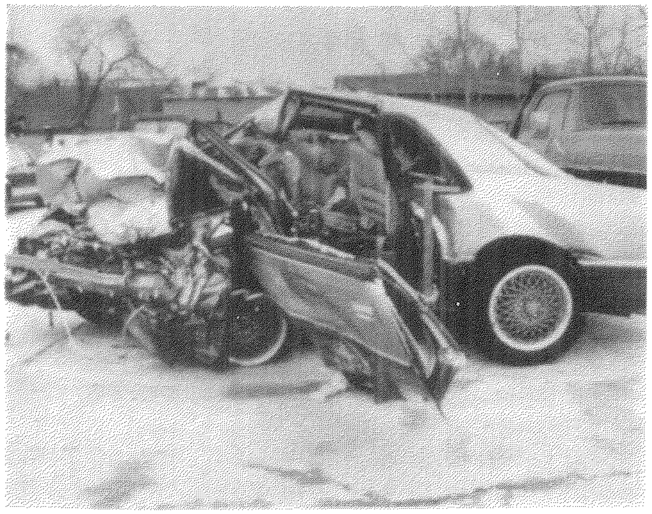


Figure 3

Obviously, not everyone can be saved in any type of crash, even when fully belted in an air bag car. However, there are a number of true "success" stories, some of which are documented below. Cases 3 through 9 involve drivers who were using the 3-point restraint system. Cases 10 through 13 are unbelted drivers in crashes.

The case below shows that air bags are designed to SUPPLEMENT the protection of the 3-point restraint. Air bags only activate once during an accident, therefore, only the belts can help restrain occupants in multiple-impact collisions.

Case 3 (UM-NAB-013) This was a violent crash; the air bag in the Infiniti car significantly reduced the injury level, along with the 3-point restraint. A 1977 Plymouth Gran Fury was traveling westbound; attempted a left turn in front of a 1990 Infiniti M30 that was traveling at an estimated speed of about 72 kmph. The two cars struck head-on. After impact, the M30 rotated clockwise while the Plymouth rotated counterclockwise and the vehicles struck again; the left rear quarter panel of the M30 contacted the right rear quarter panel of the Plymouth. The maximum crush to the front of the M30 was extensive, about 64 cm (Fig. 4). The left rear quarter panel was crushed about 36 cm.

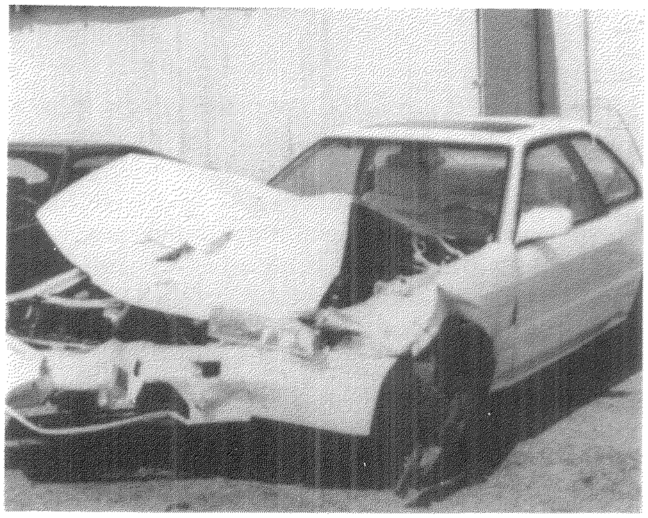


Figure 4

The air bag of the M30 deployed during the first crash sequence. The 3-point restrained driver sustained the following minor (AIS 1) injuries: cervical and thoracic strain (impact force), contusions across the abdomen and chest (3-point restraint), contusion left knee (lower instrument panel), contusion right lower leg (center console trim piece), contusion right anterior forearm and abrasions (air bag) and first degree thermal burns to the top of his right hand (air bag gas). The two front seat occupants in the Plymouth Gran Fury were not wearing their safety belts and were seriously injured.

The Lincoln Continental was the first American-made car to feature an air bag as standard equipment for the driver and front right seat passenger. In this case, both air bags deployed and both front seat occupants were wearing the 3-point restraints, providing maximum protection.

Case 4 (UM-FMA-020) A 1989 Toyota MR-2 crossed the centerline at a high rate of speed and struck the Continental head-on. The police estimated the pre-crash speed of the MR-2 to be 105 kmph and the Continental pre-crash speed of 43 kmph. The maximum crush to the front of the Continental was about 47 cm (Fig. 5). The two front seat passengers in the MR-2 were not wearing the 3-point restraint systems and sustained very serious injuries.

In the Continental both the driver's and passenger's air bags deployed. The 31 year old, male driver (183 cm, 68 kg) was wearing the 3-point restraint; he loaded the restraints, sustaining cervical and lumbar strain (impact force), a laceration to his forehead (rear view mirror), a contusion to his left knee (lower instrument panel) and

Figure 5

a contusion to his right knee (ash tray) (MAIS 1). The 28 year old male front right passenger (183 cm, 95 kg), also wearing the 3-point restraint, sustained cervical and thoracic strain (impact force) and contusions to both knees (glove box) (MAIS 1). A 25 year old male right rear seat passenger was wearing the 3-point restraint system did not sustain any injuries.

Case 5 (UM CCA-055) This is another "success story" where the driver benefited from the air bag and 3-point restraint. This 1990 Plymouth Acclaim had been traveling at a speed of about 88 kmph in the far right lane on a 4 lane divided highway behind a slow-moving tractor-trailer. As the Acclaim entered the left lane in order to pass, the semi truck also entered the left lane. The front right of the Acclaim struck the rear of the trailer. The damage to the front right of the Acclaim was very extensive where the maximum crush was about 85 cm (Fig. 6).

Figure 6

The 23 year old belted male driver (185 cm, 84 kg) continued forward and to the right against the restraints and the deployed air bag. He sustained a contusion across his shoulder from the shoulder portion of the belt, contusions to both knees (lower instrument panel), multiple lacerations to his right fingers and forearm (upper center panel or flying glass) and multiple abrasions to his right upper arm (MAIS 1).

Case 6 (UM-2863-91) (CCA-056) A 1991 Daytona driven by a 19 year-old female wearing the 3-point restraints ran a yellow light and struck a left turning 1985 Audi 5000. The front of the Daytona struck the right side of the Audi. Damage to the Daytona was moderate with maximum crush of 47 cm. to the right front bumper corner (Fig. 7). The driver (168 cm, 52 kg) sustained contusions of both legs (lower instrument panel). There were no injuries reported from driver loading of the tethered type air bag.

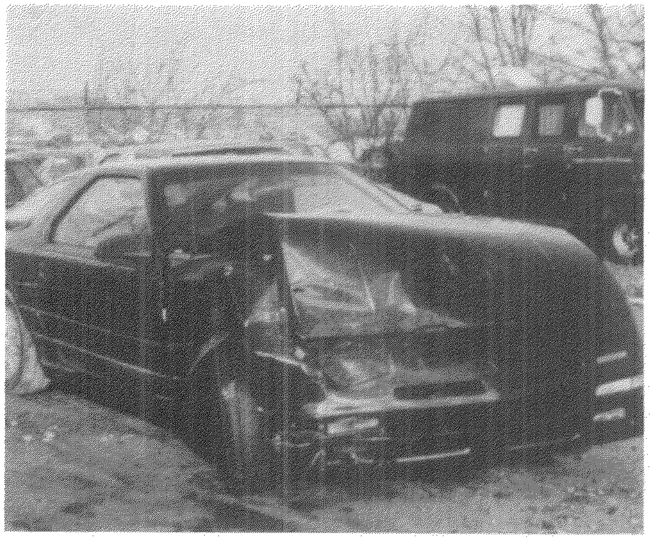


Figure 7

Case 7 (NHTSA CA-90-18) A 1991 Ford LTD Crown Victoria, driven by a 34 year-old lap-shoulder belted male (180 cm, 93 kg) was involved in an extremely severe head-on crash with a 1974 GMC 1500 series pickup truck. The velocity change in the 12 o'clock direction was approximately 50 mph for each vehicle (Fig. 8). The air bag deployed. The driver sustained a fractured right patella with a 1.5 inch laceration of the right knee (knee bolster), a contusion of the anterior left shoulder, a mid chest contusion, and an abdominal wall contusion (belt restraint system), and pain of the right hand (steering wheel rim/instrument panel). MAIS 2 There are no injuries reported from contacting the air bag restraint. The driver of the pickup truck was dead at the scene.

Case 8 (UM-CCA-037) A 1988 Dodge Diplomat, driven by a restrained 32 year old male (180 cm, 84 kg) struck the left side of a tractor-trailer unit that had turned left in front of the car. Damage was concentrated

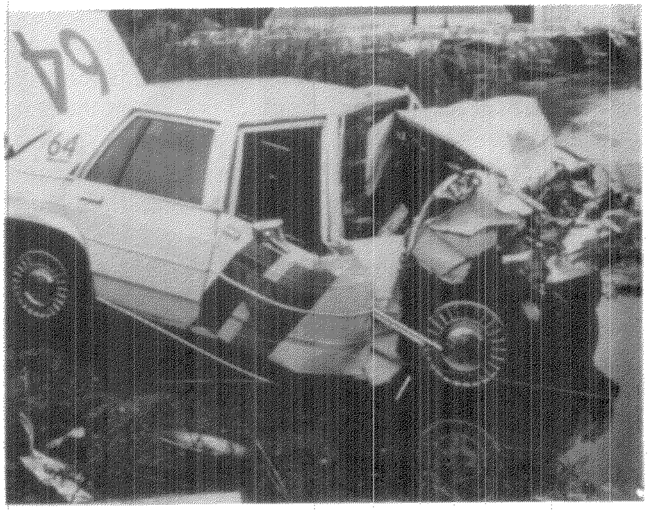


Figure 8

about the right front of the Diplomat (Fig. 9). The air bag deployed. No facial or torso injuries were sustained. Heavy braking by the driver accounts for the right ankle sprain (MAIS 1).

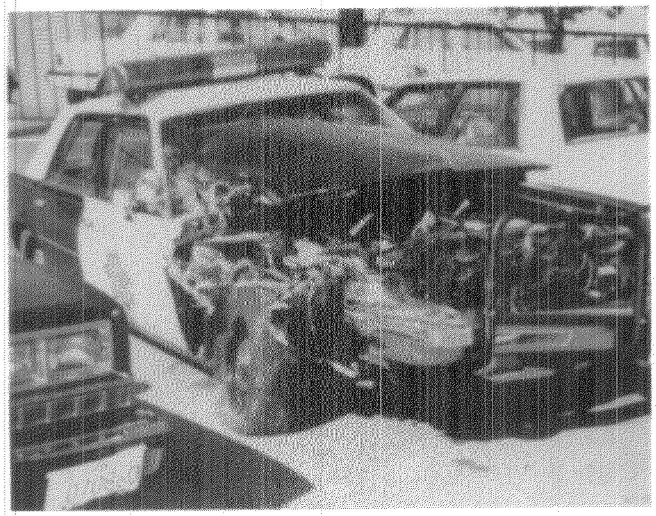


Figure 9

Case 9 (PSU 09 066A) A 1989 Dodge Diplomat struck a 1990 Dodge Dynasty in the left front side (Fig. 10). The lap-shoulder belted driver of the Diplomat, a 23 year old male (183 cm, 73.5 kg) sustained a right leg fracture from the toe pan intrusion (AIS 2).

In the case below the female driver was not wearing the 3-point restraint and appeared to be well protected by the air bag alone, sustaining only minor injuries. She refused medical assistance at the scene but voluntarily went to the emergency room a few hours after the collision.

Case 10 (UM-CCA-035) At an intersection a 1983 Chevrolet Camaro attempted to turn left in front of a 1989 Chrysler LeBaron convertible that was traveling at about 48 kmph. The front of the LeBaron struck the right

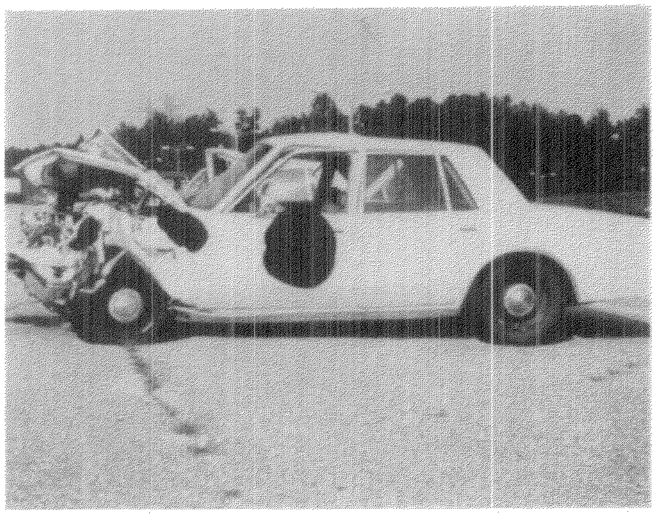


Figure 10

side of the Camaro. The damage to the front of the LeBaron was quite extensive where the maximum crush was about 44 cm (Fig. 11). The 40 year old (168 cm, 89 kg), unbelted female driver continued forward against the deployed air bag. She sustained the following AIS-1 injuries: contusions and abrasions to her chest and forearms (air bag), contusions to both knees (lower instrument panel), cervical strain (impact force), a laceration to the top of her right foot (broken bottle) and a contusion to her right forearm possibly from contact with either air bag or the upper instrument panel (MAIS 1).

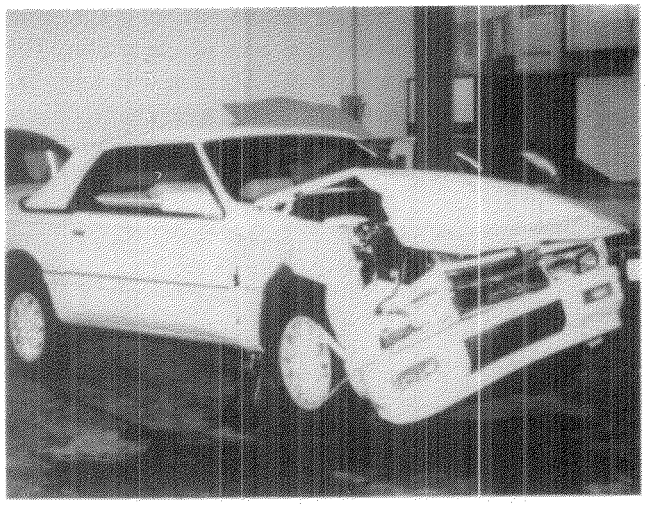


Figure 11

Case 11 (UM-CCA-027) In this crash the unbelted driver sustained a fractured right femur (MAIS 3) from impact with the lower instrument panel. The air bag provided excellent protection to his head and torso. A 1966 White 9564 TD Wrecker was towing a 1974 Freightliner 6x4 Truck in front of a 1988 Chrysler

LeBaron. The wrecker and Freightliner stopped waiting to make a left turn when the Chrysler struck the rear of the Freightliner (the towed vehicle). The damage to the front of the LeBaron was quite extensive with maximum crush about 58 cm. (Fig. 12). In addition to damage to the front bumper, grille assembly and hood, the left wheelbase was reduced about 8 cm. The 47 year old male (178 cm, 72 kg), male driver sustained a fractured right femur (lower instrument panel), chin abrasion and chest contusion (air bag) and cervical strain (impact force) (MAIS 3).

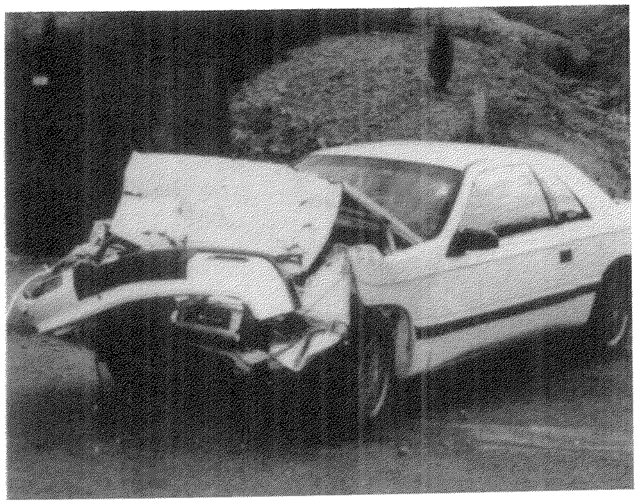


Figure 12

Case 12 (UM-CCA-036) (NHTSA CA89-51) This is a multiple impact collision. The air bag deployed during the first crash sequence protecting the unbelted driver. The driver was then ejected through the open left door prior to the second impact.

A 1989 Daytona was traveling on a two lane suburban roadway. The driver reached down to insert a cassette tape and when he looked back to the road, he saw something in his travel lane. He steered to the right, downshifted and went off the roadway striking a bridge support pillar. The damage to the front of the car was quite extensive where the maximum crush was about 230 cm. The total Delta V for the first impact was calculated at 96.9 kmph (Fig. 13). Following this impact, the Daytona rotated in a clockwise direction, spun off the support pillar, and continued in an easterly direction. Its left door, which had opened as a result of the first impact, subsequently struck a second concrete pillar.

The 24 year old male unrestrained driver (183 cm, 79 kg) moved forward against the deployed air bag at initial impact and then was ejected through the open left door. Because of the ejection, it is unsure if all of his injuries were caused by the first impact (steering wheel contact) or the ejection and impacting the pavement. He sustained the following injuries: Cerebral concussion, 2-3 cm chin laceration, lip laceration, abrasions right side of his face, abrasions and contusions to the chest, abdomen, right elbow and both feet. Also, he sustained a spleen laceration and a myocardial contusion (MAIS 4).

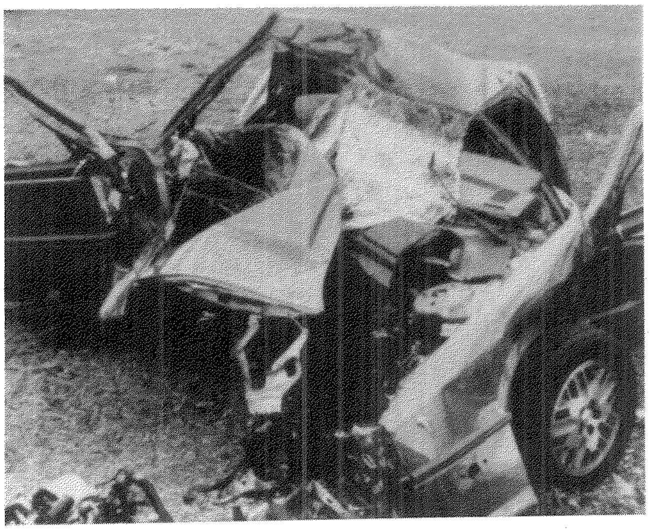


Figure 13

We believe that his survival was due to the deployment of the air bag in this extremely high speed impact. Note the minimal injuries to the face and chest where expected injuries of the facial bones and intrathoracic are not found.

Case 13 (UM-CCA-032) (NHTSA CA 89-45) The case below also involves an unbelted driver in a very severe crash where the air bag provided excellent protection to the driver's head and torso. The driver sustained multiple serious injuries to his lower extremities. (Details on the driver and his injuries were obtained from police and rescue personnel and therefore are not complete).

This 1989 Dodge Daytona was westbound on a 2-lane roadway in a rural area at a police estimated speed of 129 kmph. The stolen Daytona was being pursued by a police car. The Daytona was accelerating as it went into a curve in the road. As the car continued to accelerate it began to yaw out of control, went off the side of the roadway and struck a large tree stump. The car rotated counterclockwise around the stump and came to rest. The damage (130 cm crush) was concentrated to the front of the Daytona (Fig. 14). Damage to the interior of the car was also extensive and the occupant compartment intrusion was significant. The 18 year old male driver was not wearing the 3-point restraint. He sustained the following injuries: Arm fracture, multiple contusions and multiple fractures of the lower extremities, two pelvis fractures and an ankle fracture (MAIS 9).

Other Cases of Interest

Occasionally we found an air bag deployment case where the driver/owner should have realized that there was a fault in the air bag system. The diagnostic module turns on the air bag warning light for several seconds at ignition "on." If there is a fault in the system this light will stay illuminated or flash in some pattern. Some

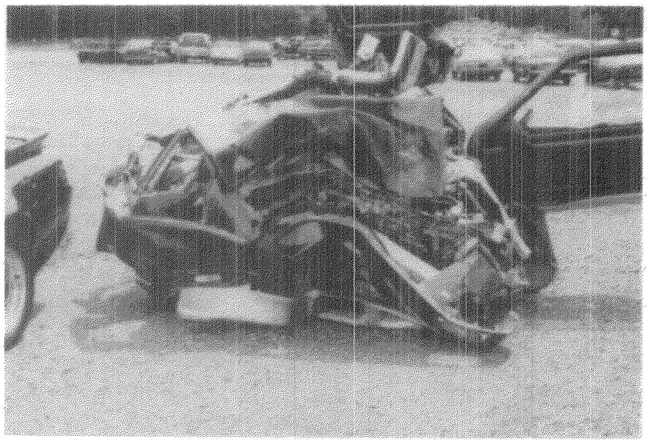


Figure 14

people ignored the light for several weeks or months before the air bag deployed in a situation where bag deployment would not have been expected.

A. In one case the driver thought that the illuminated air bag light on the instrument panel was an indication that the car was equipped with an air bag.

B. In another unusual case the air bag deployed at a relatively modest impact and the owner/driver did not want to report this event to the insurance company. Therefore the owner repacked the bag into the steering wheel container and taped the air bag in place (UM-CCA-10).

C. This 1990 Plymouth Sundance struck the rear end of a stopped 1989 Pontiac LeMans. The 65 year -old lap-shoulder belted female driver (163 cm, 72 kg) sustained an anterior neck abrasion (air bag) and a thermal burn to her hand (Figs. 15, 16). She wore gloves made of synthetic materials that were melted in the area of the hand caused by escaping gasses from the bag vent port on the back side of the bag (Fig. 17). The car bumper had been removed prior to the vehicle inspection. Minor sheet metal damage was noted (Fig. 18) (UM-2854).

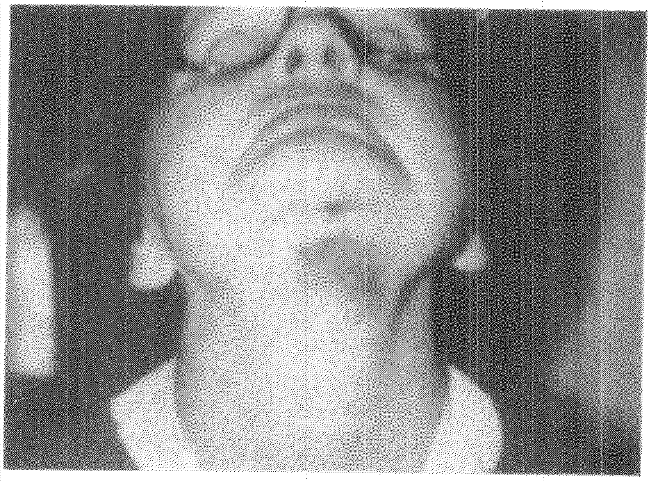


Figure 15

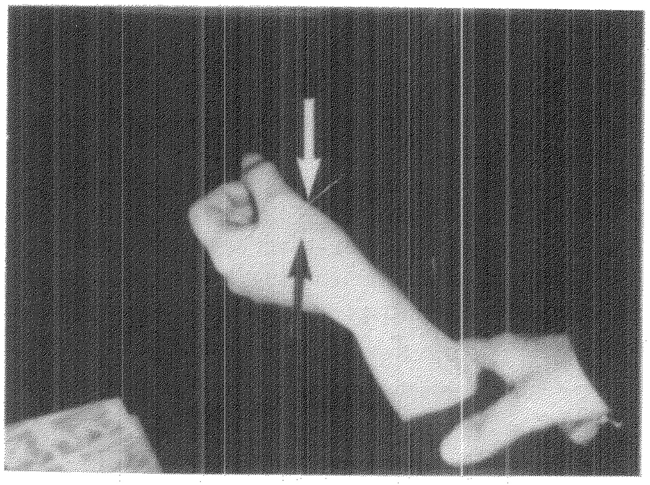


Figure 16

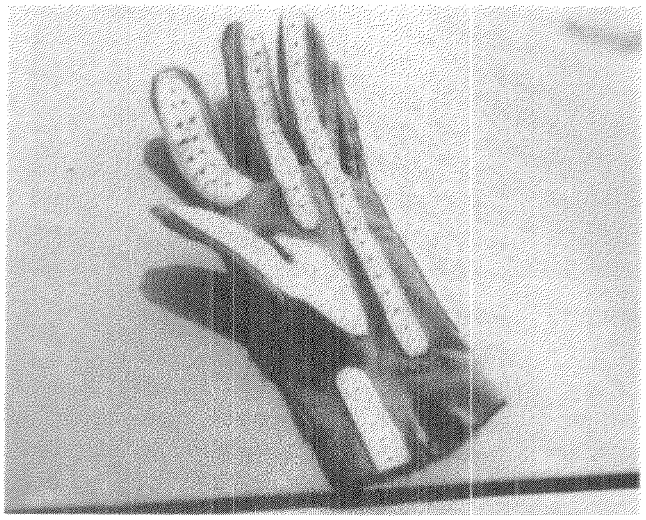


Figure 17

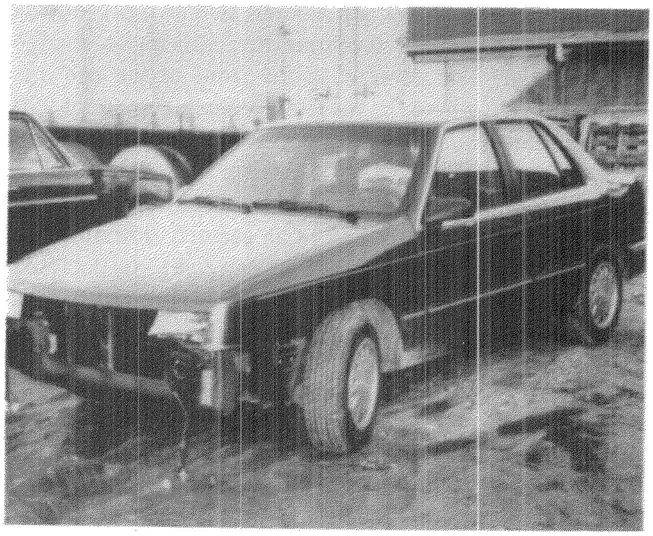


Figure 18

Discussion

From our studies of crashes involving air bag deployments it was noted that approximately *19% of the 97* occupants, in crashes investigated by the UMTRI team did not use the available lap-shoulder belt restraint system at the time of the crash.

Many of the crashes were non-spectacular. In those where the 3-point restraints were worn, injuries were at the AIS-1 level. Mainly the injuries were contusions to the knees and lower legs, contusions to the abdomen, chest or shoulders from the 3-point restraints and cervical or lumbar strain.

In those crashes where the 3-point restraints were not worn the damage profiles on many of the cars were similar to those where belts were worn. However, in these cases the unrestrained drivers also had primarily AIS-1 level injuries but in each of these cases there were more AIS-1 injuries and an occasional AIS-2 injury in a third of these drivers (Table 1).

Table 1. AIS, Air Bag Deployment and Belt Restraint Usage

	With 3-Pt. Worn		Without Belts Worn		With Lap Belt Only	
AIS	No.	%	No.	%	No.	%
0	9	12	0		0	
1	54	71	9	50	3	100
2	10	13	7	39	0	
≥3	3	4	2	11	0	

Field accident investigations and the data obtained are the only way to study the actual effectiveness or the potential for air bag injury reduction. From the on-going investigations it is obvious that the air bag is providing its role as a supplement to seat belts for reducing facial impact severity with the steering assembly. Additionally, in higher speed crashes, it offers additional protection to the torso, head and neck. The data are relatively sparse on air bag deployments in other than non-frontal crashes such as in rollovers, side impacts or rear-end crashes, or frontal crashes followed by other events such as spinout, a second car impact or rollover. Therefore the need for an on-going investigative program is obvious.

Only through the accident investigations can the "outliers" be found, i.e., the unusual injury, the life-saving benefits of the air bag in high speed crashes, or the unusual or unexpected events related to air bag deployment. In a number of cases there were facial erythema (redness) or abrasions due to the air bag deployment (Figs. 19-24). These illustrate the worst of the minor facial injury cases that we have in the study to date. There have been a few cases of eye abrasions (corneal abrasion, sclera laceration) due to interaction with the air bag.

Figure 19

Figure 20

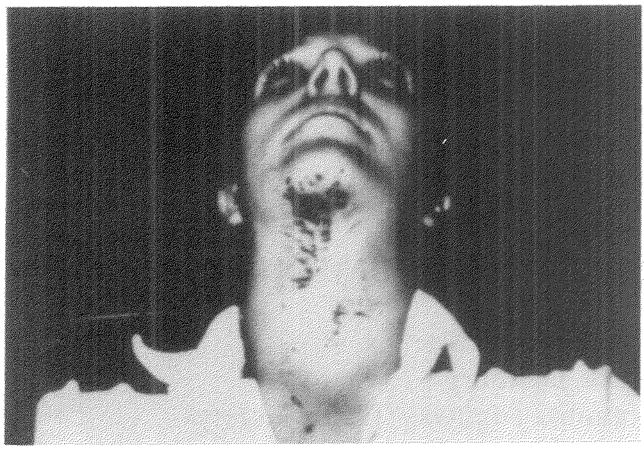


Figure 21

Most of the cars presented are manufactured by Chrysler Corporation since Chrysler had the largest fleet of air bag equipped cars during the study period. As indicated earlier, in our studies, we find that 78% of the people involved in air bag crashes were wearing their 3-point restraint systems. Needless to say, in other than frontal crashes, the air bag cannot be expected to be the primary restraint system, and reliance must be made on the available lap-shoulder belt. The outlier kinds of cases, (i.e., from facial or corneal abrasions to the other extreme of the life saving effect of the air bag in very high speed crashes) cannot be directly studied by laboratory testing.

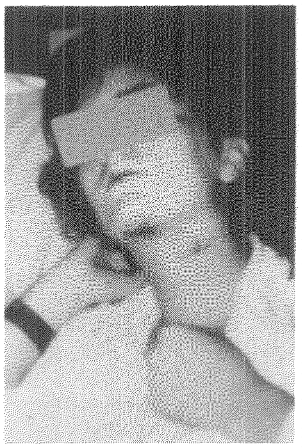


Figure 22

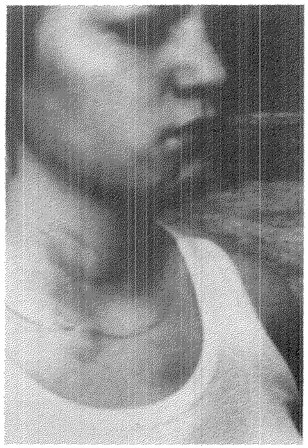


Figure 23

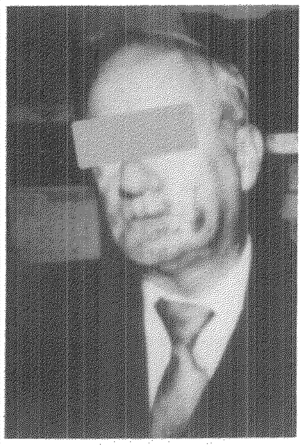


Figure 24

In a study of the seating positions of drivers in simulated laboratory car environments, Schneider found that the driver's chin can be as close as 240 mm to the steering-wheel hub under normal driving conditions (1). Additional forward movement of the driver's head may occur during a crash but prior to air bag deployment, particularly in low-speed impact near the threshold of air bag sensor firing. Cases involving facial erythema or abrasion may therefore occur when the face of the driver is less than 240 mm from the wheel hub at the time of facial interaction with the deploying air bag. Additionally bag leading edge velocity, whether at full pressure or shear action developed when undergoing inflation, bag excursion, bag depth, bag denier, etc. may all play a role in the production of this type of minor injury.

Reference

1. Schneider, L.W., "Ergonomic Investigation of the Armrest Location in G-, H- and S-Body Vehicles Using a Computer Controlled Universal Seating Back." Final Rept. UMTRI-87-29, July, 1987.

S1-W-21

The Incidence of Multiple Injuries in Motor Vehicle Crashes

Stephen Luchter
Ruth Isenberg
National Highway Traffic Safety
Administration

Abstract

Multiple injuries are the norm in motor vehicle crashes, however, data on which injuries occur with which other injuries is limited. This paper identifies the most frequent injury combinations found in police reported crashes in the early 1980's in the U.S. Specifically, the paper identifies the five injuries with the highest incidence at each AIS level in the National Accident Sampling System (NASS) for the period 1982-1986. For each of these twenty five injuries, the five associated injuries with the highest incidence are also identified. The results show that the five most frequent injuries comprise between one third and two thirds of the incidence of all of the injuries at the various AIS levels. The results also show that, with a few exceptions, the incidence of the most frequent associated injuries is in the range of 5 to 10% of the incidence of the most frequent injury. These results have important implications to the estimation of the long term consequences of motor vehicle injuries.

Introduction

Each of the more than 3.7 million people injured each year in police reported motor vehicle crashes in the U.S. sustains an average of 2.5 injuries. Some of these injuries have long term consequences, and our goal is to quantify these consequences at the national level.

One unanswered question is how these consequences are affected by the large number of multiple injuries. This question is usually sidestepped and the effects of the associated injuries are assumed to be included in the total costs or other impacts measured for the most serious injury. One reason for this approximation is that over two thousand different injuries have been identified in police reported crashes and the number of possible injury combinations is staggering.

This paper focuses on solving a tractable portion of the problem, identifying the most frequent injury combinations. Once these have been identified, it will be possible to compare the consequences of the most frequent injury as a single injury to the consequences of the most frequent injury in combination with the injuries associated with it.

Background

Multiple injuries are the norm in motor vehicle crashes, see Table 1. This includes people injured in police reported crashes (Luchter 1986, Luchter 1990), and emergency room (Peterson 1989) and trauma center patients (Siegel et. al. 1989, Siegel et. al. 1990) injured in motor vehicle crashes in the U.S. Multiple injuries in motor vehicle crashes have also been reported to be typical in Germany (Reidelbach and Zeidler, 1983, Zeidler et. al. 1989, Pletschen et. al. 1990) and Japan (Japan Research Center, 1986).

Table 1. Overview of Multiple Injury Literature

Author	Type of Data	N	% With Multiple Injuries	Average Number of Injuries per Injured Survivor	Average Number of Injuries	Mortality Rate, Overall %
Reidelbach & Zeidler, 1983	Manufacturer's Records, '80-'83	655	NA	1.9	1.9	1.4
Luchter, 1986	Police Reported Injuries (NASS) 1982-1984	34,542	NA	2.3	NA	1.3
Japan Research Center, 1986	Insurance Claims 1982	807,000	NA	1.8	NA	1.6
Siegel et. al. 1989	Trauma Center (Pelvic Injuries)	197	NA	NA	1.5	16
Peterson, 1989	Emergency Room 1987-1988	1,454	NA	2.0	NA	1
Zeidler et. al. 1989	Workman's Compensation, 1985	16,584	11	1.1	NA	6
Siegel et. al., 1990	Trauma Center (Brain Injured) 1983-1986	1,709	60	NA	1.2	18
Luchter 1990	Police Reported Injuries (NASS) 1982-1986	64,698	56	NA	2.5	1.7
Pletschen et.al. 1990	Mercedes Benz Occupants	143	NA	NA	NA	NA

The average annual incidence of occupant and pedestrian injuries in police reported crashes in the U.S. during the period 1982-1986, disaggregated by body region, are shown below (Luchter, 1990). Integumentary (skin) injuries to any body region are considered as if they were a separate body region since they comprise between a third and a half of the injuries to that region. The values are percentages of injuries, not people injured.

These data show that injuries to a particular body region are a significant part of all injuries when that body region is the most severely injured region (MSIR). For example, for people whose most severe injury is to the head, 31.6% of their injuries are head injuries, (17.7% of which are single injuries), 50.5% are integumentary injuries, and the remainder, 17.9%, are injuries to other body regions. Although this approach provides insights into the overall injury mix by body region, it does not provide information on which injuries are associated with which other injuries.

Body Region	Injuries to Region % of Total Injuries	% of Injuries to Body Region When Region is MSIR Single Injuries		
		Single Injuries	Injuries to Body Region	Integumentary Injuries
Head	5.3	17.7	31.6	50.5
Spine	13.0	37.6	56.8	36.6
Lower Extremity	3.0	14.4	38.1	48.1
Upper Extremity	4.0	21.2	39.5	49.5
Abdomen	1.2	4.3	32.0	43.3
Thorax	2.3	8.8	36.0	51.1
Face	4.0	11.7	41.8	56.6
Integumentary	67.3	14.9	99.5	99.5

A diagram illustrating the overall multiple injury relationship is shown in Figure 1. The central circle represents an injury of interest. The other circles represent the injuries associated with the injury of interest. The areas of the circles represent the injury incidence, and the overlapping areas represent the incidence of the associated injury when it occurs simultaneously with the injury of interest.

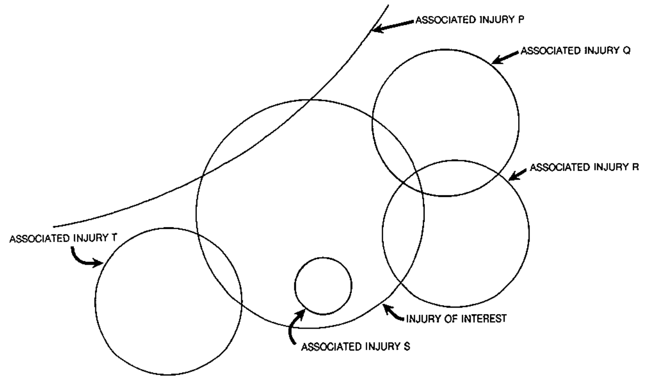


Figure 1. Schematic Diagram of Multiple Injuries

A number of different situations are possible. The total incidence of an associated injury could be larger than the injury of interest incidence (Associated Injury P) or smaller (Associated Injuries Q, R, S, and T). An injury could be associated with the injury of interest and with other associated injuries (Associated Injuries Q and R). Some portion of the incidence of any of these injuries could be a single injury (the non-intersect areas) or an injury could not occur as a single injury (Associated Injury S).

For each injury of interest, in this paper the most frequent injuries at each AIS level, (MFI), the paper discusses the following:

- The MFI incidence (the area of the central circle in Figure 1).

- The injuries associated with the MFI and their incidence (the number of intersecting circles in Figure 1, their "names", and their areas).
- The multiple injury incidence (the intersect areas in Figure 1).
- The single injury incidence (the non-intersect areas in Figure 1).

Data

Injury records on motor vehicle occupants involved in police reported motor vehicle crashes contained in the data files of the National Accident Sampling System (NASS) for the years 1982-1986 form the basis for this study. During this period, NASS collected data on the injuries sustained by 64,698 motor vehicle occupants.

The NASS file for the 1982-1986 period contains about 400 data elements describing vehicle and scene data for each crash, as well as detailed injury information for up to six injuries per occupant. The injury data is obtained from autopsy reports, hospital discharge summaries, emergency room reports and interview data. To obtain the data, full crash investigations are conducted by trained researchers, based on a statistical sample of police reported motor vehicle crashes of all types and severities.

The injury data in NASS are reported using the Occupant Injury Code (OIC), which is an extension of the injury description found in the AIS (Abbreviated Injury Scale) dictionary (Association for the Advancement of Automotive Medicine, 1980). The AIS description includes the injured body region, the lesion, the organ affected, and the AIS severity level. The OIC adds the aspect, that is, right, left, upper, lower, etc. This additional information is often important when developing countermeasures.

The time period 1982-1986 represents a homogeneous data base, since the same basic sampling procedure and the same version of the AIS dictionary were used for injury descriptions during the entire period. A major change was made in NASS in 1987, with a new sampling scheme and the use of the 1985 version of the AIS. Data for 1987 are not complete. A cursory check of the 1988 data showed similar results to those reported here, but since the data bases are not fully compatible, the more recent data were not analyzed.

Results and Discussion

The five years of NASS data (1982-1986), when extrapolated to the national level, represent about 13.5 million occupants with over 37 million injuries. Eliminating those injuries where the body region was not identified (130,000 cases), and those where the severity level was not identified (3.1 million cases), there were an estimated 34 million injuries with a complete injury description (NASS Occupant Injury Code (OIC)) during this period. This represents an average of 2.7 million occupants receiving 6.7 million injuries per year, or 2.5 known injuries per occupant. These occupants sustained 2,130 unique injuries. The average annual injury incidence for motor vehicle occupants over the five year period by body region and severity level is summarized in Table 2. Body regions are as defined in NASS.

Table 2. Annual Incidence of Motor Vehicle Occupant Injuries by Body Region

	SEVERITY LEVEL							
BODY REGION	AIS 1	AIS 2	AIS 3	AIS 4	AIS 5	AIS 6	TOTAL	PERCENT
ARM	131,000	7,300	3,500	0	0	0	141,800	2.1
BACK	304,600	29,200	4,200	100	400	0	338,500	5.0
CHEST	276,300	28,600	23,500	8,600	3,000	12,400	352,400	5.2
ELBOW	189,500	2,500	1,000	0	0	0	193,000	2.8
FACE	1,414,300	42,100	5,200	900	0	0	1,462,500	21.6
HEAD	591,500	139,600	23,600	9,800	6,200	3,100	773,800	11.4
KNEE	793,500	25,800	5,600	*	0	0	824,900	12.2
LOWER LEG	266,500	20,100	16,100	0	0	0	302,700	4.5
ABDOMEN	69,300	1,300	21,400	9,500	4,600	*	106,000	1.6
NECK	625,500	19,100	6,400	900	500	700	653,100	9.6
WHOLE BODY	91,900	600	200	100	300	500	93,600	1.4
PELVIS-HIP	123,800	19,000	10,100	300	0	0	153,200	2.3
ANKLE-FOOT	150,800	32,200	7,300	0	0	0	190,300	2.8
FOREARM	154,600	16,600	7,900	0	*	0	179,100	2.6
SHOULDER	266,700	38,000	6,800	0	0	0	311,500	4.6
THIGH	192,100	3,800	18,600	200	0	0	214,700	3.2
WRIST-HAND	336,800	27,500	3,800	0	0	0	368,100	5.4
UPPER EXTREMITY	57,000	1,900	300	0	0	*	59,200	0.9
LOWER EXTREMITY	58,100	2,100	100	0	0	0	60,300	0.9
TOTAL	6,093,800	457,300	165,600	30,400	15,000	16,700	6,778,800	
PERCENT	89.9	6.8	2.4	0.4	0.2	0.2		

Note: Values are annual average incidence between 1982 and 1986 as shown in the NASS file, rounded to the nearest 100. Annual incidence less than 50 cases per year are shown with an asterisk. The body regions are as defined in NASS.

* Incidence was less than 50 cases per year.

The five most frequent injuries (MFI) at each AIS level from 1 through 5 and their average annual incidence are shown in Table 3. (All values have been rounded to two significant figures). For each of these 25 injuries, the Table also shows the incidence expressed as

Table 3. Most Frequently Occurring Injuries by AIS Level

Injury	Annual Incidence	Percent of Total	Percent of AIS Level	Single Injury Incidence/%
AIS 1	6,100,800	90		
Whiplash	580,000	8.5	9.5	260,000/45
Forehead Contusion	310,000	4.6	5.1	100,000/32
Left Knee Contusion	260,000	3.8	4.3	44,000/17
Right Knee Contusion	250,000	3.7	4.1	32,000/13
Forehead Laceration	200,000	2.9	3.3	36,000/18
Subtotal	1,600,000	23.5	26.3	
AIS 2	460,000	6.8		
Concussion	120,000	1.8	26.1	7,400/06
Left Shoulder Fracture	16,000	0.2	3.5	800/05
Right Shoulder Fracture	15,000	0.2	3.3	1,400/09
Right Ankle Fracture	15,000	0.2	3.3	1,100/09
Left Rib Fracture	14,000	0.2	3.0	3,200/23
Subtotal	180,000	2.6	39.2	
AIS 3	166,000	2.4		
Concussion	10,000	0.15	6.0	200/02
Left Femur Fracture	9,000	0.13	5.4	400/04
Right Femur Fracture	9,000	0.13	5.4	200/02
Left Lower Leg Fracture	8,000	0.12	4.8	100/01
Right Lower Leg Fracture	7,000	0.10	4.2	100/01
Subtotal	43,000	0.63	25.8	
AIS 4	30,000	0.44		
Liver Laceration	3,600	0.05	11.8	*/01
Concussion	3,400	0.05	11.0	100/03
Spleen Rupture	3,100	0.05	10.2	200/06
Left Rib Fracture	2,300	0.03	7.5	*/00
Right Rib Fracture	1,500	0.02	5.0	0/00
Subtotal	13,900	0.20	45.5	
AIS 5	15,000	0.22		
Concussion	4,000	0.06	26.8	300/08
Liver Laceration	1,900	0.03	13.0	0/00
Chest Bld Vessel Laceration	1,500	0.02	10.2	*/02
Heart Laceration	1,300	0.02	8.8	0/00
Chest Blood Vessel Rupture	700	0.01	4.7	*/02
Subtotal	9,400	0.14	63.5	
Total		27.1		

* Denotes less than 50 cases

a percentage of the total injury incidence, and as a percentage of the incidence at the respective AIS level. In addition, the table shows the single injury incidence of each of the 25 injuries and that incidence expressed as a percentage of the total incidence for that injury. For example, there were 9,100 AIS 3 right femur fractures annually during this period. This represents 0.13% of all of the 6,800,800 total injuries, and 5.49% of the 160,000 AIS 3 injuries. Of these AIS 3 right femur fractures, 200 occurred as a single injury, or 2.2% of all AIS 3 right femur fractures were single injuries.

For each injury in Table 3, the five most frequently occurring associated injuries are shown in Tables 4 through 8. In these tables, information relating to the MFI is shown in bold type. This includes the identity of the MFI, its incidence, the number of different injury types (other OIC's) associated with the MFI, and the number of associated injuries per 100 MFI. Here too, all values have been rounded to two significant figures.

The remaining information in Tables 4 through 8 concerns the five injuries associated with the MFI having the highest incidence. The tables show two values for the incidence for each of the associated injuries: the incidence when that particular injury is associated with the MFI, and the total incidence of the injury in the entire data base. In addition, for each of these five associated injuries, the Tables show:

Table 4. Five Most Frequent Associated Injuries for AIS 1 MFI

		Associated Injuries			
MFI*/(Number of Other OIC's) Associated Injury		Per 100 MFI Injuries	% of Total Associated With MFI	Total Incidence	Assoc. With MFI, %
Whiplash/(674)	**580,000**	**129**			
AIS 1 Lower Back Strain	65,000	11	9	150,000	43
AIS 1 Left Knee Contusion	37,000	6	5	260,000	14
AIS 1 Forehead Contusion	37,000	6	5	310,000	12
AIS 1 Right Knee Contusion	35,000	6	5	250,000	14
AIS 1 Upper Back Strain	31,000	5	4	51,000	61
Subtotal	205,000	34	28		
Forehead Contusion/(583)	**310,000**	**168**			
AIS 1 Whiplash	37,000	12	7	580,000	6
AIS 1 Right Knee Contusion	36,000	12	7	250,000	14
AIS 1 Left Knee Contusion	36,000	11	7	260,000	14
AIS 1 Forehead Abrasion	30,000	10	6	120,000	25
AIS 1 Forehead Laceration	20,000	7	4	200,000	10
Subtotal	159,000	52	31		
Left Knee Contusion/(576)	**260,000**	**228**			
AIS 1 Right Knee Contusion	110,000	42	18	250,000	44
AIS 1 Whiplash	37,000	14	6	580,000	6
AIS 1 Forehead Contusion	36,000	14	5	310,000	12
AIS 1 Left Knee Abrasion	17,000	6	3	88,000	19
AIS 1 Forehead Laceration	17,000	6	3	200,000	8
Subtotal	217,000	82	35		
Right Knee Contusion/(580)	**250,000**	**243**			
AIS 1 Left Knee Contusion	110,000	44	18	260,000	42
AIS 1 Forehead Contusion	36,000	14	6	310,000	12
AIS 1 Whiplash	35,000	14	6	580,000	6
AIS 1 Right Knee Abrasion	17,000	7	3	93,000	18
AIS 1 Forehead Laceration	16,000	6	3	200,000	8
Subtotal	214,000	85	36		
Forehead Laceration/(754)	**200,000**	**224**			
AIS 1 Forehead Contusion	20,000	10	4	310,000	6
AIS 1 Forehead Abrasion	19,000	10	4	120,000	16
AIS 1 Left Knee Contusion	16,000	8	4	260,000	6
AIS 2 Concussion	16,000	8	4	120,000	13
AIS 1 Right Knee Contusion	16,000	8	4	250,000	6
Subtotal	87,000	44	20		

*From Table 3

Table 5. Five Most Frequent Associated Injuries for AIS 2 MFI

		Associated Injuries			
MFI*/(Number of Other OIC's) Associated Injury		Per 100 MFI Injuries	% of Total Associated With MFI	Total Incidence	Assoc. With MFI, %
Concussion/(766)	**122,000**	**325**			
AIS 1 Forehead Laceration	18,000	15	4	200,000	9
AIS 1 Whiplash	17,000	14	4	580,000	3
AIS 1 Forehead Contusion	15,000	12	4	310,000	5
AIS 1 Forehead Abrasion	10,000	8	2	120,000	8
AIS 1 Right Knee Contusion	9,000	7	2	250,000	4
Subtotal	69,000	56	16		
L Shoulder Fracture/(395)	**16,000**	**326**			
AIS 1 L Shoulder Contusion	1,500	10	3	89,000	2
AIS 2 Concussion	1,500	9	3	120,000	1
AIS 1 Left Rib Fracture	1,300	8	3	22,000	6
AIS 1 L Shoulder Abrasion	1,200	7	2	24,000	5
AIS 2 Left Rib Fracture	1,100	7	2	14,000	8
Subtotal	6,600	41	13		
R Shoulder Fracture/(378)	**15,000**	**316**			
AIS 2 Concussion	1,800	13	4	120,000	2
AIS 1 Right Knee Abrasion	1,200	8	3	93,000	1
AIS 1 Right Rib Fracture	1,100	8	2	20,000	6
AIS 1 R Shoulder Contusion	1,000	7	2	61,000	2
AIS 1 R Shoulder Abrasion	900	6	2	22,000	4
Subtotal	6,000	42	13		
Right Ankle Fracture/(341)	**14,000**	**276**			
AIS 1 Forehead Laceration	1,900	13	5	200,000	1
AIS 2 Concussion	1,200	8	3	120,000	1
AIS 1 Lowr Face Laceration	1,000	7	2	140,000	1
AIS 1 Right Knee Abrasion	1,000	7	2	93,000	1
AIS 1 Forehead Abrasion	800	6	2	120,000	1
Subtotal	5,900	41	14		
Left Rib Fracture/(343)	**14,000**	**277**			
AIS 1 Whiplash	1,900	14	5	580,000	0
AIS 1 Lower Face Contusion	1,700	12	4	54,000	3
AIS 2 L Shoulder Fracture	1,300	10	4	16,000	8
AIS 3 Left Lung Contusion	1,000	7	3	5,300	19
AIS 2 Right Rib Fracture	1,000	7	2	7,300	14
Subtotal	6,900	50	18		

*From Table 3

Table 6. Five Most Frequent Associated Injuries for AIS 3 MFI

		Associated Injuries			
MFI*/(Number of Other OIC's) Associated Injury		Per 100 MFI Injuries	% of Total Associated With MFI	Total Incidence	Assoc. With MFI, %
Concussion/(383)	**10,000**	**396**			
AIS 1 Forehead Laceration	1,700	17	4	200,000	1
AIS 1 Forehead Contusion	1,000	10	3	310,000	0
AIS 1 Forehead Abrasion	1,000	10	2	120,000	1
AIS 1 Lowr Face Laceration	900	9	2	140,000	1
AIS 1 Whiplash	900	9	2	580,000	0
Subtotal	5,500	55	13		
Left Femur Fracture/(435)	**9,300**	**374**			
AIS 3 R Femur Fracture	1,000	11	3	9,000	11
AIS 3 L Lower Leg Fracture	1,000	11	3	8,000	12
AIS 1 Forehead Laceration	1,000	11	3	200,000	0
AIS 2 Concussion	700	8	2	120,000	1
AIS 2 L Lower Leg Fracture	600	7	2	8,700	7
Subtotal	4,300	48	13		
Right Femur Fracture/(402)	**9,100**	**360**			
AIS 3 Left Femur Fracture	1,000	12	3	9,300	11
AIS 1 Forehead Fracture	900	10	3	200,000	0
AIS 2 R Lower Leg Fracture	900	9	3	9,000	10
AIS 2 Concussion	800	9	2	120,000	1
AIS 3 R Lower Leg Fracture	800	9	2	7,200	11
Subtotal	4,400	49	13		
L Lower Leg Fracture/(304)	**8,500**	**223**			
AIS 2 Left Ankle Fracture	700	9	4	14,000	5
AIS 3 R Lower Leg Fracture	700	9	4	7,200	10
AIS 2 L Lower Leg Fracture	700	8	4	8,700	8
AIS 3 Left Femur Fracture	700	8	4	9,300	8
AIS 2 Concussion	400	5	2	120,000	0
Subtotal	3,300	39	18		
R Lower Leg Fracture/(286)	**7,200**	**253**			
AIS 3 L Lower Leg Fracture	700	9	4	8,500	8
AIS 3 Right Femur Fracture	600	8	3	9,100	6
AIS 2 Right Ankle Fracture	500	7	3	14,000	3
AIS 2 Concussion	500	6	2	120,000	0
AIS 1 Forehead Laceration	400	5	2	200,000	0
	2,700	35	14		

*From Table 3

Table 7. Five Most Frequent Associated Injuries for AIS 4 MFI

MFI*/(Number of Other OIC's) Associated Injury		Associated Injuries			
		Per 100 MFI Injuries	% of Total Associated With MFI	Total Incidence	Assoc. With MFI, %
Liver Laceration/(281)	**3,600**	**430**			
AIS 3 Spleen Laceration	1,000	27	6	2,400	40
AIS 5 Bld Vessel Lacration	500	13	3	1,500	30
AIS 3 Right Lung Contusion	400	10	2	4,800	7
AIS 3 Left Lung Contusion	300	9	2	5,300	6
AIS 2 Right Rib Fracture	300	9	2	7,300	4
Subtotal	2,500	68	15		
Concussion/(234)	**3,400**	**346**			
AIS 1 Forehead Laceration	400	13	4	200,000	0
AIS 1 Lowr Face Laceration	200	7	2	140,000	0
AIS 1 R Face Laceration	200	7	2	28,000	1
AIS 3 R Lower Leg Fracture	200	7	2	7,200	3
AIS 1 Forehead Contusion	200	7	2	310,000	0
Subtotal	1,200	41	12		
Spleen Rupture/(255)	**3,100**	**382**			
AIS 1 Whole Body Contusion	400	12	3	57,000	1
AIS 2 Concussion	300	8	2	120,000	0
AIS 3 Left Lung Contusion	200	8	2	5,300	4
AIS 1 Whle Body Laceration	200	7	2	5,500	4
AIS 5 Liver Rupture	200	7	2	500	40
Subtotal	1,300	42	11		
Left Rib Fracture/(224)	**2,300**	**479**			
AIS 3 Left Lung Contusion	600	24	5	5,300	10
AIS 4 Right Rib Fracture	400	16	3	1,500	24
AIS 3 Spleen Laceration	300	13	3	2,400	12
AIS 4 Liver Laceration	300	13	3	3,600	8
AIS 2 L Shoulder Fracture	300	12	2	16,000	2
Subtotal	1,900	78	16		
Right Rib Fracture/(185)	**1,500**	**468**			
AIS 4 Left Rib Fracture	400	24	5	1,500	24
AIS 4 Liver Laceration	300	19	4	3,600	8
AIS 5 Liver Laceration	300	18	4	1,900	15
AIS 5 Bld Vessel Lacration	200	16	4	1,500	16
AIS 6 Bld Vessel Severence	200	16	3	1,100	22
	1,400	93	20		

*From Table 3

Table 8. Five Most Frequent Associated Injuries for AIS 5 MFI

MFI*/(Number of Other OIC's) Associated Injury		Associated Injuries			
		Per 100 MFI Injuries	% of Total Associated With MFI	Total Incidence	Assoc. With MFI, %
Concussion/(302)	**4,000**	**344**			
AIS 1 Forehead Laceration	500	11	3	200,000	0
AIS 1 Lowr Face Laceration	200	6	2	140,000	0
AIS 2 Left Ankle Fracture	200	6	2	14,000	1
AIS 1 Right Rib Fracture	200	5	2	20,000	1
AIS 1 R Head Laceration	200	5	2	28,000	1
Subtotal	1,300	33	11		
Liver Laceration/(193)	**1,900**	**469**			
AIS 5 Bld Vessel Lacration	400	20	4	1,500	27
AIS 5 Heart Laceration	300	16	4	1,300	23
AIS 3 Spleen Laceration	300	16	3	2,400	12
AIS 4 Right Rib Fracture	300	15	3	1,500	20
AIS 4 Left Rib Fracture	200	13	3	2,300	9
Subtotal	1,500	80	17		
Chest Bld Vessel Laceration/(175)	**1,500**	**410**			
AIS 4 Liver Laceration	400	28	7	3,600	11
AIS 5 Liver Laceration	300	20	5	1,900	16
AIS 5 Heart Laceration	300	17	4	1,300	23
AIS 4 Right Rib Fracture	200	14	3	1,500	13
AIS 3 Spleen Laceration	200	14	3	2,400	8
Subtotal	1,400	93	22		
Heart Laceration/(106)	**1,300**	**330**			
AIS 6 Bld Vessel Severence	300	27	8	1,100	27
AIS 4 Liver Laceration	300	25	8	3,600	8
AIS 5 Liver Laceration	300	24	7	1,900	16
AIS 5 Bld Vessel Lacration	300	21	6	1,500	20
AIS 4 Heart Laceration	200	15	5	700	28
Subtotal	1,400	112	34		
Chest Bld Vessl Ruptre/(82)	**700**	**382**			
AIS 3 Left Femur Fracture	200	23	6	9,300	2
AIS 6 Chest Crush	100	18	5	1,800	6
AIS 2 Right Knee Fracture	100	18	5	4,600	2
AIS 3 R Lung Laceration	100	18	5	500	20
AIS 3 Left Lung Laceration	100	18	5	700	14
	600	95	26		

*From Table 3

- the frequency of the associated injury expressed as the number of occurrences per 100 cases of the MFI,
- the percentage of the associated injury incidence relative to the total incidence of all injuries associated with the MFI,
- the percentage of the total incidence of a particular injury when that injury is associated with the MFI.

For example, consider again the AIS 3 right femur fracture MFI (see Table 6). Associated with this injury were 402 other injuries, with a total incidence of 33,000 (9,100 x 3.6). The fifth most frequent of these 402 injuries was an AIS 3 right lower leg fracture, which occurred 800 times in combination with the AIS 3 right femur fracture. These 800 cases represent 8.8 AIS 3 right lower leg fractures for each 100 cases of the AIS 3 right femur fracture. These 800 represent 2.4% of the 33,000 injuries associated with the MFI. As part of the 6,800,000 total injuries, there were 7,200 AIS 3 right lower leg fractures. The 800 of these AIS 3 right lower leg fractures associated with the AIS 3 Right Femur Fracture represent 11.1% of all of the AIS 3 right lower leg fractures.

Other results show how the multiple injury characteristics vary with AIS level (Table 9), the associated injuries that occurred frequently per 100 MFI (Table 10), and the injuries that had a large part of their total incidence associated with a particular MFI (Table 11).

Table 9. Overview of Multiple Injury Characteristics of Most Frequent Injuries

AIS Level	Associated Injuries per 100 MFI		Number of OIC'S per MFI		OIC's in 25 Assoc. Injuries	AIS Distribution of OIC'S in 25 Associated Injuries					
	Weighted Av.	Range	Weighted Av	Range		AIS 1	AIS 2	AIS 3	AIS 4	AIS 5	AIS 6
1	182	129 - 243	627	576 - 754	11 (5)	10	1	0	0	0	0
2	317	276 - 326	635	341 - 766	19 (2)	13	5	1	0	0	0
3	327	223 - 396	368	304 - 435	15 (4)	5	6	4	0	0	0
4	411	346 - 468	244	185 - 281	22 (1)	6	3	6	3	3	1
5	381	344 - 469	216	82 - 302	21 (2)	4	2	4	4	5	2

* Values in parentheses are the number of MFI injuries that also are associated injuries.

Table 10. Associated Injuries with High Incidence per 100 MFI

Associated Injury	MFI	Incidence per 100 MFI
AIS 1 Right Knee Contusion	AIS 1 Left Knee Contusion	41
AIS 1 Left Knee Contusion	AIS 1 Right Knee Contusion	43
AIS 3 Spleen Laceration	AIS 4 Liver Laceration	27
AIS 3 Left Lung Contusion	AIS 4 Left Rib Fracture	24
AIS 4 Left Rib Fracture	AIS 4 Right Rib Fracture	24
AIS 4 Liver Laceration	AIS 5 Chest Bld Vessel Laceration	28
AIS 6 Blood Vessel Severence	AIS 5 Heart Laceration	27
AIS 4 Liver Laceration	AIS 5 Heart Laceration.	25
AIS 5 Liver Laceration	AIS 5 Heart Laceration.	24
AIS 5 Blood Vessel Laceration	AIS 5 Heart Laceration	21

Table 11. Associated Injuries with High Percentage of the Total Incidence

Associated Injury	MFI	% OF TOTAL
AIS 1 Lower Back Strain	AIS 1 Whiplash	44
AIS 1 Upper Back Strain	AIS 1 Whiplash	60
AIS 1 Right Knee Contusion	AIS 1 Left Knee Contusion	43
AIS 1 Left Knee Contusion	AIS 1 Right Knee Contusion	40
AIS 3 Spleen Laceration	AIS 4 Liver Laceration	40
AIS 5 Blood Vessel Laceration	AIS 4 Liver Laceration	30
AIS 5 Liver Rupture	AIS 4 Spleen Rupture	44
AIS 4 Right Rib Fracture	AIS 4 Left Rib Fracture	24
AIS 4 Left Rib Fracture	AIS 4 Right Rib Fracture	24
AIS 6 Blood Vessel Severence	AIS 4 Right Rib Fracture	22
AIS 5 Blood Vessel Laceration	AIS 5 Liver Laceration	25
AIS 5 Heart Laceration	AIS 5 Liver Laceration	24
AIS 5 Heart Laceration	AIS 5 Chest Bld Vssel Laceration	20
AIS 6 Blood Vesssel Severence	AIS 5 Heart Laceration	33
AIS 4 Heart Laceration	AIS 5 Heart Laceration	30
AIS 3 Right Lung Laceration	AIS 5 Chest Blood Vessel Rupture	26

Applying the method to only the five most frequent injuries at each AIS level was necessary to simplify the analysis. It does, however, provide considerable insight into the overall motor vehicle injury problem. At the AIS 1 and 3 levels the incidence of the five most frequent injuries is more than a quarter of the total incidence at those levels. At the AIS 2 and 4 levels, this rises to almost half, and at the AIS 5 level to nearly two thirds of the total incidence at that level.

With a few exceptions, multiple injuries are the norm. For 19 of the 25 MFI, the single injury incidence is 9% or less of the overall MFI incidence. For 14 of these 19, the single injury incidence is 5% or less of the overall MFI. At the AIS 1 level, single injuries range from 13 to 44% of the MFI total incidence, and for one frequent AIS 2 injury there is a 23% single injury incidence.

There are an average of 1.3 to 4.7 associated injuries per MFI. The number of associated injuries per MFI increases as the AIS level increase from 1 to 4, with a slight decrease between the AIS 4 and AIS 5 levels.

There are from 82 to 754 different injuries associated with the twenty five primary injuries. As the AIS level increases, there are fewer different injuries associated with each primary injury (fewer OIC's). The incidence of the most frequent associated injuries ranges from 1.5% of the total associated injury incidence for the particular MFI (AIS 1 Right Face Laceration associated with AIS 5 concussion), to 17.8% (for the AIS 1 knee contusion associated with a contusion of the other knee). The combined incidence of the five most frequent associated injuries ranges from 9.6% (associated with AIS 5 Concussion), to 35.6% (associated with AIS 1 Left Knee Contusion) of the total associated injury incidence.

The results also show that the predominant body regions vary with AIS level.

- The most frequent AIS 1 injuries are whiplash, head contusions and lacerations, and knee contusions. ("whiplash" is used as a synonym for cervical spine muscle strain). The injuries associated with whiplash are other back strains and knee contusions. The other associated injuries are all AIS 1 contusions, lacerations, and abrasions to the face and knees, except for one instance of AIS 2 concussion. ("Concussion" is used as a synonym for diffuse brain injury).
- Injuries to the head, shoulders, right ankle and left rib are the most frequent AIS 2 injuries. The most frequent associated injuries are primarily at the AIS 1 level, with a few AIS 2's and one AIS 3. The injuries associated with the shoulder are largely to the same side of the body, i.e. left shoulder fracture has associated with it left rib fracture, and other left shoulder injuries.
- At the AIS 3 level, the most frequent injuries are to the head and lower extremities. The most frequent associated injuries are to these same body regions at the AIS 1, 2, and 3 levels.
- The most frequent AIS 4 injuries are primarily to the thorax/abdomen and head. The associated injuries are also primarily to the same body region, except for a shoulder fracture associated with left rib fracture. The injuries associated with the AIS 4 concussion are to the face and a lower leg fracture. The severity of the associated injuries at the AIS 4 level is the most diverse of any AIS level, with associated injuries from AIS 1 to AIS 6.
- Head and thorax/abdomen injuries also are the most frequent AIS 5 injuries. The severity level of the most frequent associated injuries is almost as diverse as at the AIS 4 level, with injuries from the AIS 1 to AIS 6 levels. Most of the injuries associated with thorax/abdomen injuries are to the same region, except for a right knee fracture as one of the associated injuries. The injuries associated with the head injury are to the face, rib and ankle.

A few other general trends are seen in the results:

- At each AIS level, an injury to the head is either the most frequent injury or the second most frequent injury. Lower limb injuries are included in the most frequent injuries at the AIS 1, 2, and 3 levels, and injuries to the thorax/abdomen are included in the most frequent AIS 4 and 5 most frequent injuries.
- For those cases where a relatively large part of the incidence of the associated injury was found with a particular most frequent injury, the associated injury was to the same general body region as the most frequent injury.

Some limitations on the use of the results are as follows:

- The national estimates produced from NASS data contain sampling errors because they are based on a probability sample. In general, as the magnitude of the NASS statistics decrease, the coefficient of variation increases, primarily because the number of cases which contributed to it decrease. (The coefficient of variation is defined as the standard error of the estimate divided by the estimate itself. This statistic provides an immediate comparison between the reliability of various statistics that have differing sizes of standard error). Consequently, particular care should be used when interpreting figures based on a relatively small number of cases.
- The results described here do not necessarily represent the present safety situation. After 1986 both manual safety belt usage and the portion of the fleet with automatic occupant protection increased. As a result, the injury patterns may have changed.
- Changes between AIS 80, used here, and AIS 85, used in NASS for 1987 and beyond, are largely in the severity level of head injuries. Thus the results presented here may not be comparable with those obtained from using the later version of the AIS dictionary.

- NASS data are difficult to compare with other data bases, as NASS covers injuries in police reported crashes, while many other injury data bases cover hospital discharge data. A possible mitigation is that it is rare that the more severe injuries are not hospitalized, so that the AIS 3+ injuries may be similar. Also, NASS uses a unique injury descriptor, the Occupant Injury Code, which is not comparable to hospital discharge data, which typically use an injury code from the International Classification of Diseases (ICD).

Conclusions

An analysis of the multiple injury patterns for the most frequent injuries (MFI) experienced by occupants of motor vehicles injured in police reported crashes in the U.S., based on 1982-1986 NASS data, confirmed that multiple injuries are the norm. Only three of the twenty five MFI at AIS levels 1 through 5 occurred as single injuries greater than 20% of the time. A large number of different injuries were associated with each most frequent injury, typically several hundred. As the AIS level of the MFI increased, the associated injury incidence increased, however, these comprised fewer different injuries.

For each of the 25 MFI, the five associated injuries with the largest incidence were determined. None of the associated injuries had anywhere near the same incidence as the most frequent injury. Of the associated injuries considered, 105 out of 125 had an incidence of five percent or less of the incidence of the most frequent injury they were associated with. Most (but not all) of the associated injuries were to the same general body region as the most frequent injury. For example, femur fractures were not a frequent injury associated with head injury.

The analysis was limited to the most frequent injuries. In most cases, the AIS level for the five most frequent associated injuries is the same or lower than the AIS level of the MFI. The exceptions are important however, particularly at the AIS 4 and 5 levels where some AIS 6 associated injuries occur.

Although further work is needed before a definitive conclusion can be drawn, the results suggest that it may not be necessary to consider the effect of multiple injuries when determining long term consequences at the national level for the most frequent AIS 1-3 level injuries. This tentative conclusion is based upon the very low relative incidence of the individual associated injuries and the clustering of the most frequent associated injuries to the same general body region as the MFI. The MAIS approach may provide acceptable estimates at the lower AIS levels. At the AIS 4 and 5 levels however, further work is indicated.

At least three areas for further investigation suggest themselves:

- Review the long term consequences of the multiple injury patterns identified here to determine to what degree earlier analyses of these consequences already include the multiple injury effect.
- Compare the results derived from NASS with results derived from other injury data bases. Since most other available injury data are derived from hospital discharge records, it will be necessary to compare the subset of NASS data limited to hospitalized patients.
- Extend the method described in the paper to enhance the overall knowledge of multiple injuries. The results reported here show that there are so many "x", "y", and "z" injuries associated with injury "A". This is an advance over what was previously known, however, it does not show how many Axy, Axz, Ayz, Axyz, etc. injuries there are.

Acknowledgements

The valuable suggestions made by Anne Damiano and Carl Nash are gratefully acknowledged.

Disclaimer

The views expressed in this paper are those of the authors. They do not necessarily reflect the position of the National Highway Traffic Safety Administration.

References

Association for the Advancement of Automotive Medicine (AAAM), Abbreviated Injury Scale, 1980.

Japan Research Center for Transport Policy, Social and Economic Losses from Road Accidents, June, 1986.

Luchter, Stephen, Traffic Related Disabilities and Impairments and Their Economic Consequences, SAE 860505, 1986.

Luchter, Stephen, Multiple Injuries in Motor Vehicle Crashes, 34th Annual Proceedings, AAAM, October, 1990.

Peterson, Timothy, Iowa Safety Restraint Assessment, Iowa Methodist Medical Center, Des Moines, Iowa, December, 1988.

Pletschen, B., et. al., Application of the Injury Cost Scale (ICS) to Mercedes Benz Accident Data, SAE 902332, Proceedings of the 34th Staff Conference, November 1990.

Reidelbach, W. & Zeidler F., Comparison of Injury Severity Assigned to Lower Extremity Skeletal Damages versus Upper Body Lesions, 27th Annual Proceedings, AAAM, San Antonio, Texas, 1983.

Siegel, John H. et. al., Pattern of Organ Injuries in Pelvic Fracture: Impact Force Implications for Survival and Death in Motor Vehicle Injuries, 33rd

Annual Proceedings, AAAM, Baltimore, Maryland, October 2-4 1989.

Siegel, John H. et. al., The Effect of Associated Injuries and Blood Volume Replacement on Death, Rehabilitation Needs and Disability in Blunt Traumatic Brain Injury, Presented at the Eastern Association for the Surgery of Trauma, January, 1990.

Zeidler, F. et. al., Development of a New Injury Cost Scale, 33rd Annual Proceedings, AAAM, October, 1989. Also personal communication with Dr. Zeidler, January, 1990.

S1-W-22

Crash Data Plans for the United States

William H. Walsh
National Highway Traffic Safety Administration

Abstract

With an estimated 44,500 fatalities and more than six million police reported crashes in 1990 and economic losses from these crashes in excess of $100 billion per year, motor vehicle and highway safety continue as a top priority in transportation safety. The National Highway Traffic Safety Administration (NHTSA) has been charged with reducing these consequences of vehicular transportation. Essential for carrying out this mission is high quality crash data. The National Center for Statistics and Analysis (NCSA) is responsible for collecting and analyzing crash data to support key highway safety initiatives.

Through NCSA's data collection and analysis programs, NHTSA can: 1) understand the factors that influence highway safety; 2) analyze benefits of future activities; 3) quantitatively identify the effectiveness of crashworthiness and crash avoidance vehicle design characteristics; 4) relate driver behavior factors to injury and fatality rates; and 5) provide a clear and concise picture of highway crashes in the United States. This paper summarizes these data activities and discusses program changes planned during the next five years to improve NHTSA's ability to deal with emerging highway safety problems.

Introduction

Motor vehicles account for almost 90 percent of passenger miles travelled in the United States (U.S.) and provide Americans with an extraordinary degree of mobility. However, traffic fatalities account for more than 90 percent of all transportation-related fatalities. The National Highway Traffic Safety Administration (NHTSA) has been charged with reducing these consequences of vehicular transportation. As part of its mandate, NHTSA conducts research to improve motor vehicle and traffic safety, identifies specific problems to be addressed, implements standards and programs to address these problems and evaluates their impact.

Essential for carrying out this mission is high quality crash data. The National Center for Statistics and Analysis (NCSA) is responsible for collecting and analyzing crash data to support key highway safety initiatives not only for NHTSA programs but also for other Department of Transportation modes, especially the Federal Highway Administration (FHWA). The data collected by NCSA must be of superior quality since they are used by the U.S. government to support research and development of motor vehicle and highway safety policy and programs. With an estimated 44,500 fatalities and more than six million police reported crashes in 1990 and economic losses from these crashes in excess of $100 billion per year, motor vehicle and highway safety continue as a top priority in transportation safety. Overall guidance for Agency action has been provided by the President through the National Transportation Policy that was issued in the spring of 1990. Regarding crash data, the policy recommends that efforts be taken to improve reporting on crashes, data on exposure to risk, and information on trends and patterns to identify potential safety problems and causes. The following discusses the specific objectives of NHTSA's crash data collection program and initiatives to be pursued in the next several years to improve the Agency's understanding of highway safety.

Overview of NHTSA's Data Needs

Data are needed by NHTSA to develop its highway safety programs, manage agency initiatives to improve highway and motor vehicle safety, and evaluate the effectiveness of these actions. The data requirements of individual programs within the agency, while reflecting these overall needs, vary greatly in their specific requirements. In general, however, these individual needs can be associated with one or more of the following analytic requirements:

- Relate human, vehicle, environmental, and roadway characteristics to crash frequency and the severity of injuries sustained in these crashes.
- Identify injury mechanisms and associated crash dynamics in motor vehicle crashes.
- Evaluate the effectiveness of crashworthiness, crash avoidance, and traffic safety efforts.

- Monitor the magnitude of the traffic safety problem.
- Quantify the benefits resulting from proposed agency rules.

The data needed to support these analytic requirements are presently obtained from a variety of sources including the police reported accident experience of individual states, specialized databases created with information extracted from police accident reports and other public sources, in-depth investigations of accidents by trained investigators, and published data available from various private concerns and other governmental agencies such as the Federal Highway Administration.

NCSA has developed four programs for providing information on traffic crashes. The Fatal Accident Reporting System (FARS) provides basic information on all highway crashes in the U.S. in which one or more people die of their injuries within 30 days of the crash. Although fatalities are the most traumatic result of traffic crashes, injuries are a major component of the highway safety problem. The National Accident Sampling System (NASS) provides information from investigations of a statistical sample of police reported crashes at all levels of injury severity. NASS consists of two components, the Crashworthiness Data System (CDS) and the General Estimates System (GES). In the CDS, detailed investigations of real world highway crashes involving passenger cars, light trucks and vans are conducted. These investigations provide accurate and detailed information on the crashworthiness, or occupant protection characteristics, of these vehicles. The GES is based upon police reports collected from throughout the U.S. The information from these reports is used to make estimates of general traffic safety measures. State data provides a large data base consisting of all police reported crashes in a large number of States. These data files include information on crashes over the complete spectrum of crash severity from property damage to fatalities. Figure 1 illustrates the hierarchical nature of crash data that these data sets try to describe.

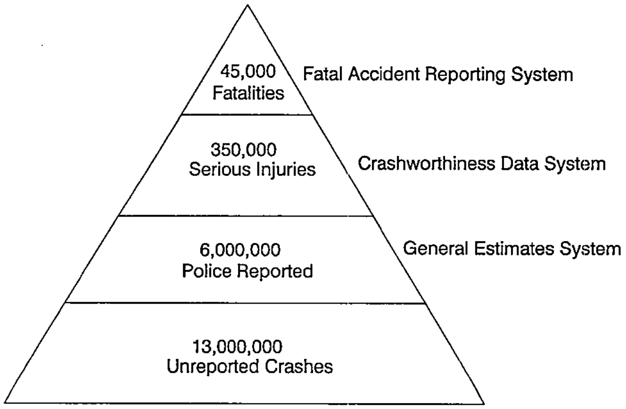


Figure 1. NCSA Crash Data

Tables 1 and 2 provide an overview of the contract dollars and people resources that are expended to support collection and analyses of these data sets. Each of these data systems will be discussed in more detail in the following pages.

Table 1. Data Related Contract Program ($000)

	FY'91	FY'92*
Fatal Accident Reporting System	$3,397	$3,933
National Accident Sampling System	7,411	9,399
Data Analysis Program	1,575	1,575
State Data Systems	475	655
Special Accident Investigations	300	315
Total	$13,158	$15,817

*FY 1992 Congressional Request

Table 2. Data Related Personnel

	FY'91	FY'92
Fatal Accident Reporting System	150	150
Federal Government Personnel	(10)	(10)
Contract Personnel	(140)	(140)
National Accident Sampling System	170	170
Federal Government Personnel	(13)	(13)
Contract Personnel	(157)	(157)
Data Analysis Program	20	22
Federal Government Personnel	(16)	(17)
Contract Personnel	(4)	(5)
State Data Systems	6	7
Federal Government Personnel	(6)	(7)
Contract Personnel	--	--
Special Accident Investigations	8	8
Federal Government Personnel	(1)	(1)
Contract Personnel	(7)	(7)
TOTAL	354	357
Federal Government Personnel	(46)	(48)
Contract Personnel	(308)	(309)

National Accident Sampling System Crashworthiness Data System (CDS)

The CDS was implemented in 1988 as a follow-on to the National Accident Sampling System which operated from 1979 through 1986. It investigates about 5,000 crashes annually, depending on the number of researchers funded. The objective of the CDS is to provide detailed information on crash dynamics, injury mechanisms, and injury consequences for a representative sample of motor vehicle crashes to support occupant protection research and rulemaking. The CDS is a nationally representative sample of police reported crashes occurring on public roads throughout the United

States involving at least one towed passenger car, light truck, van or utility vehicle. The CDS uses trained researchers to sample crashes and collect detailed data in accordance with established protocols. Information for the CDS crashes are obtained from police accident reports, hospital records, vehicle inspections, scene inspections, and interviews.

This information is used by safety researchers to help identify safety problems for which countermeasures can be developed and to provide information to support the development of occupant protection safety standards. Table 3 provides a sample of the type of data that can be derived from the NASS/CDS program.

Table 3. Number of Injured Occupants by Vehicle Damage, 1990 CDS

	Area of Vehicle Damage						
MAIS	Front	Right	Left	Rear	top	Under-carriage	Unknown
0	927,000	210,000	243,000	167,000	105,000	23,000	264,000
1	668,000	164,000	212,000	163,000	93,000	2,000	109,000
2	45,000	34,000	35,000	12,000	31,000	*	13,000
3	47,000	14,000	12,000	*	9,000	*	3,000
4	7,000	4,000	3,000	*	2,000	*	*
5	3,000	3,000	2,000	*	2,000	*	*
6	3,000	*	1,000	*	*	*	*
7	78,000	18,000	16,000	13,000	16,000	*	14,000
Total	1,879,000	448,000	524,000	337,000	259,000	26,000	405,000

* Estimates are less than 1000

NOTE: The sum of individual columns may not equal the totals because numbers have been rounded.

NASS/CDS Future

During Fiscal Year 1990, NCSA coordinated a review of agency crash data needs which concluded that the CDS could be modified to better provide for the needs of the Agency. These needs included the ability to provide an increased sample of severe crashes for clinical review while maintaining representativeness in order to produce national estimates from the data. As a result of this study, NCSA has taken the following steps to improve the design of the NASS program:

- Change the sampling protocols to include a stratum for those crashes in which vehicle occupants are reported by police as being severely injured and who the CDS researcher determines are hospitalized at least overnight, thereby increasing the likelihood of the crash resulting in a serious injury.
- Retain the national representativeness of the CDS.

There are also several special studies that are being considered over the next several years directed at improving the usefulness of the data collected by this CDS:

Special Study—Pedestrian Data Collection

A proposal has been made to collect data on pedestrian crashes at non-rural sites in CDS involving late model year passenger vehicles to: (1) establish the relationship between vehicle/pedestrian geometric parameters and injury type and severity; and, (2) enable detailed accident reconstruction. The goal is to collect data from 1,000 to 1,500 pedestrian crashes annually. Most of these cases would be investigated to collect a basic data set for trend information. However, several hundred cases annually would be part of a detailed accident reconstruction program to produce high quality specialized data. Since this would be a major CDS program and would have a significant impact on CDS field operations and funding, the study is still being considered by the Agency. If pursued actual, data collection would be accomplished in the 1993-95 timeframe.

Injury and Trauma Data Research

Comprehensive data on occupant injuries, including injury severities, body regions injured, specific lesions and systems or organs injured, and the correlation of these injuries to specific vehicle elements or components, are essential to crashworthiness research. Recent crash injury studies, conducted in cooperation with major trauma centers, have demonstrated the utility of additional trauma measures not currently collected by NHTSA. Also, in this current CDS, all injury data must be manually translated to appropriate automated codes on electronic files from paper copies of medical records and autopsy reports.

Trauma Data Analysis. Additional trauma information (e.g., Glasgow Coma Scale, Arterial Blood Gas) and some cost data are available but are not presently collected in any NHTSA data system. Supplemental data bases will be assembled of available data.

Trauma Data Supplement. Some injury information (approximately one-third) currently collected in the NASS CDS is potentially available from automated trauma data sources. A program to explore the trauma data available, and the extent of automation of such data along with the legal and privacy limitations will be undertaken. This survey will be limited to ascertaining whether or not it is possible to obtain automated injury information from those hospitals currently providing injury data for NASS/CDS investigations. The findings of the survey will be used to plan for the possible implementation of this source of data within the NASS CDS, as a substitute for manually coding this information from hardcopy hospital injury reports.

There are several technologies that are being developed or improved to increase the productivity of the CDS in the future:

Automated Injury Coding. An automated injury coding system will be developed to translate hospital and autopsy reports to electronic files. Such a system will bridge the gap until more complete automated trauma information sources are in place. Various automated approaches for coding trauma information which are being developed in the private sector for hospital use will be examined. A NASS-specific artificial intelligence concept was explored in 1989-1991. A cost effective system or concept is needed which can be easily adapted to the increasing level of detail required in trauma coding and which can accept continually changing trauma protocols (such as the shift from AIS85 to AIS90 injury classification). An automated coding system will provide more complete and consistently coded injury data with fewer errors and will reduce the cost to manually translate the records. Its application could be extended to all NHTSA data systems coding detailed trauma information, including trauma research programs at major trauma centers and other biomechanics research.

Crash Algorithm. A major element of the CDS is a measure of crash severity based on vehicle damage measurements. This severity is known as "Delta V" and is determined by means of an algorithm. This algorithm was developed in the late 1970's and work is underway to: update the vehicle stiffness properties for current cars; expand the algorithm to non-symmetrical crash modes (angled, offset, rollovers) frequently found in highway crashes; and devise acceptable algorithms for cases when full data are not available.

Clipboard Computer. The agency will prototype a hand held non-keyboard computer to collect accident and trauma data at the accident scene quickly and efficiently. Use of this device has the potential for greatly improving the quality and productivity of police collection of crash data and improving the State's ability to update their traffic records master file.

Photogrammetry. Photogrammetry is being investigated by the National Center for Statistics and Analysis as an alternate methodology to obtain vehicle crush information. It typically has required the use of expensive stereoptic metric cameras, complicated photographic techniques, and extensive time to plot and calculate the data. Recent advances in computers and photogrammetric algorithm development have permitted the use of standard, off-the-shelf single lens reflex cameras and personal computer software to document and analyze photos. We are investigating whether this new photogrammetric software when combined with computer aided design programs can be utilized to analyze and determine crush from photographs of vehicles where the damage has not been marked.

National Accident Sampling System—General Estimates System (GES)

The objective of the GES program is to provide **statistical** information on the general characteristics of the nations's police reported motor vehicle crash experience as an aid to monitoring large scale trends in the motor vehicle crash experience. GES is a nationally representative sample of motor vehicle crash data extracted from the information contained in approximately 47,000 police reported crashes collected each year. It is the only database currently in place that can provide national estimates for all police reported traffic crashes on public roads, including crashes involving heavy or medium trucks, motorcycles, or non-motorists. It was implemented in 1988 after NASS was restructured to provide more information for the agency's occupant protection research and rulemaking program. No data beyond that contained on the police accident report are entered into GES. Table 4 provides an example of the type of data available from the GES program.

Table 4. General Estimates System 1990

Multi-Vehicle Crashes by Manner of Collision and Crash Severity

	Property Damage	Moderate Injury	Severe or Fatal	Total
Rear-End	998,000	477,000	50,000	1,524,000
Head-On	35,000	32,000	17,000	85,000
Angle	1,622,000	628,000	128,000	2,378,000
Sideswipe	307,000	41,000	6,000	354,000
Total	2,962,000	1,178,000	201,000	4,342,000

NOTE: 14,000 crashes of other Collision Types

GES data are collected in 60 sites throughout the nation on either weekly, biweekly, or monthly visits to the approximately 400 police jurisdictions. During each visit, a sample of newly reported crashes are selected on a predetermined random basis to be included in the GES. Copies of selected police accident reports are forwarded to a central contractor where GES data are extracted and entered into an electronic file. Trained personnel interpret and code data directly from each police accident report. Coding operations are carried out on a daily basis, and analysis files are prepared annually. Like NASS CDS, thousands of automatic edit checks are used to assure proper values for range and consistency between different data elements.

NASS/GES Future

In the near term only minor changes will be made to the GES program. New variables will be collected to support crash avoidance research and provide additional data on heavy trucks. More importantly, an evaluation will be conducted to determine what general estimates of police reported crash characteristics are needed by the agency. Alternatives to the current method of producing general estimates of police reported crashes will be evaluated to ascertain the degree to which they can meet the Agency's needs for such statistics in a timely and cost efficient manner. Among those options to be considered are model-based national estimates using data from a convenience sample of state crash data files, and Periodic sampling of crashes directly from state computerized files.

Fatal Accident Reporting System (FARS)

The objective of the FARS program is to provide information from all fifty States on all motor vehicle crashes occurring on roadways open to the public in which a death occurs within 30 days of the crash. Information is available in the FARS that describes the vehicles involved in fatal crashes, their occupants, the roadways on which these crashes occurred, and other characteristics of interest. FARS was conceived, designed, and developed in 1975 by the National Center for Statistics and Analysis and now contains records on over 750,000 fatal crashes. FARS data are presently collected through contracts with an agency in each State government to provide information in a standard format on all police reported fatal crashes in the State. The data for the FARS are gathered from the State's own source documents and are coded on standard FARS data forms. Figure 2 illustrates a common application of FARS data. Table 5 provides an overview of the fatal crash experience in the U.S. in 1990.

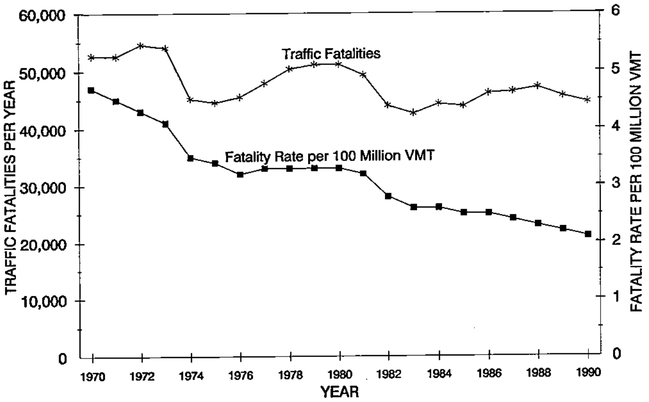


Figure 2. U.S. Traffic Fatalities and Fatality Rates per 100 Million Vehicle Miles Traveled by Year

Table 5. Motor Vehicle Traffic Fatalities 1990

Type of Vehicle	1990
Passenger Cars	24,025
Light Trucks/Vans	7,381
Medium Trucks	133
Heavy trucks	571
Buses and Others	521
Utility Vehicles	1,212
Motorcycles	3,238
Nonoccupants	
Pedestrians	6,468
pedalcyclists	856
Other Nonoccupants	124
TOTAL FATALITIES	**44,529**
FATALITY RATE	**2.1**

FARS Future

The FARS program will remain basically unchanged in the near future. As with any data collection system, the data being collected are periodically reviewed to see if changes need to be made to better meet program needs. For instance, several highway elements were modified according to Federal Highway Administration (FHWA) specifications in 1987. In addition, elements were added on emergency medical service arrival times, alcohol and drug involvement, driver zip code, and death certificate number. In 1990, another user review resulted in recommendations for 12 new data elements and modifications to 4 elements. These new factors reflect changing priorities in NHTSA's programs and include additional data on crash avoidance maneuvers, expanded data on heavy truck configurations, hazardous material information, and new data on drug use.

In addition, there are several special studies scheduled to be undertaken within the FARS data collection system:

Special Drug Information In Selected States

Several States will be testing fatally injured drivers for both alcohol and the presence of other drugs. Information will be obtained from these States on the drugs they tested for and the specific type of drug found in these fatally injured drivers. A total of 1,000-2,000 drivers is the target sample size. Information on drugs such as cocaine, THC, amphetamines and other popular drugs will be obtained. This effort will be initiated in four States the first year and could be expanded to a total of 10 states in the second and third year if the drug information is found to be available and useful.

Detailed Injury Information on Surviving Occupants in FARS

This initiative involves the collection and analysis of detailed injury information on the more than 40,000 occupant survivors of fatal crashes. At present, only seating position and police reported injury severity are obtained for these survivors. A description of the injuries sustained by these occupants, including body region, will be piloted in several States. NHTSA researchers will have the ability to study those general factors influencing survivability in these very severe crashes. This data base is critical to the advancement of research on crashworthiness countermeasures.

Autopsy Information on Selected Motor Vehicle Fatalities

This initiative calls for the collection and analysis of detailed autopsy information on selected motor vehicle fatalities. FARS Analysts who have access to copies of autopsy reports will collect these reports to provide detailed descriptions of specific injuries, causes of death and probable vehicle contact points for pedestrians, child fatalities and motorcyclists. This will provide NHTSA researchers with critical data to learn more about the factors influencing the effectiveness of various child restraints, motorcycle helmets and the contribution of vehicle size and shape to pedestrian fatalities. In later years, if the data proves to be useful, the program could be expanded to support the evaluation of new standards such as the side impact rule for passenger cars.

TIFA Development

The Trucks in Fatal Accidents (TIFA) file is a source of information that combines detailed cargo, truck, and driver data obtainable from FHWA's motor carrier accident file, but unavailable in FARS, with the detailed accident data on all fatal crashes involving trucks from FARS. Data not otherwise available to FHWA on unregulated carriers describing driver, truck configurations, and cargo is developed under a contract with the University of Michigan's Transportation Research Institute.

State Data Systems

The objective of NCSA's state data system program is to fully develop the analytic potential of all state data of relevance to highway safety including police reported accident data, trauma data, and exposure data. Data from FARS, CDS, and GES are of limited utility when addressing many contemporary issues in highway safety. In particular, these data systems are not well suited for examining the statistical relationships between specific vehicle design characteristics and the frequency with which they are associated with either the occurrence of a crash, or its injury consequences. While a variety of state data offer a potentially rich source of information well suited for studying issues of this general nature, their application has not been fully exploited. Police reported accident data are a readily available source of crash data, for example, but are lacking in uniformity and quality. Similarly, trauma data offer a potentially excellent source of injury information, but are not as yet available in sufficient numbers and are not readily linkable with police accident reports. The successful resolution of these deficiencies will greatly enhance the analytic utility of these data.

Unfortunately, most of the data is of limited utility because of missing data elements and poor quality. Efforts are currently underway to review DOT's utilization of this data source with the objective of enhancing the efficiency with which these data can be accessed and utilized. Efforts are also underway to construct a database utilizing police reported accident data from selected States to support crashworthiness analyses, and to enhance the efficiency of Crash Avoidance Research Database (CARD) file operations.

State Data Future

CADRE

A major effort to enhance the analytic utility of police reported accident data was initiated in 1990. A cooperative effort was developed with the States and other highway safety interests to define a core set of data elements that should be available in states' automated data bases. This core set of data was given the name "Critical Automated Data Reporting Elements" (CADRE). The objective of this program is to create national uniformity in a small number of variables that are essential to the use of police reported crash data for highway safety analyses. Data items have been tentatively identified, public comments on the items received, and a task force assembled to review these comments and suggest changes to CADRE. A final list of CADRE items is expected by the fall of 1991, to be followed by a nationwide survey to determine the extent to which these data items are currently collected by States. Subsequent initiatives will be developed to facilitate the implementation of CADRE in all States.

Trauma Data

A potentially rich, untapped resource for investigating highway safety issues is trauma data. Trauma data come from merging police accident reports data sets with injury information from hospital and emergency medical services data bases. Trauma data are a potentially important source of information for quantifying the relationship between crash characteristics, motor vehicle design features, and the injury consequences of motor vehicle crashes. At present, however, obstacles to linking these data with police accident reports remain and experience in utilizing these data to address many highway safety issues is limited. Neither is there any understanding of the statistical properties of these data. Further, there is a lack of agreement as to what trauma data should be collected, and on what patients. These and other issues must be resolved before the analytic utility of trauma data can be accurately assessed.

An initial investigation of these issues is being examined in a joint project with the State of Virginia to study injury mechanisms in motorcycle crashes. This project will provide the experience needed to assess the extent to which trauma data can support highway safety analytic requirements. This project will also assist NCSA in developing a model trauma data system and assessing the status of trauma data systems nationally.

Unreported Crash Analysis

Traffic crashes not reported to police have different characteristics than reported crashes. Principal among these is their low severity. Many crash avoidance countermeasures being developed are most effective in preventing such low severity crashes. Without an accurate accounting of these crashes, it is impossible to accurately predict and assess their benefits. Further, data on time and location of unreported crashes would provide a means of assessing the vehicle-hours of delay caused by unreported crashes, a major factor underlying the development of intelligent vehicle highway subsystems.

Data Analysis Program Plans

NCSA is responsible for analytical and statistical support to the agency and the highway safety community at large in the general areas of data analysis, sampling, and survey design. NCSA's analytic activities are typically undertaken in response to requests to support particular programmatic needs of the agency. Major analytic requirements are developed through an "analytic agenda" process. At the beginning of each fiscal year, NCSA staff meet with program representatives to jointly identify and prioritize analytic needs. These analyses take advantage of all of the data sets managed by the Agency. A summary of the types of analytic applications is shown in Table 6. The results of these activities are published in technical reports available to the public.

Table 6. Analytical Applications

ISSUE	DATA SYSTEMS	ANALYTIC METHOD
Car Size & Weight	State data, FARS	Logistic/Linear Regression
Vehicle Stability	State data, CDS	Logistic Regression
Light Truck R/O Injuries	CDS	Analysis of Variance
Effectiveness of AOPS	State data, CDS, FARS	Logistic Regression
IVHS Utility	State data	Descriptive Statistics
Age/Sex Factors	State data, FARS	Descriptive Statistics
Effect of 65 mph Speed Limit	FARS	Descriptive Time Series

In addition to these analytic activities, NCSA publishes a number of statistical reports which summarize major aspects of the nation's crash experience on an annual basis. Included among these reports are:

- Summary of Nation's Fatal Crash Experience
- Crashworthiness Data System Annual Report
- Summary of Nation's Police Reported Crash Experience
- Medium/Heavy Truck Crash Experience
- School Bus Crash Experience
- Alcohol Involvement in Fatal Crashes

Examples of recent analytic activities supporting the various agency program areas are as follows.

Traffic Safety

A major issue under study has been the effect on fatalities of raising the speed limit to 65 mph on rural interstate highways. For this analysis, it was necessary use the Fatal Accident Reporting System coupled with vehicle miles traveled data from the Federal Highway Administration. Interrupted time series/linear regression models were developed using fatalities on unaffected roads as a comparison group.

Other analyses recently conducted in this area and using FARS data include the effects of raising the minimum legal drinking age on fatalities, which utilized changes in the odds ratio of fatalities per licensed driver in the affected age group compared with the same ratio for the unaffected age group; and the effect of implementing mandatory safety belt usage laws on fatalities, which used interrupted time series/linear regression methods.

Lastly, several analyses have been conducted to study the relationship between driver age/sex and crash involvement using state data files and driver licensing data. Descriptive statistics as well as log-linear models have been developed to characterize these relationships.

Crash Avoidance

One of the Agency's major program initiatives is in the area of light duty vehicle rollover. The current initiative involves a large-scale data analysis to determine which vehicle metrics best predict the likelihood of vehicle rollover in a single-vehicle crash. For this effort, it was necessary to obtain a large sample of crashes for specific vehicle makes and models in order to link involved vehicles with specific measures of static and dynamic vehicle stability. State data files from five states were selected for use, based on their high degree of reporting of the vehicle identification number (VIN) used to uniquely identify specific vehicles in the sample. Since the specific outcome under study was whether or not the vehicle rolled over, logistic regression was used. The analytical results of the first phase of this effort are being presented in this conference. In addition, the recent acquisition of special software for conducting logistic regression on complex survey data has presented the opportunity to investigate light vehicle rollover using data from the National Accident Sample System's Crashworthiness Data System. Of all of NHTSA's current crash data systems, the CDS provides the greatest level of detail on specific crash characteristics due to the level of investigative effort invested by NHTSA.

State data have also been used to investigate the utility of Intelligent Vehicle and Highway Systems and their opportunity for preventing crashes from occurring. In this instance, descriptive statistics on crash locations, crash mode and outcome have been generated.

Crashworthiness

Two of the agency's top priority evaluation efforts over the last year focused on the relationship between vehicle weight and injury severity and the effectiveness of automatic occupant protection systems. On the vehicle weight/safety issue several analytical methods were employed, focusing on the likelihood of occupant injury as a function of vehicle weight in the presence of other influencing factors such as occupant age/sex and crash mode. FARS and state data were used to evaluate rollover risk using log-linear regression models as part of the evaluation of Federal Motor Vehicle Safety Standards 206 (Door Latch Integrity) and 216 (Roof Crush Strength). Injury risk in single-vehicle nonrollover crashes as a function of passenger car weight was assessed using data from NASS coupled with state data in a linear regression model. Lastly, fatality risk in single-vehicle nonrollover crashes and injury risk in two-car crashes was modeled as a function of vehicle and location of impact using logistic regression models.

The second major ongoing analytical effort in the area of crashworthiness is the evaluation of the effectiveness of automatic occupant protection systems. This evaluation makes use of almost all of the agency's data collection systems including FARS, NASS Crashworthiness Data System, state data and R. L. Polk new car registration files. A number of approaches are being used such as linear regression of fatalities per 100 million vehicle years as a function of automatic occupant protection type and other relevant vehicle attributes, logistic regression of ejection risk as a function of restraint type, crash mode, etc., and the investigation of other descriptive statistics normalized to the experience of manual belt restrained front-seat occupants.

Enforcement

The enforcement program area generally requires the investigation of issues at the vehicle make/model level, to support compliance testing selection procedures or the investigation of alleged vehicle defects. This level of detail almost always requires the use of state data in order to obtain sufficiently large sample sizes to be able to draw meaningful conclusions. Over the past year, the Agency has analyzed several issues including rollover risk of Jeep CJ vs. other cohort utility vehicles using logistic regression methods; door openings leading to increased ejection risk for unrestrained occupants in specific vehicle make/models vs. vehicle cohort using simple t-test for difference in ejection rates, and ejection risk in certain vehicles equipped with a specific type of automatic occupant protection system.

Plans and Policy

In support of the agency's regulatory efforts, one of the missions of the Office of Plans and Policy is the development of estimated benefits from implementation of the various proposed rulemaking activities. In this regard, NCSA's efforts involve supporting Plans and Policy staff in developing estimates of the target population. This generally involves the use of both FARS and the NASS Crashworthiness Data System, which is the only data system capable of estimating the prevalence of injury at various levels of severity using the Abbreviated Injury Scale (AIS). In this regard NCSA provides both estimates of the current target population, imputing unknowns so as to provide a complete accounting of vehicle occupants under investigation, as well as estimating standard errors of these estimates. Since the NASS data is a sample of crashes, these estimates are subject to both sampling and nonsampling errors, the former of which can be estimated and presented so the readers are aware of the inherent variability of the data.

S1-W-24

A Proposal for a Simplified Injury Scale "SAIS 9" for Use in Large Scale Accident Studies[1]

Felix Walz
Institute of Forensic Medicine
Klaus Langwieder
Office for Motor Vehicle Safety Research,
HUK-Insurers' Association

The Need for a Simplified Version of AIS 90

The publication of the first AIS-manual in 1971 immediately constituted the starting point of a new era in accident research. For the first time a worldwide comparability of injury-descriptive data was achieved, enabling researchers to exchange their experiences in a common language: the AIS.

Its international acceptance, popularity and application to an increasing number of fields induced an ongoing process of refinement, which brought the number of its entries from a rudimentary 75 on the onset to about 1300 in the present AIS 90 edition. Inevitably this development from a rather easy tool of injury description to a highly sophisticated scale with features of an expert system oriented towards research in clinical traumatology

---

[1] Contact address: Felix Walz, MD, Institute of Forensic Medicine, University of Zurich Zürichbergstrasse 8, CH-8028 Zürich, Switzerland, Phone 0041 1 257 28 50, Fax 0041 1 252 14 56.

Consultants: K. Langwieder, A. Spomer, Th. Hummel, Büro für Kfz-Technik, HUK-Verband,Leopoldstr.20, D-8000 Munich 40 (Office for Motor Vehicle Safety Research of the German Association of (Third party, Accident,) Motor Vehicle (and Legal Protection) Insurers). G. Beier, MD, Institute of Forensic Medicine, Ludwig-Maximilian University of Munich. M.G. Bömer, MD, BG-Trauma Clinic Frankfurt. D. Otte and M. Nerlich, Accident Research Unit, Medical School Hannover. G.R.Treviranus, MD, Institute of Forensic Medicine, University of Zurich.

Advisor: Elaine Petruccelli, Executive Director, Association for the Advancement of Automotive Medicine, 2340 Des Plaines River Road, Suite 106, Des Plaines, IL 60018, USA.

and allocation of resources had to come to a point of critical divergence from the needs of accident research projects.

This holds especially true for the use of AIS in large scale accident studies limited by raw data lacking details or by encoders with little medical training. "Fahrzeugsicherheit '90" (Motor Vehicle Safety '90) is a large scale investigation of german motor vehicle accident reality of this kind for the nineties, and is currently set up by the Office of Motor Vehicle Safety.

"Motor Vehicle Safety 9" embraces the analysis of some 10,000 road traffic accidents causing personal injury. Given this extent the application of the new and sophisticated AIS-90 version didn't seem promising, and therefore the idea of a reduced version of the AIS-90 came up, which at the same time was desired to be better than the AIS 80 or 85 "Revision" in use before, but even more manageable.

We started by defining our special needs as traffic accidentologists, believing that they would conform to our colleagues' needs:

- We typically dispose of summarized diagnostic data; *not* of detailed information as extractable from hospital treatment reports, discharge letters or operation reports;
- Our data commonly is evaluated by *non-medical* personnel, usually by engineers, who dispose of a general medical knowledge, which just can be increased by a brief medical training session;
- *Injury pattern* recognition is one of our prime interests. Refinement by itself dilutes data into innumerable rills escaping recollection. Larger entities have therefore to be maintained.

We then began to think about the means, and thought of roughly two ways to proceed:

- Either one would discard uncommon injuries and their codes altogether;
- or one would integrate the less common injuries into codes for frequent or for less specified injuries belonging to the same body area and injury type.

We thought that by discarding uncommon injuries, among other draw-backs, the already not entirely solved problem of multi-traumatized accident victims[2] would be exacerbated. The latter alternative instead was thought to be practicable, and therefore chosen.

Aims and Methodology of the Simplified Version

The intellectual wealth connected with the AIS-system can't be properly described in a short publication as the present. The reader interested in a very abridged description of the AIS-venture is referred to the introductory remarks in part II (the manual), which are largely inspired by those to be found in the previous editions of the AIS-manual.

Especially the current "1990 Revision" already greatly enhanced the user-friendliness of the manual. Obviously because the maturity reached in the basic refined framework now allowed to concentrate on questions of acceptance and ergonomy.

In this contribution we too aimed at the preservation of a nearly complete upward compatibility with the full AIS-90 version, as was attempted in the previous revisions. We therefore set certain rules, e.g. that anatomically neighboring classes in the system's tree should coalesce only into one of their neighbor's where the label of the surviving code was still able to describe the swallowed instances correctly, although with less detail. This label was allowed to be amplified though. Obviously the codes and labels where injuries were transferred from were canceled in the process.

But obviously some compromise had to be made, and labels were amplified accordingly. Usually the codes with the highest expected frequency and the most representative AIS-severity score were chosen, and the NFS-sign meaning "not further specified" was added to the label, together with further clarifying comments. The lowest severity level was usually also the most common one. Sometimes the codes of the former NFS-labels, those with the "99"-feature, were retained. Among these also some carrying the undetermined score "9". This was intended as a last resort for cases where hardly any information is present on considerable injuries.

Overall eleven additional new codes were introduced. Two for certain lethal injury patterns, two for blunt abdominal trauma cases, one for medium size neck vessels, three for severe sprains of the spine, one for impalement-like perineal injuries, one of grade 5 to replace high cord injuries graded 6 and one for complete forearm fractures. Of these only five are thought to occur with a noticeable frequency. We furthermore attached certain small or rarely injured organs or structures to a larger structure in their proximity, when neither the consequences of the injury nor their especially protected location seemed to stand out. About twenty references tell the encoder where to go.

We also attempted to improve the user-friendliness of the manual by giving it a closer correspondence with the occurring injury patterns, and by adding twelve suggestion lists comprising one to three, and altogether about two dozen codes, from which to chose for additional important features of the injury, implying that, were none such suggestions were made, one code should suffice.

The diamond shape of the AIS, as created with the contribution of some of the world's most eminent scientific surgical associations had to suffer from this.

---

[2] See St Luchter, Isenberg R (NHTSA) The incidence of Multiple Injuries in Motor Vehicle Crashes; this volume (13th ESV).

This simplified manual can't be more than a stimulus for a debate which by necessity will have to lead to a renewed scientific effort, maybe not as large as the previous one, but more oriented towards the aspects of practicability, building on what has been achieved before.

For now we took up the challenge to create a practicable tool for one large data survey. We herein wanted to think of ways to anticipate cumbersome decision-making activities of the encoder, struggling with true or what to him might seem to be equivocalities. A short comment or suggestion can shorten these distracting thoughts considerably. We hope that those which we found may be prove effective in that sense. We can't hope to have forged this tool already. We are not beyond the first draft yet. But it is our firm intent to work towards the realization of a first applicable version of this tool already within 1992, and we therefore hope to receive the necessary critique and encouragement or even participation by March '92 in order to be able to create a prototype-proposal which can be sustained by the Injury Scaling Committee of the AAAM (Association for the Advancement of Automotive Medicine) and the AAAM itself within 1992.

One of the main problems arising with the reduction of the AIS-90 code probably will be the question of the maintained validity of the AIS-severity score, the heart of the AIS-system, as the severity scores of injuries coalesced into a surviving code occasionally differ by one step in either direction. This question can only be addressed fully by testing the full version against the simplified version on a large motor vehicle accident data base using a transformation software program.[3] Such and other tests on inter-rater reliability, acceptance and work load economy should be undertaken both in the U.S.A. and in Europe (or elsewhere) in the next future. Our first impression after a preliminary comparative test on 50 files, whose results are reported in part III of this publication, are favorable though, in the way that this may prove to be a surmountable problem.

The content of this publication constitutes the first public draft of a proposal addressed at the entire research community involved in the field of traffic accident analysis. Our proposal has encountered the benevolence and intellectual generosity of the Association for the Advancement of Automotive Medicine and its Committee on Injury Scaling, and has taken already full advantage of a preliminary review provided by the Association's executive director, Mrs. Elaine Petrucelli, within a very short delay. Further comments by AIS-users interested in the development of the simplified version are explicitly welcome to the present task-force committee, and should be sent to the committee's coordinator Prof.Dr.Felix Walz in Zurich.

The Simplified AIS-90 Injury Scale[4]

(Simplified procedure reducing "The Abbreviated Injury Scale, 1990 Revision" of the Association for the Advancement of Automotive Medicine, 2340 Des Plaines River Road, Suite 106, Des Plaines, IL 60018, USA)

Preliminary Remark

This compendium is a proposal for a reduced procedure of AIS-coding on the basis of the original U.S.-American version "The Abbreviated Injury Scale, 1990 Revision". A deeper acquaintance with the AIS, its context and the pertaining literature, can be achieved through the consultation of the original U.S.-American version. The content of this manual should not yet be used for other than preliminary validation purposes and is therefore protected by copyright. Updates can be asked for through the coordinators address until 1993.

Introduction

The analysis of the effects of trauma requires a classification of injuries according to type and severity, which can be achieved in several ways. The AIS-code categorizes injuries according to anatomical location, specific type of injury and relative severity.

Origin and development of the AIS. The first Abbreviated Injury Scale, where "abbreviated" stands for the one- digit nature of the AIS-severity score, was published in 1971. It was developed under the joint sponsorship of the American Medical Association, the American Association for Automotive Medicine[5] and the Society of Automotive Engineers by a team of about 35 medical trauma specialists and engineers and encompassed 75 entries.

In 1973, the AAAM assumed the lead role in injury scaling and, through its Committee on Injury Scaling , became the parent organization of the AIS.[6] In its second 1976 edition The Abbreviated Injury Scale accounted for little more than 200 different injuries, and this number had grown to more than 400 labels in its

---

[3] The Simplified AIS-90 as presented in this paper, an Index-version on Excel and a combined version with the AIS85 on Excel can be obtained from the coordinator by specifying the required format (Macintosh or IBM or Windows).

[4] Copyright by AAAM, HUK, F.Walz/G.Treviranus.

[5] The American Association for Automotive Medicine was renamed Association for the Advancement of Automotive Medicine in 1987.

[6] American Association for Automotive Medicine: The Abbreviated Injury Scale. Des Plaines, Illinois, 1976. (..)1980 Revision, 1980. (..) 1985 Revision, 1985. (..) 1990 Revision, 1990.
Petrucelli,E. (ed.), An international Bibliography on Abbreviated Injury Scale usage. American Association for Automotive Medicine, Arlington Heights, Illinois (1982).
Petrucelli,E., States, J.D., Hames, L.N., "The Abbreviated Injury Scale: Evolution, usage and future adaptability," Accid Anal Prev 13: 29-35 (1981).

third 1980 edition. The entirely revised 1985 edition, written in "acceptable clinical language", expanded sharply to nearly 1200 entries. The 1990 refinement slightly increased the number to about 1300 possible codes, answering the still growing need for accuracy in the definition of trauma, as required by clinical research and the management of resources for trauma care.

The AIS 85 had a single page scaling chart, called the CAIS-85, attached to it, which proved useful in patient care, identifying patients at risk.[7] The single codes were reduced to their severity score, but not in number.

The purposes and philosophy of the AIS. The AIS-scale achieves the coding of injuries through a numerical key based on a standardized descriptive terminology. It is well suited for computer processing. It has no equal in the accidentological recognition of injury distributions after car crashes.

The AIS-scale spans from AIS 1 (minor) to AIS 6 (currently untreatable) on a 6-point ordinal scale derived from an extensive consensus creating process. Severity as mirrored by treatability remains subject to the progress of medicine, requiring periodical redefinition. Severity as interpreted by biomechanical measurements remains more constant. Severity considered as individual and societal harm, not the purpose of the AIS, again is more subject to change.

As the AIS scores injuries, and not consequences of injuries, it's decisive difference from other, physiological, injury scales rests in the immutability of the score in time. It considers all the defined injuries as they presented shortly after the accident, (e.g. at hospital entry), i.e. irrespective of outcome as influenced by complications and especially death, although it usually is computed at discharge, when the final evaluation can be made. Some immediate consequences, such as hemorrhage, are included all the same. The AIS does not explicitly assess the combined effect of injuries in polytrauma. Baker's derived Injury Severity Score (ISS, 1974) nevertheless gives a very acceptable correlation with chances for survival.[8] It is calculated by summing up the squares of the highest AIS score from the three body regions hit most severely. The Maximum AIS ("MAIS") score attained in a body region is not linearly related to mortality, but it is quite useful in the evaluation of vehicle design modifications.

Disabilities and impairment, a different dimension, have not been yet coded for, but pertaining research in the fundamental area of combined consideration of subjective harm and loss of life expectancy, injury severity and societal cost, is underway in many countries.[9]

Changes and Improvements in the "1990 Revision"

Improving practicability. The accuracy improved further with the current "1990 Revision" as a result of nearly two decades of clinical and research application of the system. After inclusion of penetrating injuries, the full array of neuro-trauma and external injury diagnoses, after an increasing coincidence with current clinical language and research into the convertability into ICD-9CM and vice versa, the "1990 Revision" already centered on questions of practicability (as coding dilemmas, management of inadequate raw data information content, encoder assistance through synonyms and parenthetical descriptions in conjunction with improved encoder training). Suggestions from peers in Pediatric Surgery and Neurosurgery were incorporated, providing easy measurement estimation criteria for severity coding decisions.

The AIS 90 used a 6-digit injury coding instead of the 5-digit system of its predecessor (AIS 85) to allow for major flexibility:

Structure of the Numerical Injury Identifier:
AIS 90 (and Simplified AIS 90 :H):

A	B	CD	EF	·	G	-	H
Body region	Type of anatomical structure	Specific anatomical structure	Level/ Lesion		AIS score		Side

The now seventh digit holds the key element: the AIS-severity score, separated by a full stop dot. The Simplified AIS 90 code (anticipating its description) is fully compatible through letters A-C, and nearly compatible beyond. Because of the particular spatial interest in motor vehicle accidentology, an eight code was added (see below).

Changes in the "Simplified AIS 90"

The philosophy and method of the Simplified AIS 90. In accidentological research, and especially in retrospective studies using clinical reports, scarce perceptibility of actual injury patterns is a common problem. Also the extent of injury is often not well defined. Furthermore in common large sample studies even well-trained teams are vexed by the excessive work load caused by the 1300 entries of the AIS 90.

Therefore the present simplified version embracing 250 entries for practical use has been developed. The following **rules** were established and features aspired to:

- Coding should not require specialized medical knowledge.
- Correlations with a) non-survival and b) overall-accident analysis should not be impaired.

---

[7] Civil, J.D., Kauder, D.R., Schwab C.W.; Use of a single page scaling chart (CAIS-85) in clinical practice. 31st AAAM Conference, Proceedings: 109-132, New Orleans, LA (1978).

[8] Bull, J.P., The Injury Severity Score of road traffic casualties in relation to mortality, time of death, hospital treatment time and disability; Acid Anal Prev 7:249-255 (1975).

[9] *U.S.A.*: Task group (AAAM) on the Injury Impairment Scale, c/o Thomas A. Gennarelli, MD c/o AAAM. *Europe*: EC-committee for Impairment and disability scaling c/o RDir.Dr.Krupp, Bundesanstalt für Strassenwesen, D 5060 Bergisch-Gladbach.

- Coding should allow for the successful use of not very detailed insurance reports and alike; discharge letters, operation reports etc. are missing as a rule.
- The reduced code is not meant for use in purely clinical research as in hospitals, requiring an elaborated medical documentation.

General features of Simplified AIS 90

- Preexisting strings don't change their meaning considerably, but rather are strings with less specified meaning used at the expense of the more detailed ones.
- Alternatively several codes of related injuries are condensed into neighboring codes, which have their meaning broadened by adding descriptive terms to their label. One of the retained strings is also labeled with the attribute: "NFS" (not further specified), to account for less specified injuries.
- Simplification of the coding process through the elimination of equivocalities and orientation through comments, where codes had been eliminated.
- Nevertheless, descriptive completeness is developed beyond AIS 90, despite the reduction of the number of codes by 4/5 down to 20%, by providing comments.
- Rare injuries, or injuries irrelevant to survival or accident analysis, were omitted.
- Only a dozen new strings were introduced. They are marked by a §-paragraph.

Specific Changes Simplifying the AIS 90

- In discordance with the AIS-90 cervical and dorsal **vertebral** injuries (fractures, luxations) are coded *separately* from injuries to the cervical, dorsal and lumbar **cord**. AIS-90 is somewhat cumbersome in separating a) injuries to the **myelin** with and without fractures of the spine from b) fractures of the spine **without** injury to the **myelin**.
- A right-left side localizing eighth digit (*Side*), separated by a horizontal line from the AIS-value, is added as new feature of the code, with five possible values: Left = 1. Right= 2. Left&Right= 3. Midline, medial= 4. Unknown=9.

Using the AIS-Dictionary

The AIS-codes corresponding to the different injuries can be looked up under the nine headings: Head (Brain and Skull), Face, Neck, Thorax, Abdomen & Pelvic Contents, Spine, Upper Extremity, Lower Extremity & Pelvic Girdle and External, Burns & Other.

Watch out: the division according to body regions as used for the computation of the ISS is not identical to the above. For example, the scores in AIS spine section are divided among three ISS body areas:[10] the cervical part goes to ISS Head or Neck, the thoracic to ISS Chest, and the lumbar to ISS Abdominal and Pelvic Contents.

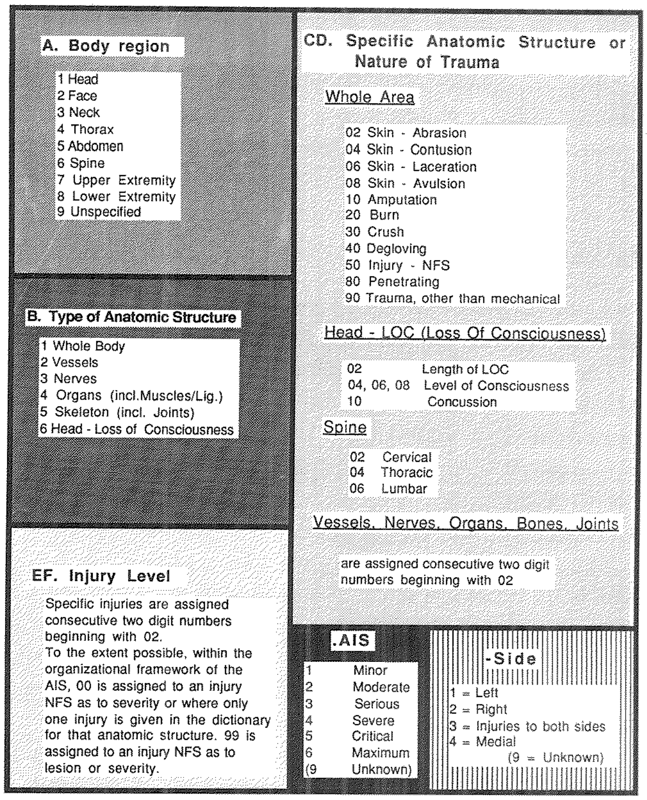


Figure 1. SAIS 90-Coding Scheme with Basic Significance of Values

The injuries, where feasible, have been listed in the numerical order of the code, i.e. generally in the alphabetical order of the anatomical groups and according to increasing severity. Within the extremities sections though a centrifugal order is chosen. Vessel injuries finally are coded in an order of decreasing size.

Rules for Assessment

a) General rules

1. "Questionable" or "probable" etc. findings are not considered to be of sufficient certainty and are therefore discarded.
2. Foreign bodies causing injuries are not coded for (but there is a special new code for impalement injuries under the 'Abdominal/Pelvic space' path).
3. Consequences of injuries (e.g. blindness) have not been coded for, as codes refer to injuries themselves (e.g. enucleation of eye); except for certain immediate consequences as pneumothorax or hemorrhage or lethal respiratory constriction, specified in the dictionary.

---

[10] The term "area" is used in this paper for the ISS-body region; the term "region" being reserved to the AIS context.

4. The kind of treatment should not influence the evaluation of the injury level (severity).
5. AIS 6 may only be used for injuries explicitly marked AIS 6. Death doesn't signify AIS 6 nor vice versa. (The pre-AIS 90 term "AIS 6+" for occurred death has been abolished).
6. *Bilateral* injuries to *paired* structures are coded separately (e.g. kidneys, eyes etc.) whenever there is a difference in severity or kind. Where there is an identity of injury in paired structures just one code is used with the "*3*=right & left"-value at the 8th digit "Side." Furthermore some injuries to a paired organ already are explicitly mentioned as such, and then again must be coded as *one injury* (e.g. lung injuries to both sides) even if the lesion is not perfectly identical on both sides. *Identical* bilateral injuries to a structure in the simplified version should be condensed in one code by using the "*3*=right & left"-value at the 8th digit "Side", separated by the horizontal mark: e.g., bilateral closed fractures of the radii gives: 752802.2-*3*, while plain fracture of the radius, right plus complete fracture of forearm, left obviously would give both 752802.2-*2* and 752808.3-*1*(§) (§=the paragraph just transiently symbolizing the newly added code). Several injuries to non-paired but *symmetric* structures—as to facial bones, the pelvis (e.g. the maxillary LeFort-fractures I & II or III)—on the other hand still are equally considered as *single* injuries, but as to their side-feature are now also generally coded as 4=midline-lesions, e.g. 250800.2-*4* or 25808.3-*4*, unless there isn't a clear laterality of the injury.
7. Open fractures (i.e. with an opening of the skin in continuity with the fracture) don't require a separate coding of the wound which is implicit, i.e. of cuts in continuity with the fractured bone, and no laceration code is therefore activated (see below under b) Special etc.).
8. If certain injuries are not clearly stated or hardly defined, as for example, when the exact nature of a blunt abdominal injury,NFS is not known, a code with a 99—value for the Level / Lesion (EF)-digits (in front of the full stop dot) has to be used. If not even the severity is known, these codes carry the value 9 after the full stop (AIS-score 9), signifying that no overall severity information on the patient's injuries becomes available. Every effort should therefore be made, by scrutinizing the raw data and looking for suitable codes, in order to avoid this imponderability, as such lack of information becomes particularly bothering when considering e.g. MAIS-distributions among occupant sub-populations.
9. Where the severity level of an injury is in doubt, the lower score is chosen: Code conservatively!

b) Special rules regarding superficial injuries

Codes from the "External" section, given their compilatory nature, may only be used where there are **multiple skin injuries distributed over more than 2 body regions** or where there are **no details of location** available, but **multiple** (overall, ubiquitous) skin injuries are mentioned. Single descriptions of AIS1 skin injuries (not burns) of unknown location are ignored.

"Contusion" in the context of the **"External"** category, covering **integumental** injuries, means non-abrasive "bruise"[11] or contusion of skin, subcutaneous tissue and superficial layers of muscles. The diagnosis may be made from an attributable tenderness alone (not due to a remote nerve irritation).

A more severe **true contusion** referred to lesions including presumed or proven damage to underlying joints and muscles, but not to a degree allowing the notion of a "crush" injury to be applied, are to be coded under **contusion of the closest joint** or under the former **muscle laceration** code of their body region expanded in its meaning to include such severe contusions.

Thoracic true contusions, not "bruises," are coded either as **rib cage** or as **sternal** contusions. "True" contusions contribute to the ISS through the body area of their location.

Calculating the Injury Severity Score ISS

a) General rules

The ISS is the sum of the squares of the highest AIS values in each of the three worst injured **ISS-body areas,** which unfortunately **differ from the body regions used in AIS**:

The six body areas used in the ISS and the AIS-body regions are:

- Head and Neck (including 1-HEAD (AIS), 3-NECK (AIS) and 6-SPINE/Cervical Spine (AIS))
- Face (including 2-FACE (AIS))
- Thorax (including 4-THORAX (AIS) and 6-SPINE / Thoracic Spine (AIS))
- Abdomen and Pelvic contents (including 5-ABDOMEN & Pelvic contents (AIS) and 6-SPINE / Lumbar Spine (AIS)).
- Extremities and Pelvic girdle (including 7-UPPER and 8-LOWER EXTREMITY & Pelvic girdle)
- External including 9-External, Burns, Other (AIS)).

---

[11] **Bruise** = **1a** an injury involving rupture of small blood vessels and discoloration without a break in the overlying skin: CONTUSION (..) **2**: ABRASION, SCRATCH (..). **abrade** = to rub or wear away especially by friction; **abrasion** = (..) **2** an abraded area of skin or mucous membrane. Webster's New Collegiate Dictionary, Springfield, MA (1979), p. 141, p. 4.

Example:

ISS- Body region	Injury	AIS-Code	Highest AIS	AIS^2
Head/Neck	Cerebral contusion left	140606.3-1	3	9
	Transection carotid artery right with ensuing brain damage	320228.5-2	5	25
Face	Ear laceration, right	210600.1-2	1	
Thorax	Rib fractures, left side, ribs 3-4	450420.2-1	2	
Abdomen	Spleen / superf. laceration	544224.3-1	3	9
Extremities	Fracture of femur, left	851800.3-1	3	
External	Overall abrasions	910200.1-3	1	
			ISS = 43	

ISS-scores range from 1 to 75, whereby it may assume 44 different values.The Maximum value ISS=75 by definition results from either **three AIS 5** injuries, or from **at least one AIS 6** injury. Again: In surviving patients (without any AIS-6 value), **no** ISS-score can be calculated if there is an injury of absolutely unknown severity (coded AIS 9).

b) Special rules regarding superficial injuries

Since external injuries (Skin, Penetrating injuries) graded AIS1 or 2 are no longer assembled under the body region heading External, as they used to be in the AIS 85 system, unless they are of a multiple nature (see above), but instead are distributed according to their location, the procedure to follow has changed with AIS 90:

In terms of the ISS-computation **integumental** injuries **outside** the "External" category, **if they are marked with an Asterisk** (*) in the dictionary (i.e. if for instance they don't cause a blood volume loss beyond 20%), contribute to the ISS by their AIS-severity scores (7th digit) according to the following rules:

1. If the asterisked (*) injury **is the only injury in the Body region**, locate it under "That Body region," but assign its score to the ISS-Body Area "External";
2. If the asterisked (*) injury **accompanies** (i.e. not overlying but still located in the **same spatial third**, midline, left, right as) **an injury to a deeper structure** (i.e. with a larger or equal AIS severity score), do code the integumental injury but *don't* assign its score to the ISS-Body Area "External" and let the deeper injury contribute to ISS alone instead. A superficial injury *not* in the *same spatial third*, midline, left, right therefore *is counted* independently for ISS (unless it is not swallowed by the multiple category in the External section). This rule is a new feature of the Simplified AIS 90. It is an extension of the retained rule No.3 to abrasions and bruises and an extension of its concept.
3. If the accompanied injury is an **Open Fracture**, the external injury "**overlying**" it in continuity with the fractured bone (by necessity a cut), is implicit in the code for the open fracture and **not coded** for separately *neither for AIS nor for ISS.* An injury that is *not "overlying"* the open fracture (and which therefore might not be a cut (laceration)) on the other hand is treated according to No. 2.
4. Abrasion or contusions *overlying* a fracture, for obvious reasons are not coded for in SAIS and not used for ISS. Severe contusions in proximity of a fracture comply with the Crush-injury criteria.

Abbreviations and Recurring Sentences Used in the Dictionary:

NFS = not further specified.

§ = new and supplementary Code (not contained in the full version AIS 90).

* (Asterisk) = this code contributes to the computation of ISS by its AIS-severity score (7th digit) according to the special rules for superficial injuries (see previous par.).

add, if appropriate: introduces suggestions for a supplemental coding of certain concomitant injuries or certain potential severe traits of an injury. It is implied, that where no suggestion is made, one code should suffice.

see or **code as**: precedes the path or address of the surviving label or heading, were the present discarded one has been integrated. The codes suggested are given either: in the form of a data bank tree path (e.g.: Thorax / heart / cardiac valves injury 441402.3), or: / heart / cardiac valves injury 441402.3 (when the reference is located already in the section beneath the Thorax heading), or: / / cardiac valves injury 441402.3 (when the path is a repetition of another one just mentioned), or: just as the code given in parentheses (e.g.: see Liver (541828.5)).

Italics and Other Fonts Used in the Dictionary

In this first public draft version of the Simplified AIS 90 manual ***Italics*** have been used to highlight new additions to the labels. Added reference of the "add, if appropriate" or "see/code as" type are all newly introduced, and therefore not set in italics.

Nonmedical, plain English terms have been added in parentheses or vice versa according to use in current language.

Elencations of anatomical substructures (as names of arteries e.g.) have been set in a smaller font size.

The "Simplified AIS 90 dictionary of regional schemes" is presented at the end of this paper.

Preliminary Validation on 50 Motor Vehicle Trauma Case Files

The purpose of this preliminary study comparing the simplified and the full version of AIS 90, was to attempt a raw estimate of the trade-off in terms of information loss and the differences between the two scales computing the ISS injury severity score. Options to counter this loss of information are briefly referred to.

Furthermore an in-depth analysis of the errors committed furnished insight into a possible methodology investigating fallacies while working with either scale. Questions of acceptance, also amongst non-medical users, are addressed besides interrater reliability.[12]

As a result of this test, and the advice from E. Petrucelli and others, the Simplified AIS 90 underwent a further in-depth review with the intent to overcome equivocalities and to facilitate coding decisions especially for non-medically trained users, and to highlight areas for further debate.

Materials and Methods

Two test persons with medical degrees were given fifty identical case file sets of data related to injuries of motor vehicle accident victims. Test person A is an expert in the field of road traffic accident data analysis who has been using mainly the AIS 80 for several years. Test person B comes from a background of several years in trauma surgery, but has no previous coding experience with AIS.

The sets used were the first 50 sets of raw personal injury data (mainly medical insurance reports) from inter-passenger frontal car collision files, which belong to the "Motor Vehicle Safety 90" file collection mentioned in Part I, satisfying 2 criteria: at least one of the two drivers had been killed and at least one of the drivers had been wearing a safety belt.

Both test persons worked through the coding procedures without double-checking systematically, i.e. in one go, without correcting the results immediately themselves, and without excessive motivation to avoid mistakes, as the investigation of potential errors was one of the purposes of the study.

After completion the two sets of data underwent a systematic error analysis procedure looking for errors of omission, invention, distortion, orthography, over- and underrating of "contusions," redundancy and lack of precision, both by inventing and omitting information. The error retrieval procedure was made as severe as possible, while the criteria for the "correct answers" were by necessity often debatable. Next, the effect on the distribution of Maximum AIS-severity scores and errors in computing the Injury Severity Score were analyzed, and the overall influence of errors expressed in the "mean" ISS-deviation from the "true" score.

Finally the distributions of the Maximum AIS-severity scores and ISS-scores were compared between the two scales on the grounds of the "corrected" results.

Results and Discussion

Besides one autopsy case with cranio-cervical dislocation. only non-lethal injuries were coded. There was a clear preponderance of cervical and thoracic injuries. Among the more severe injuries there was a Chance-fracture with concomitant duodenal and hepatic injury.

Coding error analysis. Error analysis disclosed an overall per case "error" rate of 1.3 for test person A and of 1.5 for test person B respectively.

Test results:
No. of casualties = 50. Each letter signifies one error. "**a**" stands for error implementing AIS 90, "**b**" for error committed on both scales, "**s**" for error using "SAIS 90" only.

Test person:	Coder A	Coder B
Codes...		
Missing:		
1. External	bbbbb bbb	aa bbbbb bbbbb bbbb ss
2. Other	aa bbbbb ss	aa bbbbb
Invented:		
2. Other - Injuries coded, but not figuring in the raw data:		bb
Erroneous Injury:		
1. External	0	a bb
2. Other	aa bbbbb bbb	bbbb s
Orthography:	a	aaa b ss
"Contusions":		
1. Overrated	bbbbb b	aaa bb
2. Comprehension by other code	bbbbb	aa b ss
Unprecise:		
1. Wasting information:	a aaaaa bbbbb ss	aaaaa bbb ssss
2. Inventing information:	a b	a s

As can be seen from the above there was a rather even frequency of errors of "wasting information" (15,5% mean) or "overrating contusions" (7,5%); (see remarks on contusion in the Rules for external assessment in the Manual's introduction), and a barely noticeable tendency to code slightly more than one knew (3%). Encoder B though made a 3% of "frank invention" errors.

Encoder A was leading in errors coding non-external injuries erroneously (15%), or not at all (14%), but was only half as bad in omitting external injuries. 14% of errors were made, giving codes which seemed redundant because implied by severer injuries already coded for (e.g. thoracic contusion on top of fractured sternum).

Encoder B had not much consideration for external injuries, committing 24% of his errors by omission and 11% by underrating contusions. Spelling and legibility caused 8% of his errors, a fourfold of his colleagues rate. Still he also caused 7% of his errors by not correctly coding injuries to correctly identified non-external structures, and 9% by forgetting some altogether.

Encoder B was not much advantaged by the simplified version, scoring 20% one-scale errors instead of 26% in the full version, which he used first. Encoder A made three of four errors in both versions, which he used concomitantly. Obviously the "wasting information" error was not easily achieved using the simplified version, but still with a 1-to-3 ratio in Encoder A, and a 4-to-5 ratio in Encoder B.

---

[12] Gibson, G.: "Indices of severity for medical evaluation studies: reliability, validity and data requirements," Annual meeting of the American College of Emergency Physicians, New Orleans, LA (Oct 1976).

Influence of errors on MAIS- and ISS-distribution. First, the MAIS-table of frequencies is shown:

MAIS-distribution

		AIS 90			SAIS 90	
	Coder A	"True"	Coder B	Coder A	"True"	Coder B
MAIS 1	18	18	18	14	11	17
MAIS 2	19	19	21	23	27	24
MAIS 3	6	9	8	9	8	5
MAIS 4	6	2	1	3	3	4
MAIS 5	-	1	1	-	-	-
MAIS 6	1	1	1	1	1	1

Next the same table is shown, with added relative differences of each rater's results from the "True" values. The difference of the SAIS 90 "True" values from the AIS 90 "True" level are set in italics:

MAIS-distribution: levels from "True" columns (put=zero) shown.
"True" SAIS 90 is shown with an added level from "True" AIS 90.

			AIS 90						SAIS 90			
	Coder A		"True"		Coder B		Coder A		"True"		Coder B	
MAIS 1	18	*0*	18	*0*	18	*0*	14	*+3*	11	*-7*	17	*+6*
MAIS 2	19	*0*	19	*0*	21	*+2*	23	*-4*	27	*+8*	24	*-3*
MAIS 3	6	*-3*	9	*0*	8	*-1*	9	*+1*	8	*-1*	5	*-3*
MAIS 4	6	*+4*	2	*0*	1	*-3*	3	*0*	3	*+1*	4	*+1*
MAIS 5	-	*-1*	1	*0*	1	*0*	-	*0*	-	*-1*	-	*0*
MAIS 6	1	*0*	1	*0*	1	*0*	1	*0*	1	*0*	1	*0*

An extract of the previous table shows the two scales compared:

MAIS-distribution: extract from previous table.
"True" SAIS 90 is shown with an added level from "True" AIS 90.

	AIS 90		SAIS 90	
	"True"		"True"	
MAIS 1	18	*0*	11	*-7*
MAIS 2	19	*0*	27	*+8*
MAIS 3	9	*0*	8	*-1*
MAIS 4	2	*0*	3	*+1*
MAIS 5	1	*0*	-	*-1*
MAIS 6	1	*0*	1	*0*

Differences in scoring-frequencies beyond a range of plus or minus one (±2% of values) are found only as a shift from AIS1 to AIS2, which is nearly entirely due to the newly introduced subdivision of neck injuries with the consecutive upgrading of certain (in this sample 6) injuries to AIS 2. This had a marked influence on the lower tail of this sample's distribution, due to a preponderance of 12 neck injuries (24% of cases). The arguments for this important subdivision still remain valid though, and a skewness at the lowest ratings seems negligible.

The effects of errors on the final ISS-scores are shown in an abridged manner, where stepwise approximations of the "True" ISS are shown in the condensed form of an otherwise only ordinally meaningful "mean" ISS:

"Mean" ISS scores of encoder's results
(with no other than ordinal error quantification meaning)

	AIS 90	SAIS 90
ISS-scores: raw	8.4/9.3	8.7/8.8 (9.6)*
after correction...:		
of ISS-computation:	8.7/9.3	8.6/(9.4)*
of AIS-evaluation: (i.e. "True score")	9.0	9.1 (9.3)*

*without cases computing ISS despite AIS-9 score (put=0)
Main error sources:
1) Computing ISS despite AIS-9 score (put=0). 2) Computing AIS 90-ISS without rules supplementary to AIS 80. 3) Mistakes integrating AIS body (sub) regions into ISS-body areas.

It is apparent from the above, that this rather crude overall parameter seems to be robust versus a change from AIS 90 to SAIS 90.

Conclusions

The apparent small differences in severity outcome classifying the individual injury with a simplified scale which has its entries reduced to a fifth of the full version would seem to constitute an acceptable trade-off. Furthermore at least in this minimal preliminary study inter-rater differences have been far larger, as can be seen easily from the data. If this result should be confirmed by larger tests, and by using the reviewed public draft as found below, it becomes obvious, that efforts to improve accuracy should be oriented towards encoder training and didactic improvements in the dictionary and the pertaining presentation of rules. No forecast can yet be made as a result of this study.

If there should prove to be major distortions between the overall severity ratings between AIS and SAIS, one could opt for selective corrections of single codes at their seventh digit. The prerequisite for further efforts will obviously be the confirmation of improved handling characteristics of the simplified version. We will undertake appropriate tests in the near future.

Acknowledgments

This simplified AIS is being developed in collaboration with the Association for the Advancement of Automotive Medicine (AAAM) and its Committee on Injury Scaling. The authors acknowledge the contribution of Elaine Petrucelli in reviewing this draft and of Mr.G.Treviranus MD who was responsible as trauma consultant for the final review (and partial translation) of this paper and the manual contained in it. He also realized the preliminary validation of the SAIS together with Mr. W. Hell MD, accidentologist, who made valuable contributions to the manual as well. This project was supported by the following institutions:

- HUK-Verband (German Association of Motor Vehicle Insurers) who initiated the project, provided the basic financial support and organized the project's coordination and the meetings of the Consulting Group;
- the Swiss Federal Fund for Traffic Safety (FVS), Bern, which supported the work of the consulting group at the University of Zurich.

Simplified AIS 90 dictionary of regional schemes

Simplified AIS-90 **Version 1.0 - first public draft** - XIIIth ESV, Paris 1991

Localisation	Injury description	AIS-Code
Head (Brain, Skull)		
"**Closed head injury**", "traumatic brain injury", "craniocerebral trauma", NFS		115099.9
Scalp	Abrasion, contusion, hematoma, wound < 10 cm	110099.1*
	Wound > 10 cm and into subcutaneous tissue	110604.2*
	Wound causing *blood loss >20% of blood volume*	110806.3
Entire Head	Penetration through skull, > 2 cm into brain	116004.5
	Crushing injury of both skull and brain	113000.6
	"Decapitation" code as *vertebral dislocation 650204.2 and neuro-injury brainstem 140214.6 or cord laceration and bilateral severe carotid artery lesion 320228.6§ for lower level separation.*	
Cranial nerves	Contusion, laceration, posttraumatic palsy	130299.2
Brainstem (hypothalamus, medulla, midbrain, pons)	NFS, *Contusion, herniation,diff. axonal injury, hemorrhage*	140299.5
	Massive destruction, crush.	140214.6
Cerebellum (infratentorial,posterior fossa)	Contusion, diffuse axonal injury, *NFS*	140402.3
	Hematoma epidural (extradural), subdural, intracerebellar hematoma or *infarction 2ndary to extracranial vessel injury*	140410.4
Cerebrum, "Brain"	*small superficial wound or contusion or infarction of size=<4cm(2cm<10yrs), 2nd deg. craniocerebral trauma - NFS, gross edema in children*	140606.3
	Hematoma (subdural or epidural =<1cm) *3rd deg. craniocerebral trauma - NFS* *Cerebral wound or contusion*	140630.4
	Hematoma (subdural or epidural >1cm)	140636.5
	Intracerebral hematoma, large, *NFS*	140648.5
Skull, cranium	"Skull fracture", NFS	150000.2
	Basal skull fracture (incl. orbital roof and ethmoid, sphenoid bones and foraminal portion of occipital and petrous, squamous and mastoid portion of temporal bones) *Diagnosis on clinical grounds suffices*	150200.3
	Fracture of cranial vault: closed	150400.2
	Fracture of cranial vault: compound, open, depressed > 2cm, comminuted	150404.3
Level of Consciousness		
Awake on admission	headache or dizziness as a result of head trauma, no amnesia	160402.1
Unconsciousness	<1 hour	160202.2
	" , with neurological deficit	160204.3
	1-6 hours	160206.3
	" , with neurological deficit	160208.4
	6-24	160210.4
	" , with neurological deficit	160212.5
	> 24 hours	160214.5
Concussion	Commotio cerebri, *1st deg. craniocerebral trauma (anterograde amnesia as a result of head trauma)*	161000.2
Face		
Skin (incl.eyelid, external ear, lips	Scratch, bruise/contusion, hematoma, wound < 10 cm	210099.1*
	Wound > 10 cm *reaching into subcutaneous tissue* *Severe laceration or contusion to face, parotid gland injury*	210604.2*
	As above with blood loss >20% of blood volume	210606.3
Ear	NFS, outer or inner ear injury	240299.1

Localisation	**Injury description**	**AIS-Code**
Mouth	NFS, *soft tissue injury to tongue or to gingiva or salivary glands (except parotis, see 210604.2)*	243299.1
Eye (without lids)	superficial injury, *(not beyond the lens)*, NFS	240499.1
	Injury *beneath the lens*, rupture, enucleation loss of organ, *(not "blindness")*	240402.2
Mandible (lower jaw)	Fracture, closed	250602.1
	Fracture open, comminuted or displaced *(>2cm)* *Fracture of lower jaw alveolar process*	250610.2
	Dislocation, *sprain (temporomandibular joint)*	251699.1
Maxilla (upper jaw)	Fracture, closed *fracture of upper jaw alveolar process*	250800.2
	Fracture, comminuted or open or separation of upper base from skull (LeFort III)	250808.3
	Fracture with bleeding (maxillary art.)> 20% blood volume	250810.4
Nose	Contusion, fracture add, if appropriate: Skin/ wound >10cm or Skin/ blood loss > 20%	251099.1
Orbita (eye socket):	Fracture of roof or comminuted code as	
	Brain, Sull/ basal skull fracture	150200.3
	Fracture of remaining parts, non-comminuted	251200.2
Zygoma (cheek bone)	Fracture	251800.2
Ethmoid	(code as basal skull fracture)	
Teeth	loosened, dislocated	251499.1
Neck (only soft tissues, excluding cervical spine)		
Entire neck	"Decapitation" *code as vertebral dislocation 650204.2 and neuro-injury brainstem 140214.6 or cord laceration and bilateral severe carotid artery lesion 320228.6§ for lower level separation.*	
Skin	Abrasion, bruise/contusion, hematoma, wound < 20 cm	310099.1
	Wound > 20 cm *reaching into subcutaneous tissue*	310604.2
Carotid artery	Partial (intimal) tear, perforation, NFS	320299.3
(Common, internal)	Complete laceration with severe bleeding	320212.4
	Tear, thrombosis with ensuing brain damage	320214.5
	Bilateral severe carotid artery lesion with ensuing brain death	320228.6§
Other major **neck vessels**	Carotis externa, jugularis, vertebralis: any injury	322099.2§
Larynx	Contusion	340299.2
Thyroid and cricoid cartilage *(Adam's apple) thyroid, hyoid*	Perforation, rupture, crush	340208.3
Pharynx	Contusion	340699.3
(Upper throat)	Perforation, rupture, crush	340608.4
Thyroid gland	NFS see injury to larynx	
Salivary glands (Parotid, submandibular, sublingual)	*for parotid or NFS see severe cut or contusion of face* (210604.2) *for the remaining glands see injury to mouth* (243299.1).	
Thorax		
Entire thorax	Blunt trauma NFS	415099.9
	Open "sucking" chest wound	415000.4
	Bilateral crush with severe lung injuries or *constriction*	413000.6
	Paralytic or external constrictive respiratory arrest	*414000.6§*
Skin	Abrasion, bruise/contusion, hematoma, wound < 20 cm	410099.1*
	Wound > 20 cm reaching into subcutaneous tissue	410604.2*
	Avulsion, *wound >20cm, blood loss >20% of blood vol., female breast laceration*	410806.3
Breast, female	avulsion code as previous item	

Localisation	Injury description	AIS-Code
Thoracic aorta	Perforation, small contained tear, *NFS*	420208.4
	Tear, large, contained, large surrounding hematoma, *hemomediastinum*	420216.5
	Complete laceration with esanguination (lethal bleeding)	420218.6
	add, if appropriate	
	Thorax / heart / cardiac valves (heart valve) injury 441402.3	
	or: Spine/ thoracic cord /contusion / permanent paraplegia , complete cord syndrome 640420.5	
	or: Spine / thoracic cord / contusion / permanent (transient) paraparesis, incomplete cord syndrome 640410.4 (640400.3)	
Other named vessels (esophageal, intercostal int. thoracic /"mammary" arteria and vein; azygos, cardiac, hemiazygos vein)	Perforation, minor tear, NFS	
	code as:	
	/Pleural cavity/ Hemothorax with <20% volume blood loss	442208.3
	Laceration with severe bleeding :	
	code as:	
	/Pleural cavity/ Hemothorax with >20% volume blood loss	442208.4
Mediastinum	Hemomediastinum	
	code as:	
	/Thoracic aorta contained aortic tear	420216.5
Large airways (bronchus) (for main stem bronchus see trachea)	Laceration, perforation, NFS	440208.3
	Avulsion, detachment, transection, tearing-off	440216.4
Diaphragm	Laceration, rupture	440604.3
	for bowel / liver herniation into thoracic cavity	
	add, if appropriate: Hemo-/pneumothorax code (442202.3)	
	for moderate cases , while for large bowel / liver herniation add	
	Tension pneumothorax code (442210.5)	
Esophagus	Transection , laceration, NFS	440808.4
Heart	Contusion	441002.3
	Tear	441012.5
	Rupture, multiple perforations	441016.6
-Pericardium	Tamponade without heart injury, *herniation of heart*	441606.5
	(ignore minor pericardial injuries)	
Cardiac valves (heart valves)	Laceration	441200.5
Central arterio-venous fistula	*e.g. ventricular or atrial septum perforation*	441300.5
	(also aorto-pulmonary fistula, sinus Valsalva-perforation)	
Lung	Contusion, superficial tear (only if documented)	441402.3
	(Documentation: radiological, surgical, pathological; pulmonary dysfunction is insufficient evidence)	
(Add rib fractures if appropriate: but not hemo- or pneumothorax)	Laceration, NFS	441414.3
	Bilateral laceration	441450.4
	Bilateral laceration with pneumothorax or massive air leak	441458.5
Thoracic cavity	Massive internal or external bleeding >20% blood volume	442208.4
- Pleural cavity	Hemothorax, pneumothorax	442202.3
	Tension pneumothorax	442210.5
	blood loss > 20% blood volume	442208.4
Trachea	Tear	442604.3
	Complete laceration, separation from larynx	442610.5
Rib cage	Contusion of rib cage *with intercostal damage*	450202.1
	Fracture NFS or not more than one rib fractured	450210.1
	Fracture of 2 -3 ribs	450220.2
	Fracture of> 3 Ribs, but with stable Thorax	450230.3
	Unilateral, flail (unstable) chest wall, *paradox breathing*	450260.4
	Bilateral "	450266.5
	Flail chest <15 years	450268.5
Sternum (breastbone)	Contusion	450802.1
	Fracture	450804.2

Localisation	**Injury description**	**AIS-Code**
Abdomen and Pelvic Contents		
Diaphragm	Laceration, rupture	440604.3
	for bowel / liver herniation into thoracic cavity	
	add, if appropriate: Hemo-/pneumothorax code (442202.3)	
	for moderate cases , while for large bowel / liver herniation add :	
	Tension pneumothorax code (442210.5)	
Abdomen	"Blunt abdominal injury"	515099.9
	severe "blunt abdominal injury"- NFS	515099.3§
Bleeding, intra-abdominal or retroperitoneal	Scant hemorrhage	
	see /Abdominal wall etc./contusion 540010.2	
	Moderate to severe =<20% blood volume	521499.3
	Very severe >20% blood volume	521408.4
	Esanguination	
	see /Abdominal aorta/complete laceration 520208.5	
Skin	Abrasion, bruise/contusion, hematoma, wound < 20 cm	510099.1*
	Wound > 20 cm *reaching into subcutaneous tissue*	510604.2*
Abdominal wall *and confining organ surfaces*	*Contusion of Abdominal wall resulting in contusion of abdominal organs as omentum, bowel slings, liver, kidney (not resulting in obstruction, more than scant hemorrhage, perforation or operative intervention); clinical,or diagnosis from imaging or autopsy.*	540010.2§
	Penetration *or severe contusion (run-over injury) with wall tissue loss of more than palm size or bleeding > 20% blood volume*	516006.3
VESSELS		
Abdominal aorta	Laceration	520204.4
and common Iliac artery	Complete laceration with esanguination	520208.5
(main trunk artery and bifurcation branches)		
Artery , other major	Laceration or bleeding NFS (>20% blood volume)	521408.4
(Hepatic, external or internal iliac, superior mesenteric, renal, splenic arteries)		
Artery, other named	Laceration with bleeding NFS (=<20% blood volume)	521406.4
(celiac, colic, gastric, gastrocolic, gastroduodenal, gastro-epiploic, ileocolic, inferior mesenteric, pancreatic, pancreatico-duodenal, rectal arteries)		
Vena cava,		
- inferior	Major laceration with very severe bleeding	521006.4
- superior (retrohepatic).	see Liver (541828.5)	
Large vein	Laceration with manifest bleeding , NFS	521699.3
(Hepatic, celiac, colic, gastric, gastro-epiploic, gastroduodenal, gastrocolic, ileocolic, mesenteric, iliac, pancreatic, pancreatico-duodenal, portal, rectal, renal, splenic veins)		
ORGANS		
Adrenal gland	see /Kidney	
Anus	see /Perineum	
Bladder *and lower half of ureter*	Laceration, NFS	540620.2
Colon (large bowel)	Perforation	540824.3
	Rupture with gross fecal contamination	540824.4
Duodenum	Contusion, *with obstruction, anterior perforation, NFS*	541012.3
(1st part of small intestine)	Laceration, *massive and / or fecal contamination or trauma extending to retroperitoneum or pancreas*	541028.5
Esophagus	see Thorax / Esophagus	
Gallbladder, Biliary system	Contusion, contained laceration (e.g. cystic duct), NFS	541210.2
(common and main bile duct)	Massive laceration of gallbladder and/or major extrahepatic bile ducts	541226.4
Jejunum, Ileum	Contusion, small laceration, NFS	541420.2
(Small bowel)	Perforation, *obstruction after contusion* or	541424.3
and Mesentery	add , if severe mesenterial vessel injury present:	
	/Bleeding, intraabdominal / very severe 521499.3	

Localisation	Injury description	AIS-Code
Pelvis (sacrum, ilium, ischium, pubis, acetabulum)	see LOWER EXTREMITY / pelvis	
Lumbar Spine	see under SPINE / lumbar spine	
Rib cage	see under THORAX / rib cage	
SPINE / Cervical spine		
Entire Cervical Spine	Neck injury (without fracture or luxation))i.e.: cervical or related pain, muscular stiffness, dizziness, fatigue, depression, autonomic disturbances, "whiplash", NFS.	640278.1
	" , severe, lasting for more than three weeks	640280.2§
"Decapitation"	code as: *vertebral dislocation 650204.2 and neuro-injury brainstem 140214.6 or cord laceration and bilateral severe carotid artery lesion 320228.6§ for lower level separation.*	
Cervical cord (Myelon)	Contusion NFS, including reversible quadriplegia	640200.3
(some useful sensation or motor function left)	Laceration (*or any injury*) causing permanent - - (but incomplete) quadriparesis, - incomplete cord syndrome - (*Lateral (Brown-Séquard), anterior, central cord syndrome)* NFS as for location	640242.5
	Laceration (*or any injury*) causing permanent ... :	
(no sensation, no motor function)	Quadriplegia , NFS	640260.5
(no sensation, no motor function)	Quadriplegia C4 or below	640261.5
(no sensation, no motor function)	Quadriplegia C3 or above *(including patients saved by resuscitation)*	640280.5§
	add , if appropriate: Paralytic or external constrictive lethal respiratory arrest	414000.6§
Vertebra / *Disc*	Dislocation, subluxation (predominant soft-tissue injury, no fracture except small flake)	650204.2
	Fracture	650216.2
	(Discordant to AIS-90 fracture and dislocation-codes should be added to codes for eventual cervical cord lesions)	
Nerves	Injury, lesion, postraumatic paresis, NFS (Roots, trunks/divisions/cords (brachial plexus)	630299.2
SPINE / Thoracic Spine		
Entire Thoracic spine	Sprain pain, muscular splinting (without fracture/dislocation)	640478.1
	" , severe, lasting for more than *6 weeks*	640480.2§
Thoracic cord	Contusion NFS, including transient paraplegia	640400.3
(Myelon)	Contusion - with permanent paraparesis, incomplete cord syndrome (Lateral (Brown-Séquard), anterior cord syndrome)	640410.4
	Paraplegia, complete cord syndrome (nor sensation nor motor function)	640420.5 (continued)
	Conus medullaris lesion see Lumbar spine / lumbar cord / cauda equina syndrome	630600.3
Vertebra / Disc	Dislocation, subluxation (predominant soft-tissue injury, no fracture except small flake)	650404.2
	Fracture	650416.2
	(Discordant to AIS-90 fracture and dislocation-codes should be added to codes for eventual cervical cord lesions).	
Nerves	Injury, lesion, paresis (Roots, trunks/divisions/cords (brachial plexus)	630499.2
SPINE / Lumbar Spine		
Entire Lumbar spine	Distorsion with pain, muscular splinting (without fracture/dislocation), Sprain, Disc injury	640678.1
	" , severe, lasting for more than *6 weeks*	640680.2§
Lumbar cord	Contusion, even incl. transient paraplegia	640600.3
and Cauda	Contusion - with permanent paraparesis	640610.4
	Paraplegia (nor sensation nor motor function)	640620.5
	Cauda equina syndrome or *conus medullaris lesion*	630600.3

Localisation	Injury description	AIS-Code
Vertebra / Disc	Dislocation, subluxation	650604.2
	(predominant soft-tissue injury, no fracture except small flake)	
	Fracture (e.g. Chance-fracture)	650616.2
	(Discordant to AIS-90 fracture and dislocation-codes should be added to codes for eventual cervical cord lesions)	
Nerves	Injury, lesion, paresis	630699.2
	(Roots, trunks/divisions/cords (brachial plexus))	
Arms (Upper extremity)		
Skin	Abrasion, bruise/contusion, hematoma, wound < 10 cm	710099.1*
	Wound > 10 cm reaching into subcutaneous tissue	710604.2*
	Degloving injury to arm or forearm § or major avulsion	714002.2
	For degloving injuries to fingers code 752406.2	
	For degloving injuries to wrist code 710604.2*	
	Major avulsion with blood loss > 20% blood volume	
	code as: 714002.2 and arterial laceration 721008.3	
Entire Arm	Amputation	711000.3
	Crush (severe soft tissue / muscle destruction)	713000.3
	A rterial laceration with severe bleeding	721008.3
	Venous laceration with severe bleeding	720206.2
	code as: Axillary vein laceration	(continued)
	Nerve lesion (median, radial, ulnar Nn.)	730420.1
	Muscle laceration, avulsion *severe contusion*	740400.2
Clavicle	Fracture	752200.2
Shoulder	Contusion *of rotator cuff* and joint	751010.1
	Dislocation	751030.2
	Laceration into joint *code as crush 751050.3*	
	Crush (massive destruction	751050.3
	of *soft tissues*) or laceration into joint	
	for fracture head of humerus add 752602.2	
	for fracture scapula add 753000.2	
Scapula	Fracture	753000.2
"Arm-, Hand-, Lower Arm"	Fracture, NFS	751800.2
Humerus	Fracture, closed	752602.2
(Upper arm)	Fracture open, comminuted	752604.3
Ellbow	Contusion	750610.1
(Olecranon)	Dislocation	750630.1
	Laceration into joint, *open dislocation*	750640.2
	Crush (massive destruction of	750650.3
	soft tissues)	
	add, if appropriate: fracture of humerus	
	add, if appropriate: fracture of ulna	
Radius	Fracture, closed	752802.2
(Spokebone)	Fracture open, comminuted or	752804.3
	Fracture of radius and ulna ("lower arm fracture")	752808.3§
Ulna	Fracture, closed	753202.2
	Fracture open, comminuted	753204.3
	Fracture of radius and ulna ("lower arm fracture")	752808.3§
Wrist	Contusion	751410.1
	Dislocation	751430.2
	Laceration into joint, *open dislocation*	751440.2
	Crush (massive destruction of soft tissues)	751450.3
	add, if appropriate: fracture of Radius	
	add, if appropriate: fracture of Ulna	
Carpus and Metacarpus (Hand excluding wrist and fingers)	Fracture	752002.2
Finger	Fracture	752404.1

Localisation	Injury description	AIS-Code
	Crush (massive destruction of bone and *soft tissues, degloving injury)*	752406.2
Legs (Lower extremity) & Pelvis		
Skin	Abrasion, bruise/contusion, hematoma, wound < 10 cm	810099.1*
	Wound > 10 cm, reaching into subcutaneous tissue	810604.2*
	Wound > 10 cm, reaching into subcutaneous tissue with blood loss > 20% blood volume	810606.3
Entire leg	Amputation, NFS	811000.3
	- below knee	811002.3
	- above knee, *or through knee*	811004.4
	Hemipelvic amputation code as abdomen / pelvic space / impalement 543228.5§	
	Crush (severe soft tissue / muscle /bone destruction), NFS	813000.2
	Contusion, severe or compartment syndrome or severe muscle Ischemia	
	- below knee	813002.2
	- above knee *or through knee*	813004.3
VESSELS	Femoral artery, major *or bilateral laceration* with very severe bleeding >20% blood volume and /or *severe muscle ischemia*	820208.4
	A rterial laceration with severe bleeding and /or *severe muscle ischemia* (popliteal artery)	821008.3
	Venous laceration with severe bleeding > 20% blood vol.	821206.3
	Nerve injury (femoral , tibial, peroneal Nn.)	830604.2
	Nerve injury to sacral roots see	
	Lumbar spine / lumbar cord / cauda equina syndrome	630600.3
	Muscle laceration (rupture, tear, avulsion)	840600.2
	Tendon laceration, rupture	840802.2
Pelvis (Iliac wing, Pubic ramus, Acetabulum Coccyx)	Fracture NFS, (iliac wing, pubic ramus, Coccyx, acetabular (hip joint cup)), closed Symphysis pubis disruption *(=< 2 cm)*	852600.2
	Fracture (as above) open, displaced *(> 4cm)*, comminuted Symphysis pubis disruption *(> 2 cm)*	852604.3
Acetabulum	add, if appropriate: Fracture */dislocation of head of femur*	
851808.3Sacrum, Ilium, *&Ischium*	Fracture (with or without sacroiliac dislocation) *moderately displaced (=<4cm), with contained bleeding*	852800.3
	Fracture (with or without sacroiliac dislocation) (Pelvic ring fracture, Malgaigne) with large deformation and severe blood loss >20% blood volume	852606.4
	add, if appropriate: Abdominal aorta / common Iliac art./ laceration 520204.4 or // complete laceration with esanguination (very severe blood loss) 520208.5	
Sacrum	add, if appropriate: for fracture of sacrum with major nerve lesion: Spine,lumbar / lumbar cord / cauda equina syndrome 630600.3	
Symphysis	code as /Pelvis (Pubic ramus)/ fracture NFS 852600.2	
Hip	Contusion	850602.1
	Dislocation code as	
	Fracture *and/or dislocation head of femur*	851808.3
	Laceration into joint	850622.2
Groin	Destructive massive laceration (e.g. roll-over injury) code as /Crush (severe soft tissue / muscle /bone destruction)/	

Localisation	**Injury description**	**AIS-Code**
	- above knee 813004.3	
	add, if appropriate	
	/Femoral artery, major or bilateral laceration 820208.4	
	add. if appropriate: for severe Testis injury:	
	Abdomen/Perineum,external Genitals /Larger wound e.g.Testis, avulsion, destruction 543224.2	
Femur	Condylar fracture	851804.3
	" if < 12 years old	851806.2
	Fracture head of femur and/or dislocation	851808.3
	Fracture neck of femur	851812.3
	Fracture shaft of femur, *NFS*	851814.3
	" if < 12 years old	851816.2
Knee	Contusion	850802.1
	Dislocation	
	code as /Disruption 840406.3	
	add, if appropriate:	
	/Vessels:A rterial laceration with severe bleeding and /or *severe muscle ischemia* (popliteal artery) 821008.3	
	Laceration into joint	850818.2
	Sprain, incomplete Ligamentous injury	850826.2
	1 complete Collateral and/or 1 Cruciate ligament tear, NFS	840404.2
	Disruption (anterior and posterior-(2)-Cruciate ligament tear with collateral ligament or menisceal injury	840406.3
	Patella, fracture	852400.2
Tibia (Shin-bone)	Fracture, closed, NFS,"Lower leg"	853404.2
	Condylar fracture, tibial plateau fracture	853406.2
	add, if appropriate:	
	/ Knee / Disruption (840406.3)	
	Fracture shaft of tibia, *medial malleolus*, closed, NFS	853420.2
	Fracture shaft of tibia, *medial malleolus*, open, comminuted	853422.3
Fibula (Splint-bone)	Fracture of fibula,*lateral malleolus*, closed, NFS	851606.2
	Fracture,*lateral malleolus*, open, comminuted	851610.2
Ankle	Contusion of ankle *and foot*	850202.1
	Sprain	850206.1
	Dislocation, i.e. ***unstable injury*** to ankle (also dislocation of "foot with talus", or of talus)	850210.2
	Ligament rupture, ***stable injury*** to ankle, *avulsion fracture*	840402.2
Ankle fractures	Ankle fractures:	
	1.Stable fracture. non-comminuted, NFS	
	Fracture to **either** medial (tibia) malleolus **or** lateral (fibula) malleolus,	
	(or fracture to both mentioned as "stable")	
	code as:	
	/Ligament rupture, ***stable injury***to ankle	840402.2
	plus:	
	the appropriate item from this **list** for the bone fracture:	
	for closed **Medial** malleolus fracture,	
	/Fracture shaft of **tibia**, *medial malleolus*, closed, *NFS*	853420.2
	for open Medial malleolus fracture,	
	/Fracture shaft of tibia, *medial malleolus*, open,	853422.3
	for closed **Lateral** malleolus fracture:	
	/Fracture of **fibula**, closed, NFS	851606.2
	for open Lateral malleolus fracture,	

Localisation	**Injury description**	**AIS-Code**
	/Fracture of fibula, open, comminuted	851610.2
	2. Unstable fracture. Fracture-dislocation, comminuted ankle fracture ("Bimalleolar" fracture, unless not mentioned as stable, "Trimalleolar fracture") or fracturesof**both** malleoli, unless not mentioned as stable, code as Dislocation, i.e. ***unstable injury***to ankle	850210.2
	For the bone fracture add: the appropriate item from the above **list**.	
Foot joint	Dislocation, subluxation (Lisfranc, subtalar), (with or without flake fracture)	850402.1
	Dislocation of "foot with talus", or of talus see Ankle / Dislocation	
	Sprain, *avulsion fracture* Fracture base of 5th metatarsal	850404.1
Foot	Contusion of ankle *or foot*	850202.1
	Fracture	852000.2
Toe	Fracture	853602.1
	Crush, amputation	853606.2

External

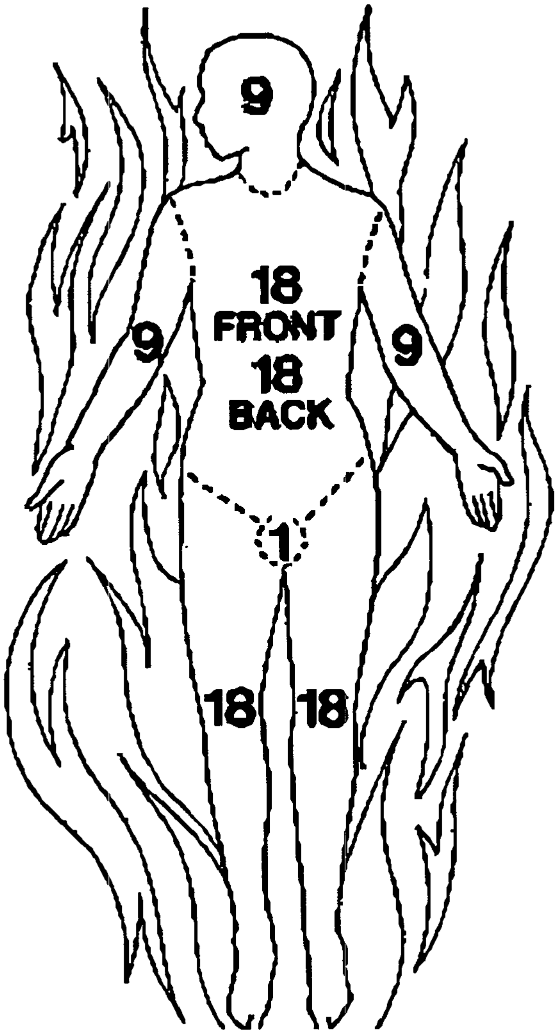
Preliminary remark: Before you start to work with this section be sure to be familiar with the content of the following two paragraphs of the Manual's Introduction: Rules for Assessment / b) External injuries (see p. X and Calculating the Injury Severity Score ISS / b) External injuries and ISS - 90.

Multiple "˜overall/ubiquitous`	Abrasion	910200.1
"	Contusion/bruise, hematoma, (incl. eventual abrasion)	910400.1
"	Wound (Crush injury, Laceration, Cut)	910600.1
"	Skin avulsion	910800.1

Burns

Degree (if "*superficial*" 2° mentioned, *code as 1°*) (if "full thickness burn" mentioned, code as 2°- 3°)		**Extension** in % of TBS total body surface (rule of 9s)	**AIS-Code**
unspecified	NFS	NFS	912000.9*
1° (*superficial* 2°)		=< 50% or > 12 months old	912002.1
		> 50% and =<12 months old (infant =<12 months old)	912004.2
2° (NFS or *deep* 2°)		< 10%	912006.1
3°		< 10%	912008.2
3° face / hand / genitalia involved		< 10%	912010.3
2° -3°		10-19%	912012.2
2° -3° < 5 years of age		10-19%	912014.3
2° -3° face / hand / genitalia involved		10-19%	912016.3
2° -3°		20-29%	912018.3
2° -3° < 5 years of age		20-29%	912020.4
2° -3° face / hand / genitalia involved		20-29%	912022.4
2° -3°		30-39%	912024.4
2° -3° < 5 years of age		30-39%	912026.5
2° -3° face / hand /genitalia involved		30-39%	912028.5
2° -3° general		40-89%	912030.5
2° -3° general		≥ 90%	912032.6

If a **burn "amputation"** or incineration *down to bone necessitating amputation* occur, *add amputation code of extremity region.* ***Chemical*** **burns** are coded *as full thickness* burns (2° *deep* - 3° = full thickness burn).



Rule of Nines - The Total body surface is divided into percentages by multiples of nine %.
(Reprinted in the AIS-Manual's "1990-Revision" with permission of the American Burn Association and the American College of Surgeons).

Other Trauma

Localisation	Injury description	AIS-Code
Inhalation injury (including unintentional CO-exposure):		
	< 20 mg% carboxyhemoblobin919202.3	
	20 - 40 mg% carboxyhemoblobin	919204.4
	> 40 mg% carboxyhemoblobin	919206.5
High voltage electrical injury *(add to burn injury code)*	NFS	919400.2

S1-W-25

Various Aspects on Crashworthiness Calculations

M. Igarashi and K. Nagai
Suzuki Motor Corporation

Abstract

In the last few years, computer simulation has been increasingly utilized as a method for seeking optimal body structure and improved occupant protection. Simulations of this type are particularly attractive since they can be used in the early stages of design and substituted for much more costly and time consuming actual vehicle barrier tests. Recently, there has been significant progress in increasing the reliability and accuracy of computer simulation of crashworthiness in various crash modes. These are due to improvement in both computer hardware (more efficient and lower costs) and computational software (computer codes and calculation models). This paper presents results of a computer simulation using finite element analysis for predicting various aspects of crashworthiness. The results of these calculations are in good agreement with experimental observations. Continuing efforts to improve both the computer hardware and computational software should further extend the application of these techniques and result in optimal structural design for specific vehicles.

Introduction

Presently, large scale calculations of crashworthiness in automobiles have been widely studied by various organizations, and their results are, in most cases, effective and promising. In fact, in frontal crashworthiness calculation the results of simulational calculations compares very favorably with experimental observations. This is due mainly to (1) recent advances in computers, (2) the advent of non-linear and large deformation codes such as DYNA3D, and (3) more accurate and practical modeling techniques.

As a progress has been made in crashworthiness calculations, their practical application in car body design has been increasing since such calculations have advantages such as shortening of development time and a reduction in the number of car crash experiments required. This fact actually accelerates the improvement of crashworthiness calculations with better reliability and accuracy. As a result of these sequences, there is incitement in interest developing it as a standard engineering design tool.

This paper presents several examples of large scale crashworthiness calculations in various aspects of an automobile crash. Although approximately one third of fatal car accidents in Japan(1) are frontal collisions, serious injury and fatality are also seen in other types of car accidents such as side and oblique impacts, or rear impacts. Thus, in order to increase the integrity for crashworthiness, studies of various types of crash calculations are required. The authors feel that the extension of crashworthiness calculations to various aspects of the crash will greatly enhance the structural integrity of the car body and increase crashworthiness in the very near future.

Since improvements in the computer program (DYNA3D) have recently been made resulting in better calculation accuracy and reduced calculation time, this paper will describe it and highlight some results from its use.

Outline of DYNA3D and Its Update

DYNA3D, originally developed by Dr. Hallquist of Livermore Science Technology Corporation, is a completely vectorized, explicit finite element program for solving three-dimensional, inelastic, and large deformation structural dynamic problems. The basic features of this program and its theoretical background have been already introduced in prior papers.(2)(3)(4)(5)(6) This paper discusses recent improvements of the Suzuki-DYNA3D. These improvements/updating of the code has been accomplished not only by our efforts but also considerably by Dr. Hallquist's work.

Highlights of recent improvements/updates in the DYNA3D include:

(1) A function for re-numbering both elements and nodes has been added. Since FEM modeling of an entire car body usually requires considerable engineering man power, several engineers (modelers) often work together to produce a full scale mesh model by sharing portions of the car body mesh generation. In the final stage, each portion of the mesh model is combined so as to generate an integrated full mesh model. This new function therefore greatly simplifies this process.

(2) To facilitate a detailed investigation of calculational result, a function was added to store specific output data such as load, displacement, velocity, acceleration, stress and strain from a specific file. With this function, the size of an output file can be readily reduced or increased depending upon the availability of a file memory.

(3) The calculation CPU time of a mesh model is governed by the critical time integration step size which is determined by element size and material sound speed. This means that as the size of an element becomes smaller for better accuracy, the CPU time must be increased. Therefore, in order to monitor the current time step size in a calculation and also to estimate the total CPU time, the print out choice of the time step and the corresponding element are available.

(4) Laminated windshield glass can be modeled.
(5) The code can not only be used for with double precision but also single precision without any loss in calculational precision.
(6) The strain rate can be input for a certain type of materials through load curve definition. The dynamic behavior of some materials is influenced strongly by the strain rate. This added function enables dramatically improved calculation accuracy for plastics, and other non-linear materials.
(7) Calculations of the effective plastic stress-strain curve is accomplished internally by the code. Accordingly, the total stress-strain curve obtained through an experiment can be input directly.
(8) A function to switch from a rigid body to a deformable body (normal FEM element) and vice versa as a restart calculation has been added. This function is manually flagged, not automatically incorporated in a problem.
(9) Other: the input and output method has been improved resulting in enhanced input and output handling as well as better graphic display.

Various Aspects on Crashworthiness Calculation

Large scale crashworthiness calculations were initially studied on so called frontal impact;(5) i.e. in which a vehicle hits to a rigid wall with a certain speed. Because the calculations are relatively straightforward, many researchers have initiated studies to increase calculation accuracy and improved modeling techniques for this particular crash mode.(7)(8)(9)(10) This movement was also associated with the fact that the number of fatalities caused by frontal impacts such as a car to barrier impact and a car to car collision is particularly large throughout the world, although the actual percentage varies from country to country. Another motivating features was the fact that we felt it desirable to have a computational tool for investigation of better crashworthiness performance thereby decreasing the burden of full-scale tests of prototype vehicles. Due mainly to such the demands, large scale frontal crash simulation has been widely studied and utilized throughout the automotive industry. The authors would classify this period (1986-1989) as the 1st stage in crashworthiness calculations.

Once structural analysts and engineers become accustomed to this calculation tool, it is natural that they would try to extend its applications. Such attempts have been aided by recent advances in computer and also the advent of improved FEM programs such as DYNA3D. These most recent applications of crashworthiness calculations—which can be classified as the 2nd stage of crashworthiness calculations—will now be discussed.

Full Frontal Impact

The FEM model, shown in Figure 1, was used to analyze a frontal barrier crash. The mesh shown has about 14,000 shell elements and 12,000 nodes to represent a typical small sized vehicle. The front bumper, engine, transmission and front suspension including tires, are all incorporated in the model. Furthermore, a side door and steering column shaft are also modeled to better simulate the actual vehicle and produce better experimental results. The inertia of the rear suspension, components placed in the compartment such as seats, instrument panel and other parts are incorporated in the model by scaling their masses and distributing them about the places where they are attached to the car body. As the result, the mesh has the correct overall mass. The initial velocity was taken as 50 km/h.

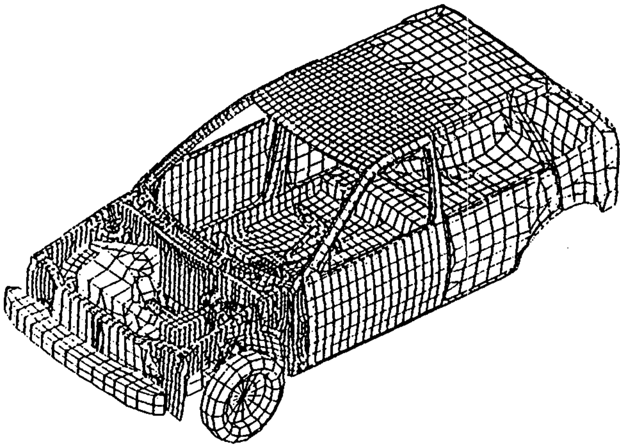


Figure 1. Undeformed Mesh of Small Sized Car Body: Frontal Barrier Impact

Figure 2 shows the deformed shape at 50 msec after impact. Figures 3 and 4 show comparisons of acceleration and velocity between calculation and experiment at one point in the side-sill member. As seen from these figures, the calculated values agree quite well with the experimental results. In particular, the dynamic movement of the steering column shaft can be calculated with reasonable accuracy. Five hours of CPU on a HITAC 820/60 (manufactured by Hitachi) were required for this calculation.

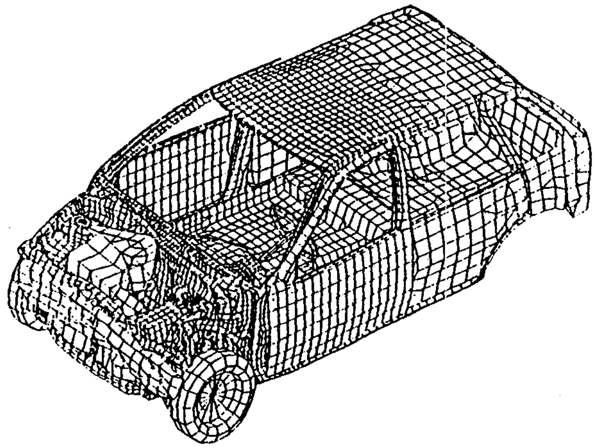


Figure 2. Deformation at 50 msec After Frontal Impact

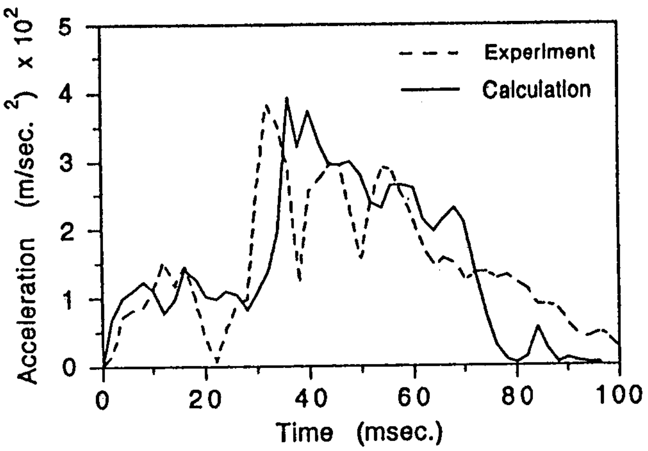


Figure 3. Acceleration Change During Frontal Impact

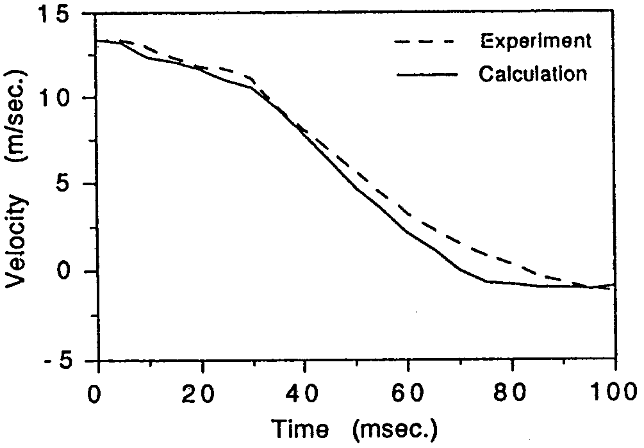


Figure 4. Velocity Change During Frontal Impact

An article by Nilsson discuss in detail the deformation of the steering column system under the frontal impact.(11)

Another advent of the recent frontal barrier crash calculation is a capability to simulate the kinematics of an occupant (dummy) kinematics with an airbag. This calculation was studied by Schelkle et al.(12) using the existing FEM code with a newly developed airbag model. The authors feel that the calculation techniques presented there is one approach for extending crashworthiness calculational applications.

Angular Impact

Figures 5 and 6 show the undeformed mesh and deformation at 60 msec, respectively, for the case of a 30 degrees angular impact at an initial velocity of 50 km/h. The FEM car body model used for this calculation was basically the some model as that used for the frontal impact calculation. As a result that there was essentially no difference in CPU time between the frontal impact and angular impact calculations.

Figures 7 and 8 show comparison of acceleration and velocity between calculation and experiment for this case. Although there is no exact peak to peak agreement in acceleration, once it is integrated, reasonable correlations were obtained. As far as car body deformations are concerned, a calculation accuracy of 80-90% has recently been achieved in both frontal and angular impacts. However, more extensive studY is needed to accurately predict occupant dynamics.

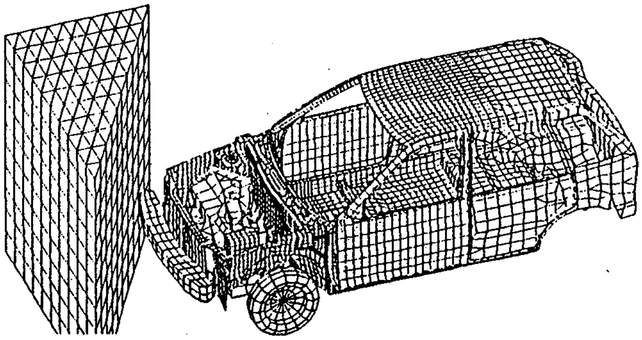


Figure 5. Undeformed Mesh: 30 deg. Angular Barrier Impact

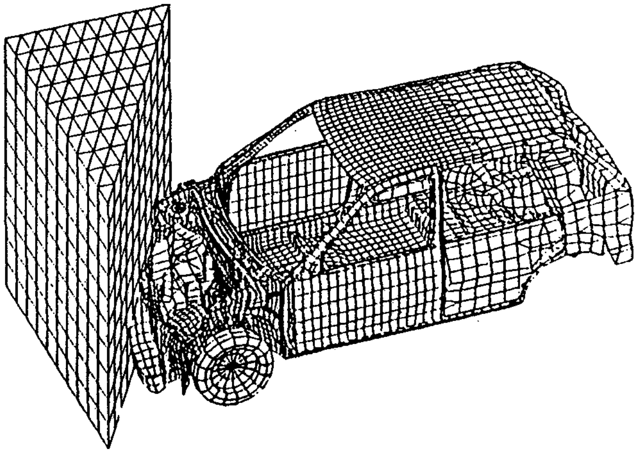


Figure 6. Deformation at 60 msec After 30 deg. Angular Impact

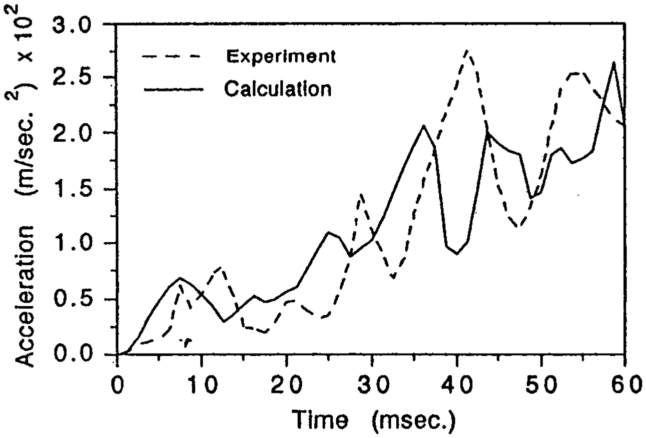


Figure 7. Acceleration Change During Angular Impact

Car to Pole Impact

A car to pole impact is another crash configuration that is commonly seen in real world accidents. Therefore,

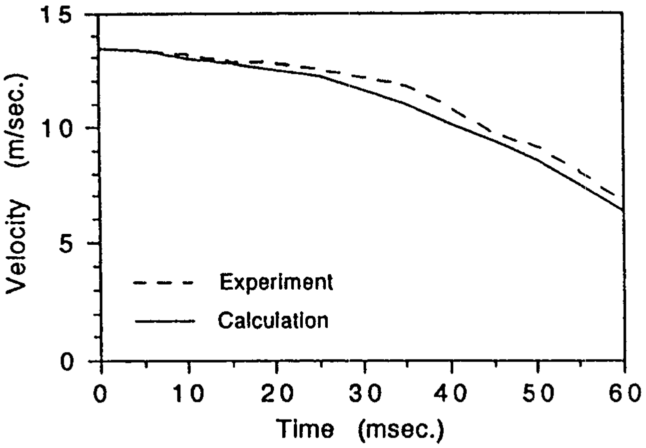


Figure 8. Velocity Change During Angular Impact

a car body structural investigation of crashworthiness performance for a car to pole impact is important. In particular, the acceleration pulse of the car body under a car to pole impact will influence the airbag sensoring system since this type of impact is relatively soft. There could therefore, be a delay in the acceleration pulse to the sensors if the front end car body structure is not designed so as to effectively transmit the pulse to the specific location where the sensor is attached.

Figure 9 shows the undeformed mesh, and Figure 10 shows the body deformation at 50 msec with an impact velocity of 50 km/h for this case. Figure 11 shows a comparison between calculation and experiment for the acceleration at one point in the side-sill member. Then comparing the deformed body shown in Figure 10 with the one shown in Figure 2, there is quite a large difference between the respective body deformation modes. For the case of frontal barrier impact, deformation is relatively simple. The impact (kinetic) energy is mainly absorbed through (1) buckling (2) plastic deformation (compression) and (3) friction of each member and component over the entire width of the car. On the other hand, for car to pole impact, the impact energy is not only absorbed by the mechanisms mentioned above but also by tension and bending phenomena. Figure 12 shows the comparison of the ratio of the impact energy absorbed by main structural components between in a car to pole impact and in a frontal barrier impact. The same FEM model and the same crash speed were used for both calculations.

As shown in Figure 11, there is little difference between results from calculations and experiments in terms of the time at which the maximum acceleration occurred and its peak value. The exact cause for this is still under study. The authors presently feel that based on the current FEM modeling technique, the limited time (man power) spent in modeling, and available CPU time (as modeling becomes finer and more precious, CPU time increases drastically to as much as 30-50 hours. This would not be realistic), it could be difficult to

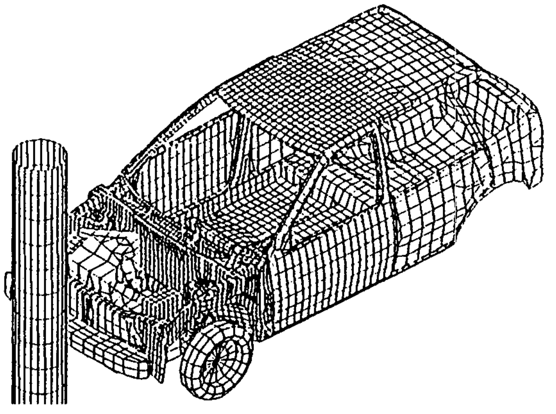


Figure 9. Undeformed Mesh: Car to Pole Impact

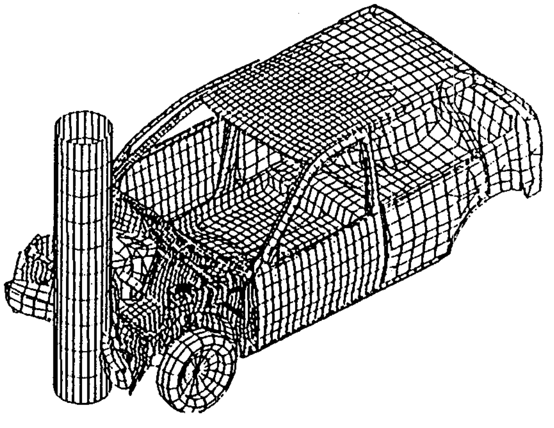


Figure 10. Deformation at 50 msec After Pole Impact

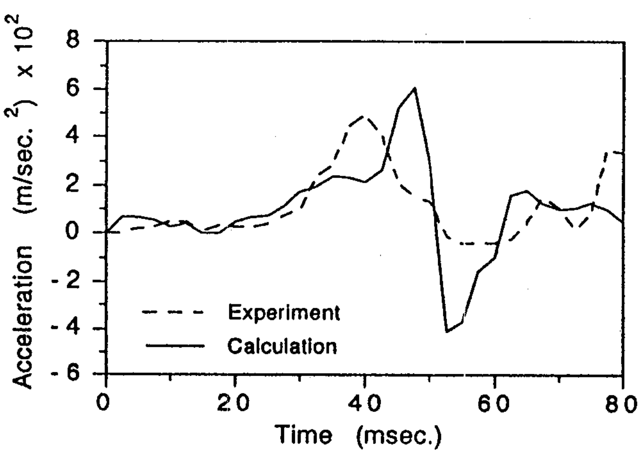
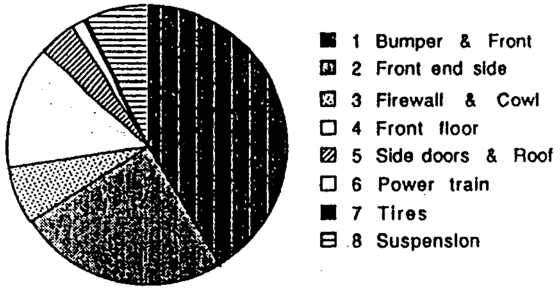
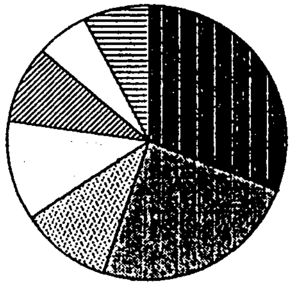


Figure 11. Acceleration Change During Pole Impact

obtain a better correlation than that shown in Figure 11. At the same time, the experimental data may not accurately represent what actually happens during impact. The sampling frequency and filtering frequency adopted by the experimental measurement system may result in uncertainty. Nevertheless, the authors are continuing efforts to further refine the method to bring about better correlation between calculation and experiment.



Frontal Impact



Pole Impact

Figure 12. Comparison of Crash Energy Absorbed by Main Components Between Frontal Impact and Pole Impact

Frontal Impact with Partial Overlap: Offset Crash

Another frontal impact configuration is a frontal impact with only partial overlap. The importance of a consideration for this type of offset crash is well discussed by Grosch et al.[13] When real-world frontal crashes are considered a frontal impact with only partial overlap is often seen. The reason for this is that most drivers try to steer away from a collision at the last moment of crash, resulting in striking the opposing vehicle or barrier with less than half the front end area of the striking vehicles. This is also true for vehicles impacting obstacles such as poles and trees. When comparing partial overlap impact with full frontal impact, it is noted that although the same impact energy should be absorbed in both cases, there is a large difference in the energy absorbing mechanisms for these two impact configurations. For the case of the partial overlap impact, in the beginning the impact energy is absorbed by a small part of the front end structure. This may result in larger deformation than that observed at the full frontal impact. There seems to as yet be no concrete structural guideline established, but the continuous accumulation of this kind of simulation study will obviously play an important role in establishing the structural guidelines for better performance in partial overlap impact.

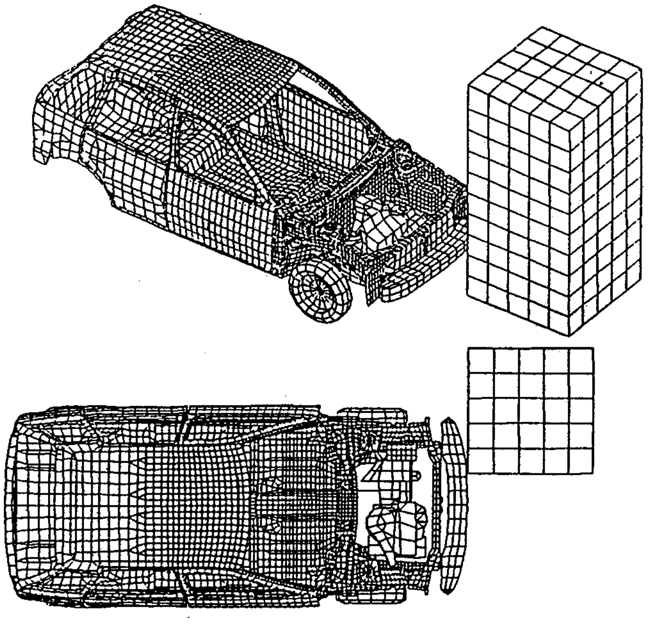


Figure 13. Undeformed Mesh: Offset Impact

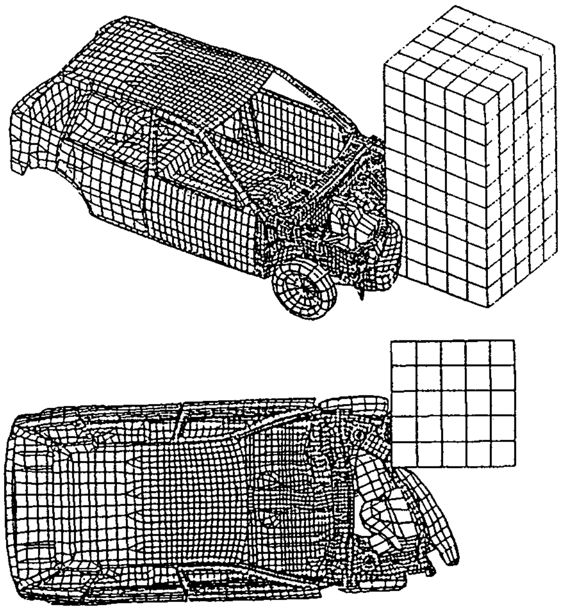


Figure 14. Deformation at 50 msec After Offset Impact

Figure 13 shows the undeformed mesh of a frontal impact with partial barrier overlap, and Figure 14 shows the deformed shape at 50 msec after offset impact. When compared with the deformed shape under full frontal impact shown in Figure 2, there are apparently large differences in the deformed shape of the front end body structure.

Rear Impact

For the case of rear impact, the experiment quite often uses rear moving barrier impact. Figure 15 represents a FEM model for this particular impact. In this calculation and associated experiment, one must not only be concerned with minimizing the deformation of the rear compartment, but it is also important to protect the fuel tank from leakage resulting from the excessive deformation of the rear portion of a car body.

Figure 16 shows the deformed shape at 50 msec after impact. In this calculation, the kinetic energy of the

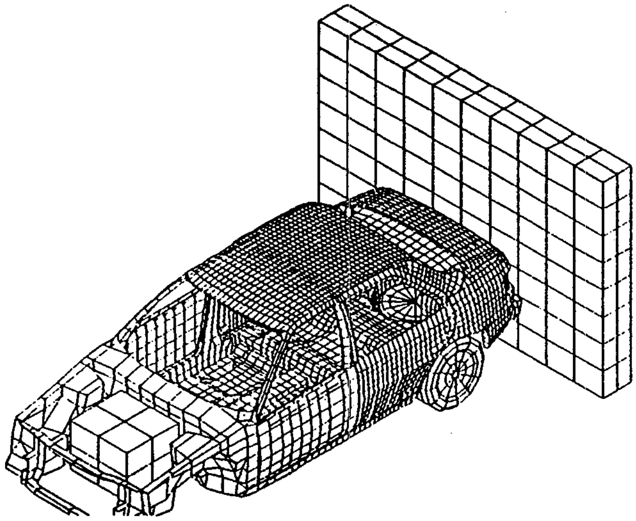


Figure 15. Undeformed Mesh: Rear Moving Barrier Impact

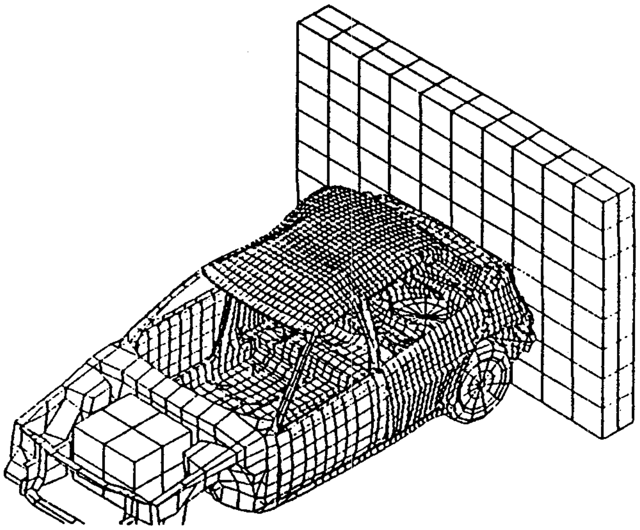


Figure 16. Deformation at 50 msec After Rear Moving Barrier Impact

moving barrier having a mass of 1,800 kg is absorbed relatively well through the deformation of the rear car body. The initial velocity of the rear moving barrier was taken as 50 km/h. In order to have better correlation between rear moving barrier impact calculation and the experiment, it was found that proper modeling of the rear suspension and the rear axle is a key element.

Side Impact

Very recently, computer simulation of side impact has been studied by several researchers and structural analysts.(14)(15) This movement is motivated by the fact that many efforts have, over the years, been undertaken in Europe and the United States to define safety standards for side impacts. Under the proposed side impact testing procedures—depending upon the organization involved—a deformable barrier made from aluminum honeycomb or polyurethane foam is required. This means that in the experiment, the deformable barrier must be replaced each time. This results in additional work for the testing engineers. Therefore, the benefit of the type of simulation described in this paper is obvious. Once a model of the deformable moving barrier is completed, it can be repeated used.

The authors started side impact calculations in 1988. Unfortunately, computer capacity was not enough to execute the full-scale side impact calculation at that time. Since then, due to improvements in both computer performance and the FEM code (DYNA3D), side impact calculation are now realistic. Figure 17 shows a typical FEM model of side impact calculations that has been evaluated by the authors for several months. As the reader may see, in Figure 17 a finer mesh is used, and the front and rear seats are also modeled. This is in an effort to get a better correlation between the calculations and experiments in terms of car body deformation. Figure 18 shows the deformed shape at 50 msec after impact. These calculations took about 8 hours of CPU on a HITAC 820/60.

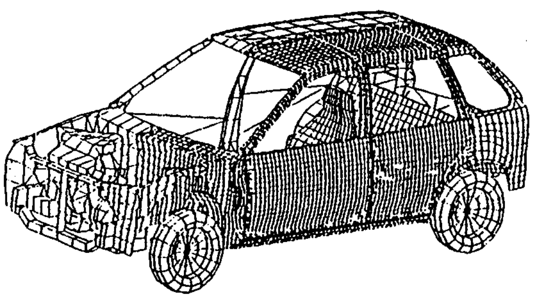


Figure 17. Undeformed Mesh: Side Impact

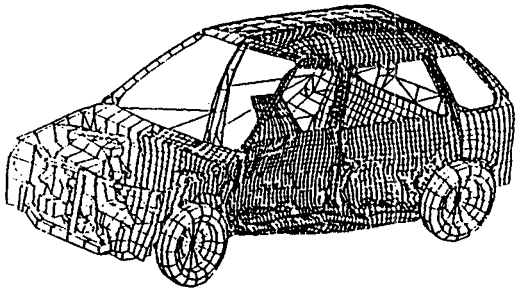


Figure 18. Deformation at 50 msec After Side Impact

The authors feel that further study of side impact calculations is needed to get a better correlation between calculations and experiments. One of the areas in which an improvement is required is a means of modeling and calculating the friction forces exerted between the ground and the tires. Another area for improvement is the modeling of the front and rear seats. These components are structurally complicated. If a faithful model of the seats is used, the increase in the number of the FEM elements increases results in a very large CPU time. On the other hand, if a coarse simple model is used, accuracy is sacrificed to a certain extent. In this regard, additional studies should be conducted on side impact simulation.

There is another recent research area of side impact simulation. H. Lupker et al.(16) studied occupant kinematics simulation of side impact using MADYMO. There was no detailed discussion on how to model an occupant and a car body using this code, but the combination of DYNA3D with codes such as MADYMO, CAL3D or MVMAZD may be a promising of approach to evaluate integrated side impact performance of a vehicle.

Bumper Impact

As a final example of crashworthiness calculation, consider Figure 19 which simulates a bumper attached to the front (rear) of the automobile body subjected to impact by a pendulum having the same weight as the vehicle. Figure 20 shows the deformed configuration of the bumper at 30 msec after the pendulum touches the vertical fascia of the bumper. Not only can one calculate the configuration of the bumper deformation as a function of time, but also the history of the force exerted on the structural body frame and the kinetic energy absorbed by the bumper as shown in Figure 21. Information obtained through such calculations as the force transmitted to the bumper attachment and the energy absorbed by deformation of the bumper could be very useful in the early stages of the car body structural design process.

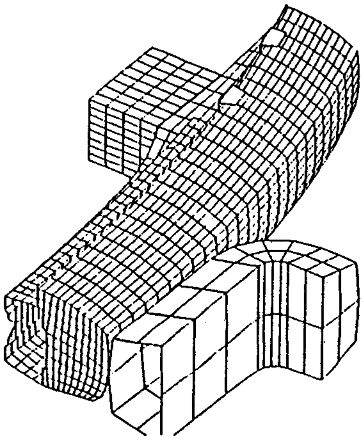


Figure 19. Undeformed Mesh: Bumper Impact

Conclusion

Several examples of automobile crashworthiness calculations have been introduced and discussed. These calculations were performed for the purpose of investigating not only the possibility of simulating the deformation of car body though various impact configurations in detail with the aid of the FEM code DYNA3D and a supercomputer, but also the effectiveness of the computer simulation technique for designing an integrated car body structure for crashworthiness. This study demonstrates that, information can be obtained from the calculations, which agreed both qualitatively and quantitatively with experiments, and that the results obtained can be used to support the design of an integrated car body structure in terms of crashworthiness.

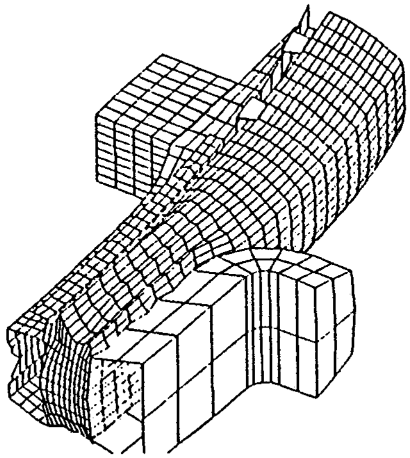


Figure 20. Deformation at 30 msec After Bumper Impact

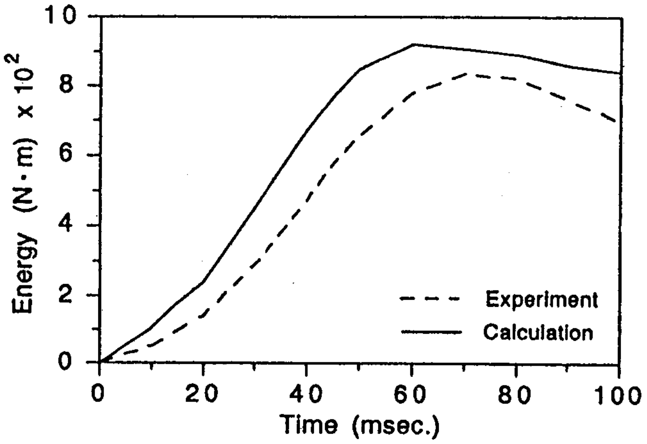


Figure 21. Impact Energy Absorbed by Bumper as a Function of Time

The application of crashworthiness computer simulation is best used in the early stages of body structural design where there is a relatively large degree of freedom to modify the design. In other words, the effectiveness of computer simulation technique likely will be best realized when it is used as a tool to exteriorize design concepts and ideas at an early stage of the body structural design on the assumptions that: (1) it will be effective in reducing the time and the procedures for development and design work through the application of this simulation technique, (2) it has been established that there is a reasonable level of accuracy in this simulation technique, and (3) a lot of time preparing calculation model is not required.

Unfortunately, these three prerequisites are not always satisfied with the present simulation technique. Particularly, there should be considerable improvement in preparing a calculation model. Simply stated, there is a qualitative gap between CAD data and FEW mesh data. At present, the bridge to cross this gap is mainly due to man-power (analysts and/or modelers). This is the area that needs to be improved. Nevertheless currently the simulation technique actually has the advantage of reducing the cycling process of crashworthiness experiments on actual vehicles.

The authors feel that work should be continued to improve (1) calculation model preparation, (2) calculation accuracy associated with modeling techniques, and (3) the software code and computer performance. Such efforts are still essential in order to extend the simulation technique to car body structural design and integrated crashworthiness performance in final pact of the second stage of crashworthiness simulations. The third stage of this study, will involve coupling of the technique presented here with occupant kinematics simulation, which will be an important major accomplishment.

References

(1) 1989 Traffic Accident Report, All Japan Traffic Safety Association.

(2) J. O. Hallquist, *"Theoretical Manual of DYNA3D,"* LLNL, Rept. UCID-19401, 1982.

(3) J. O. Hallquist and R. G. Whirley, *"DYNA3D User's Manual,"* LLNL, Rept. UCID19592, Rev. 5.

(4) J. O. Hallquist and D. W. Stillman, *"LS-DYNA3D Course Note,"* LSTC, 1990.

(5) M. Igarashi, et al., *"Application of DYNA3D to Large-Scale Crashworthiness Calculations,"* J. of the Society of Auto. Engineers of Japan, Vol. 40, No. 11, 1986.

(6) K. Shimomaki and M. Igarashi, *"Large Scale Crashworthiness Calculations in Automobile and Its Future Trend,"* 18th International Symposium on Automobile Technology & Automation, Florence, Italy, May-June, 1998.

(7) D. Vander Lugt, et al., *"Passenger Car Frontal Barrier Simulation Using Nonlinear Finite Element Methods,"* SAE paper 871958.

(8) T. Sakurai, et al., *"Crash Analysis on Passenger Cars,"* J. of the Society of Automotive Engineers of Japan, Vol. 42, NO. 10, 1988.

(9) T. Scharnhorst, *"FFM Crash—A Supercomputer Application,"* SAE paper 880897.

(10) B. Shkolnikov, et al., *"On Analytical Approaches in Crash Simulation,"* SAE paper 891975.

(11) L. Nilsson, "Computational Crash Analysis at the Saab Car Division," 12th International Technical Conference, ESV Goteborg 1989.

(12) E. Schelkle and R. Remensperger, *"Integrated Occupant—Car Crash Simulation with the FEM: The Porsche Hybr;d III-Dummy and Airbag Model,"* SAE paper 910654.

(13) L. Grosch, et al., *"Safety Performance of Passenger Cars Designed to Accommodate Frontal Impacts with Partial Barrier Overlap,"* SAE paper 890748.

(14) K. Gruber, et al., *"Computer Simulation of Side Impact Using Different Mobil Barriers,"* SAE paper 910323.

(15) K. Taga, et al., *"The Application of Super Computer Focused on Safety Development,"* Supercomputing Japan 91 Conference, Feb. 1991.

(16) H. A. Lupker, et al., *"Advances in MADYMO crash simulations,"* SAE paper 910879.

S1-W-26

Crash Pulse Recorder (CPR)—Development and Evaluation of a Low Cost Device for Measuring Crash Pulse and Delta-V in Real Life Accidents

B. Aldman, A. Kullgren,
A. Lie, C. Tingvall
Folksam Research and
Chalmers University of Technology

Abstract

The importance of accident reconstruction and analysis is fundamental. Accident severity can be measured in a variety of ways, but in frontal collision the change of velocity (ΔV), mean acceleration and crash time duration are most often used. ΔV and mean acceleration are estimated from vehicle damages. It is however known, that these estimates are poor if compared to laboratory test conditions. In order to increase the possibilities to evaluate real life accidents in the future, on board measurements is an effective technique. In this presentation, a new device aimed at measuring the crash pulse in real life accidents, is described. The device, called Crash Pulse Recorder (CPR), is a low cost spring mass system including a photographic technique. In the presentation, the construction as well as the output, performance and reliability are given.

Background

Accident data collection concerns several important parameters. Most of the material today is collected by untrained people as a secondary task and will therefore be poor with low precision. One parameter of certain interest is the severity of an accident. Often is the accident severity calculated by accident reconstructions where ΔV, change of velocity, is the most often used parameter. Such calculations gives a random error of around 15% (1). Another way to take care of the accident severity is by indirect statistical methods (paired comparisons (3)). The accident severity is essential for several reasons. Both concerning accident severity distribution and also injury risk as a function of accident severity. The relation between risk of injury and severity can be seen as a dose response problem where the dose is the severity of the crash and the response is the injury of the occupant in the accident.

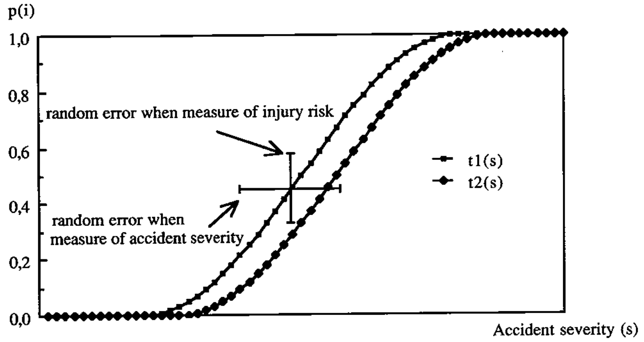


Figure 1. Schematic Probability Functions for Injury Risk for Different Accident Severity
$t_1(s)$ refers to construction (1) and $t_2(s)$ to construction (2).

At low severities no injuries occur and at a certain level the risk is 100%. The figure also shows error estimates both concerning biological variation and variation concerning the severity measurements. For measurements of the severity of injuries many systems are existing (AIS etc).

In most cases the accuracy of accident severity is to low to be able to detect changes in safety levels. The error intervals is greater than the changes in safety levels.

The ultimate data available would of course be identical measurement precision of the dose as in laboratories, i.e. the whole acceleration time history for the crash.

This paper describes a crash recorder with the main purpose of producing ▲V estimations. It is a low cost one dimensional accelerometer which can register the acceleration time history, though with a lower precision and a lower sampling frequency than an accelerometer for laboratory use. The loss of precision of ▲V estimations will be under five percent.

Description and Mathematics

General description

The accelerometer in this case, called Crash Pulse Recorder (CPR) (see fig 2), is based on a spring mass system where the movements of the mass in a collision is measured. It includes mechanical, electronic and optical features. The quote spring coefficient over the mass, is chosen in that way so the time for the displacement of the mass takes a little bit longer time than a normal crash takes in time. It means that around 120 ms will be registered depending of the shape of the crash pulse.

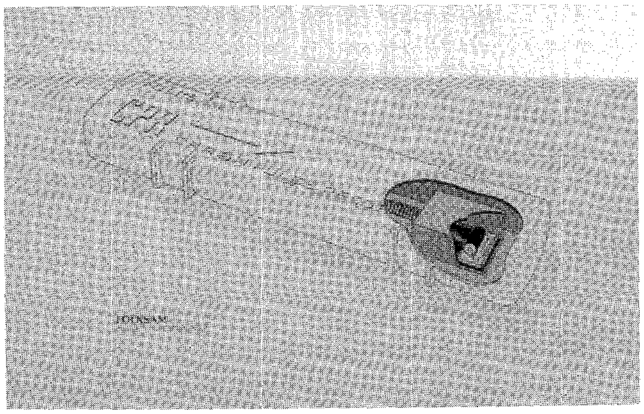


Figure 2. Crash Pulse Recorder (CPR)

The displacement of the mass is registered on a photographic film (Fig 3), where a light emitting diode (LED) registers its location. The LED is driven by a crystal oscillator circuit which gives a modified square pulse with a frequency of 1000 Hz. The circuit has its own power cell and does not need an external power unit. The power cell is of lithium type and can be inactive for several years and then give the accurate volt level when the circuit is activated. The temperature stability of the lithium cell is also very good in the actual temperature range (-30°C to +50°C). The circuit is activated via a micro switch when the mass starts to move in a crash. The trigger level is chosen to be approximately 1 g to avoid registration of maneuver deceleration.

How to take care of a registration after a crash

After an impact the registrations on the photographic film (Fig 3) is scanned into a computer as a digital image. A computer program finds the greylevel center of gravity for each mark. From these measurements it is possible to get the displacement of the mass as a function of time. With all characteristic parameters for the CPR measured and with the displacement time history the acceleration time history is calculated with the mathematics presented below. To take care of the errors in the measurements of the registrations on the photographic film the displacement curve is filtered with a frequency of 50 Hz.

Mathematics

x = displacement of the tube relatively a fixed point
s = relative displacement of the mass
$m = m_{mass} + m_{spring}/2$ = equivalent mass for the system
c = damping coefficient for the system
k = constant for the spring
F_0 = prestress force of the spring
F_μ = frictional drag

The coordinate system chosen for the calculations is described in Fig 4, where x and s are described above.

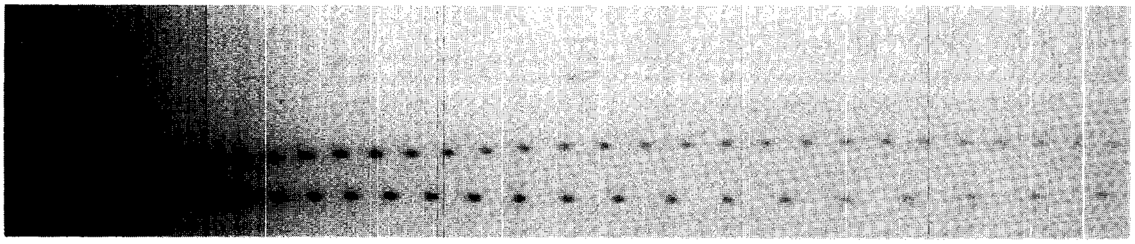


Figure 3. Displacement Registration of the CPR on a Photographic Film

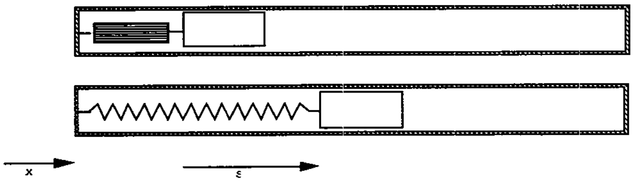


Figure 4. Schematic Picture of Coordinate System for the Mathematic Model of the CPR

The relation between the force of inertia and the external forces acting on the mass is shown in equation 1. Included are terms for spring force, viscous damping, prestress force and frictional drag.

$$m(s''+x'') = - cs' - ks - F_0 - F_\mu \qquad \text{eq 1}$$

$$x'' = - s'' - c/m\ s' - k/m\ s - (F_0 - F_\mu)/m \qquad \text{eq 2}$$

$$s' = ds/dt \qquad \text{eq 3}$$

$$s'' = ds'/dt = d^2s/dt^2 \qquad \text{eq 4}$$

x'' is the acceleration pulse for the tube and by that the acceleration pulse for the car if the tube is fixed to the car.

The initial conditions in this case are

$$x(0) = s(0) = 0, x'(0) = s'(0) = \Delta V$$

Comparison Tests Between Accelerometer for Laboratory Use and CPR

Several tests was made on a sled crash testing track to see the accuracy and precision of the CPR both concerning the shape of the acceleration pulse and also the change of velocity and mean acceleration. The displacement curves was measured and the acceleration for the sled was calculated. The displacement curve for the spring mass system in the CPR in test F51 is shown in Fig 5 and the accelerations pulse from the CPR and the accelerometer in the same test is presented in Fig 6.

The acceleration pulses was divided in three different parts and the change of velocity and mean acceleration for each part was calculated. In Table 1 the results from three tests, F49, F50 and F51, are presented. The accuracy for the total change of velocity in the tests were all under 3 percent.

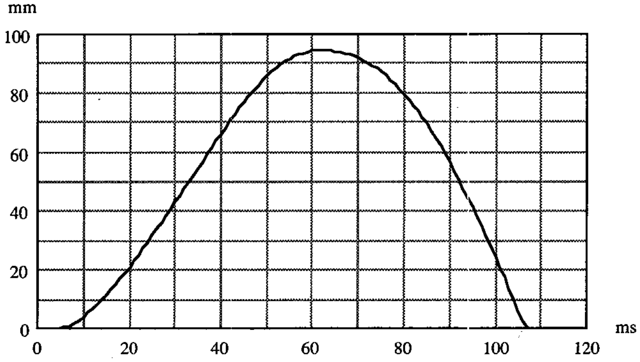


Figure 5. Displacement Curve for the CPR in Test F 51

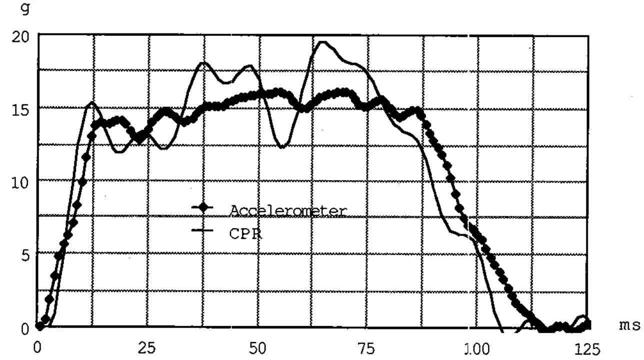


Figure 6. Comparison Between Acceleration Pulse for the CPR and an Accelerometer in Test F 51

Table 1. Results from Tests F49, F50, and F51

	Accelerometer values		CPR-values	
	ΔV(km/h)	acc-mean(g)	ΔV(km/h)	acc-mean(g)
test F49				
tot	47,7	13,0	49,0	12,5
0-30 ms	14,0	13,2	12,2	11,5
30-60 ms	18,3	17,3	17,1	16,1
60-90 ms	14,1	13,3	16,2	15,3
test F50				
tot	48,3	13,5	48,9	12,5
0-30 ms	14,6	13,8	12,1	11,4
30-60 ms	18,3	17,3	17,9	16,9
60-90 ms	13,8	13,0	15,9	15,0
test F51				
tot	49,0	13,5	49,1	12,4
0-30 ms	13,7	12,9	12,3	11,6
30-60 ms	16,9	15,9	16,6	15,7
60-90 ms	16,2	13,0	16,2	15,3

Discussion

Accident severity estimations based on accident reconstruction have several drawbacks. The reconstruction is based on deformations of the car, mass, stiffness, direction of force in the crash etc. Deformation measurements are often made by hand which gives an accuracy of ±7,5 cm (1). The estimations of the angle of the crash are done with an accuracy of ±20 degrees (1). This leads to an average accuracy of around ±15% of the ΔV computation (1) in an idealized case with collisions made in laboratory. It can be expected that the error in real life is even larger, up to 20-30%. To detect the change in safety level of a new safety system or a new car with that accuracy of accident severity is impossible when the difference in safety level is moderate but still important.

A problem is that poor accident data will result in an inaccurate answer even if a large data material is collected. Measurements with low accuracy can not be replaced with more data (2). A simple analysis of the influence of measurement errors and their effect in a comparison between accident severity and risk of injury was made in ref (2). The model used was a simple linear model, y=a+bx, where a was the intercept and b the slope. In Table 2 it can be seen that the regression coefficient, where the error is 30%, is reduced by more than 50%. The possibility to draw conclusions from the data material collected is by that affected as the relation between what can be detected and the measurement error is highly affected.

Table 2. Regression Coefficients (a for intercept and b for slope) and Amount of Variance Explained (R^2) by a Simple Linear Model (y = a + bx where x is subject to measurement errors of 0, 10, 20 and 30%.)

parameter	0% error	10% error	20% error	30% error
a	2.23	10.6	26.3	38.8
b	1.93	1.67	1.19	0.81
t(b)	65.7	18.5	9.5	6.4
R^2	0.98	0.85	0.61	0.41

It can be discussed what should be measured and what accuracy is needed. Kurimoto et al. (4) have made comparisons of occupant response for different shape of crash pulses. In that study the shape of a crash pulse was made by approximated trapezoids. The crash pulse was built by two trapezoids with different acceleration levels. It can be seen that the difference in occupant displacements between pulses using approximated trapezoids and the original pulse was very small. It is also analyzed how small variations of g level and deformation of each trapezoid in the approximated pulse results in large variation to the dummy parameters, HIC and chest g.

The study shows that it is not enough to have the total change of velocity to compare with injuries. It also shows that it is enough to split the pulse in a few different parts and know the change of velocity and the time duration for each part to be able to discriminate between pulses.

Another study made by Hartemann et al. (5) shows that intrusion affects the injury and fatality rate very much. To measure only ΔV or other parameters as mean acceleration is not enough to relate to injury and fatality rates. Deformation measurements, especially interior, is therefor essential.

In order to make large fleet field experience with crash recorders it is essential that the cost for each unit and its installation is low. With the CPR presented in this paper it is possible to, in retrospect, calibrate it and measure all the parameters necessary for the analysis. The production cost can therefore be reduced dramatically.

The presented recorder will in relation to other proposed recorders (8,9), only measure variations, that are fairly insensitive to the integrity of the driver. The change of velocity is only one part of the accident process. The aim for the CPR described in this paper was that it should be able to detect the mean acceleration levels for at least three different parts in the pulse. The time duration and ΔV will also be included. It is optimized for measuring collisions with a ΔV of around 50 km/h. The maximum ΔV possible is around 60 km/h. In a study made by Otte (6) it can be seen that over 95% of all collisions occur with ΔV under 50 km/h. At ΔV of 60 km/h over 99% of all collisions is covered.

The method used for this purpose is to measure the displacement of the mass in a spring mass system in an impact. The acceleration pulse is then calculated in retrospect with the CPR calibrated and all adequate parameters measured.

One drawback with using photographic film as registering media is that there is a limit concerning frequency of the LEDs to be registered. If using magnetic tape and tape recorder head instead it is possible to have much higher frequency. The major reason for choosing the photographic film is low cost. To be able to detect all points on the photographic film it is essential that all points are very small and sharp. The light in the CPR is therefore passing small holes in the mass with a diameter of a 10th of a mm.

It is essential that the measurements of the registrations on the photographic film has very high precision. There will of course be errors when measuring the registrations on the photographic film, even if they are minimized, therefore the displacement curve is filtered before making calculations of the acceleration pulse.

For several reasons the mass has a relatively large lateral space. The major reason is that it otherwise would be very difficult to measure all points when the points from the mass on its way back would be on the same vertical line as the points on its way out. Another reason is for minimizing the damping effects which otherwise would be considerable. It is also possible to measure the main direction of force in the crash in a ±5 degrees range from full frontal impact.

A drawback with the CPR is that it only can measure the acceleration levels in one direction. Still it is useful for a large proportion of all collision types in real life accidents. A result from the study made by Otte (6) is that 50% of all impacts are frontal impacts, and from these around 65% is in the angular range for the CPR. Also a small part of lateral collisions can be measured with the CPR. In total at least 40% of all collisions can be measured with the CPR. The figure 50% frontal impact is though a little bit lower than results from other studies in the area.

To be able to also take care of lateral impacts and rear end collisions it is of course possible to let the mass be held by three springs in a large square box, or to install CPR in several different directions. For side collisions, the change of velocity for the struck car is, however, of interest in assessing the severity of a side impact to the occupant (7). In this project the aim was to analyze mainly frontal impacts as a first step.

The tests made to verify the accuracy and precision of the CPR showed that the accuracy for the total ΔV of the crash were under three percent for all tests. The shape of the acceleration pulses in fig 6 is also very similar, the g-levels is in the same region and also the time duration. The tests were all trolley or sled tests where the shape of the acceleration pulse was similar for all tests and the shape were very rectangular. Full scale tests will be made, both barrier tests and car to car tests, to see the performance of the CPR in other types of acceleration pulses. A large scale field experience will be performed during next year with 20.000 units.

Conclusions

- By specifying the necessary precision in accident severity assessment, a low cost crash recorder (CPR) was developed.
- The output from the CPR can be used to calculate change of velocity, pulse duration and simplified pulse shape (as well as mean deceleration).

References

1. R A Smith, T Noga, Accuracy and sensitivity of CRASH, In: proceedings of the 26th Stapp Car Crash Conference 821169, 1982.
2. Kamren B, v Koch M, Kullgren A, Lie A, Nygren A, Tingvall C, Advanced accident data collection—description and potentials of a comprehensive data collection system, accepted for publication at the ESV conference 1991.
3. Gustafsson H, Hagg A, Krafft M, Kullgren A, Malmstedt B, Nygren A, Tingvall C, Folksam Car Model Safety Rating 1989-90.
4. Koji Kurimoto, Koji Taga, Shigeru Haruna, Hiroyuki Matsumoto, The evaluation of the—influence of vehicle crashworthiness and interior parts on occupant injury, In: proceedings of the Stapp Car Crash Conference 892009, 1989.
5. F Hartemann, J Y Foret-Bruno, C Henry, G Faverjon, C Got, A Patel, J C Coltat, The characteristics of frontal impacts in real world accidents, In: proceedings of the ESV conference 1987; 424-431.
6. D Otte, Comparison and realism of crash simulation tests and real accident situations for the biomechanical movements in car collisions, In: proceedings of the Stapp Car Crash Conference 902329, 1990.
7. Kamren B, Kullgren A, Lie A, Tingvall C, Side protection and child restraints—accident data and laboratory test including new test methods, Accepted for publication at the ESV conference 1991.
8. Wilkie K, Baird B, Miller C, The inexpensive crash recorder project, technical report from Synergetic Engineering Associates.
9. Kock M, Salomonsson O, Crash recorder for safety system studies and as a consumers product, In: SAE SP 852, Frontal crash safe technologies for the 90's, 1991.

S1-W-27

An Overview of the Vehicle Inspectorate's Database on Bus, Coach and Goods Vehicle Examinations Following Major Accidents

Donald Macdonald
Department of Transport Vehicle Inspectorate
Accidents, Defect and Recalls Branch

Abstract

The Department of Transport's Vehicle Inspectorate examines approximately 1,800 accident involved vehicles each year to establish whether vehicle condition contributed to the cause of the accident. The majority of these vehicles are heavy goods vehicles (HGVs), buses and coaches. The information may be used by the Vehicle Inspectorate to investigate vehicle safety defects of a design or manufacturing nature. The information collected from the vehicle examinations is coded and entered onto a computer database.

This paper describes how the information is collected, coded and subsequently used to identify vehicle safety concerns or to provide information used in formulating government policy. The strengths and limitations of this method of collecting and analysing this data are described and examples used to illustrate these.

Lessons learned about data collection, coding, and accessing of the information are included. Future development of all these areas is described in the paper including the move to place greater emphasis on the secondary safety aspects of vehicle examinations.

Introduction

Responsibility for the safety of road vehicles is split within the Department of Transport between the Vehicle Standards and Engineering Division (VSE), the Vehicle Certification Agency (VCA) and the Vehicle Inspectorate (VI). The last two of these have recently been constituted as Executive Agencies. VSE is responsible for policy and legislation of vehicle construction standards, VCA for type approval of vehicle types between national and EC standards and VI for roadworthiness testing and enforcement.

The roadworthiness checks include statutory testing of heavy goods vehicles (HGVs) at 93 VI test stations, initial certification and statutory testing of buses and coaches, monitoring of the car test scheme at 17,000 independent authorised premises throughout the United Kingdom (UK), roadside spot checks on vehicles and detailed vehicle inspection following accidents (1). During each of the last three years there have been an average of 1,800 such post accident inspections carried out by VI staff. Reports on these are checked, coded and entered on to a computer database for future analysis.

Collecting the Data

The majority of road accidents are attributable to human error rather than a vehicle defect although very often a driver claims that a defect caused the accident rather than admitting his own error. It is therefore important to establish at an early stage if the condition of the vehicle contributed to the accident in any way to enable appropriate action to be taken either against the driver or the owner of the vehicle.

Although police forces are able to inspect smaller vehicles involved in accidents they do not always have the necessary skills and resources to examine HGVs, buses and coaches. In the case of these vehicles, if the driver alleges a vehicle defect or the police suspect a defect was contributory to the cause of the accident, they will request that an inspection of the vehicle is carried out by a VI Vehicle Examiner. In addition VI may examine vehicles if the accident has a particular interest for the Department of Transport.

The inspection covers the primary safety systems on the vehicle including brakes, steering, tyres, suspension, lights, transmission and bodywork. The Vehicle Examiner completes a written report which includes operator details, accident circumstances and information on any defects found during his inspection. It is these reports which are used to produce the VI computer database. In addition the police receive a statement on the condition of the vehicle which may be used to support prosecution action. If a Vehicle Examiner considers it necessary a prohibition notice will also be issued to prevent the vehicle being used until it has been repaired. Prohibitions are recorded on the operators file and may influence the granting of an Operators Licence.

Vehicle Examiners are also encouraged to comment on the performance of secondary safety items—seats, seat mountings, restraint systems, door locks and safety glass. Any items or systems liable to increase the risk of injury to vehicle occupants or other road users involved in the accident should be included in the Vehicle Examiners accident report. Examples of these include hostile interior fittings, seat belt performance, fires, crashworthiness of the vehicle structure and possible evacuation problems from an accident damaged vehicle.

Compiling the Database

From 1982 onwards all reports sent to VI headquarters have been coded and entered on a computer database. This database now holds in excess of 15,000 records. The average annual number of reports over the last three years is 1,800 and the types of vehicle inspected are shown below (Table 1).

Table 1. Vehicle Types Inspected by VI Vehicle Examiners

Year	Goods Vehicles	Buses and Coaches	Others	Total
1988	961	634	95	1690
1989	969	720	85	1774
1990	1089	775	88	1952

Initial coding of the accident circumstances, casualties and vehicle identification is an administrative task, which is followed by technical coding by a VI engineer. All codes used for this exercise must conform with those set out in the VI coding manual. Any mechanical deficiencies found with the vehicle attributable to inadequate maintenance or defects in design and manufacture are coded under subject headings, and sub coded to a further three stages where appropriate. In general accident damage is not coded for primary safety defects, but is coded for secondary safety defects. For example tyre deflation due to the impact would not be coded, but failure of a seat mounting in an accident would be coded as body, seat, mounting, fix.

Data Analysis

Any safety defects identified on the vehicle which may be attributable to design or manufacturing deficiencies are investigated with the vehicle manufacturer. This investigation may result in the issue of service information, a design change for future vehicle builds or recall to enable modifications to be made to vehicles already in service. It is important to search the database for related cases to determine if an incident is isolated—perhaps due to the severity and nature of the accident, or is one of a number of similar occurrences. Comparison of the performance of peer group vehicles can also be used to indicate if one manufacturers vehicle performs better than another in similar circumstances.

The database can also be used to identify particular groups of vehicles or accident features. Examples of these include occupant ejection from buses and coaches, or articulated vehicles in jack knife accidents. By looking at the hard copies of the accident reports it is possible to determine ejection routes, glazing security failures, door opening mechanisms, or incompatibility of tractor trailer combinations. The results of such analysis may be used to support the case for legislative changes, or may indicate an area of work which requires further investigation. Typical examples are given below.

On some coaches the roof hatches are also used as secondary emergency exists in the event of a vehicle rollover. Incorrect operation of the handles by a passenger on one of these hatches as the coach was being driven along caused the hatch to detach from the vehicle. After consultation the manufacturer agreed to offer a service fix to operators by fitting an extra securing strap and improving the markings and operating instructions on the hatch. A second hatch detachment occurred a year later on an unmodified vehicle and in this case struck a following goods vehicle. A second similar incident with such a small vehicle parc, clearly indicated the need for further action. The manufacturer agreed to recall action to ensure that all vehicles were upgraded to the latest specification.

Examination of incidents of occupant ejection from buses and coaches via glazed apertures has shown that these are often associated with people standing in the vehicle or with horseplay. Poor glazing security, due to deterioration of gaskets, enlargement of window apertures or incorrectly sized windows may be contributory factors. It was therefore viewed as a matter of concern when it became apparent that a coach manufacturers bonded windows were becoming insecure in service. From the manufacturers point of view there was also a concern about the repair techniques being used by vehicle operators. The problem was tackled via a service action by the manufacturer. A service bulletin and video were produced with step by step instructions on how to replace windows and damaged body panels.

In some accidents it is necessary to make a judgement on whether a failure is beyond what is considered to be an acceptable design specification. One such severe coach accident resulted in virtually all the seats becoming detached from their mountings, and the seat frames also breaking allowing the seat backs to come free of the seats. Although there is currently no mandatory seat strength requirement for coach seats, these particular seats were tested to 10g. This is the proposed European strength requirement for such tests. A search of the VI database showed that such catastrophic failures are rare, and the manufacturer confirmed that this was the most severe accident they had seen on one of their vehicles. Design improvements were already in place on current production vehicles and further improvements are planned for future builds of the coach.

Strengths and Limitations of the Database

The Vehicle Inspectorate has trained Vehicle Examiners at district offices throughout the UK and can therefore provide complete national coverage. Good liaison with the police, contacts with all vehicle manufacturers, and interfacing with other government departments provides a strong base from which to investigate accidents. Where appropriate material specialists may be called on to determine if a component failed prior to or as a result of the accident. Since the number of occupant casualties in HGVs, buses and coaches is relatively small, and the Vehicle Inspectorate specialises in examinations of these vehicle types, the database contains a significant proportion of all such accidents in any given year (2) (Table 2).

Table 2. Occupants Suffering Fatal Injuries in HGVs, Buses and Coaches in Great Britain and Included in VI Database

Year	HGV Casualties Great Britain	HGV Casualties VI	Bus and Coach Casualties Great Britain	Bus and Coach Casualties VI Data
1987	75	30	15	8
1988	73	25	17	11
1989	82	31	20	18

The accident report form currently used is directed towards the examination of particular vehicles rather than the whole accident, and the primary rather than secondary safety systems on that vehicle. The Vehicle Examiner is asked to provide detailed information on the operators, driver, accident, circumstances and mechanical condition of the vehicle. The format of the form is biased towards descriptive text rather than questions which require an absolute answer. This has the advantage of encouraging the Vehicle Examiner to provide the level of detail appropriate to the system being examined, but can lead to problems of interpretation when the form is being coded for entry on to the computer database. Care must be taken when interrogating the database to ensure that all casualties and vehicles in the accident are identified. As the report form is focused on the vehicle itself any information on accident circumstances and injuries to casualties is of a more limited nature. This information can only be obtained second hand by talking to the police, vehicle operator or on rare occasions the driver of the vehicle.

Although a coding manual is used to standardise makes, models and vehicle deficiencies there are other coded items which are open to mis-interpretation. It is sometimes possible to code a vehicle defect in different ways, so it is imperative that users of the database are aware of these possibilities. An example is wheel detachments which may arise from either failure of the studs and nuts securing the wheel or from bearing failure where the complete hub becomes detached. It is therefore essential to search under the subject heading of axles, as well as wheels, to ensure all detachments are identified.

Not all the information collected on the accident report form is coded and entered on the database. This is because the information may only be relevant at a local level to the Vehicle Examiner—for example in his dealings with the operator on maintenance issues, or because it was considered that analysis on those fields was unlikely to be necessary. Conversely there is information coded and entered on the database although the question is not specifically asked on the accident report form. This situation can cause problems for the engineer coding the information and in doing analysis. Searches may take more time and need to be much broader, with reference being made to the hard copy to establish if the report is relevant or not for the particular analysis being undertaken. Vehicle weights and seating capacities are typical examples where this may be an issue.

Although all types of vehicle including bicycles and caravans are included on the database there are insufficient numbers of some vehicle categories to do meaningful analysis. Great care must be taken when considering the information on cars, caravans, motorcycles and other poorly represented vehicle types. Since there is also a bias towards vehicles which are alleged or suspected of being defective, it is not possible to draw conclusions about the state of the vehicle population as a whole.

Future Developments

Consideration is currently being given to ways that the current VI accident investigations and the accident report form can be improved. One option is to have a tick box form with multi choice questions which can also be used as a computer input document. Space would still be allowed for descriptive text to be added by the Vehicle Examiner where appropriate. Another area for consideration is the amount of secondary vehicle information collected following different types of accident. In a collision with a pedestrian it would be beneficial to have information on the driver's field of vision, and for HGV impacts with smaller vehicles the effect or possible benefit of underrun protection would be relevant.

Until such time as detailed information of this type is collected it is difficult to quantify the casualty savings which may ensue from changes to vehicle design affecting these areas.

In common with many accident databases it is much easier with hindsight to say what data should have been collected and what would have been the best way to arrange the data. It is much more difficult to predict what will be required in the future.

References

(1) Vehicle Inspectorate Annual Report.
(2) Road Accidents Great Britain 1989. The Casualty Report HMSO 1990.

S1-W-28

A General Approach to Estimating Frontal Impact Collision Speeds

Denis P. Wood
Wood & Associates

Abstract

It is shown that the specific energy absorption characteristics of the car population in frontal collisions can be represented by a single equation which has a coefficient of determination of 0.76. Comparison of predicted and actual Delta V's when using this relation shows that the equation yields similar accuracies to CRASH 3. When the energy absorption characteristics of individual cars are known the resulting predictions are superior to both the derived relation and to CRASH 3. A simple method is derived to estimate the energy absorption of the missing vehicle when only one of the collision partners is available for measurement.

Introduction

Various approaches have been developed to estimate the speeds of vehicles involved in collisions from the permanent crush damage of the vehicles. All centre on estimation of the energy of approach of the vehicles from the crush damage and the subsequent determination of collision speeds and speed changes from the impact-energy loss equations.

This approach, originally demonstrated for frontal collisions in Campbell's classic paper (1), is based on the assumption of uniform absorption of energy across the front of each vehicle. McHenry (2) developed this approach and classified the car population into six groups by wheelbase size, each group being represented by a single set of energy absorption parameters. In Europe the EES method (3) has been developed along similar lines. More complex representations, which allow for the variation in energy absorption across the width of the front of the car and between the upper and lower parts of the front structure have been made for individual car types (4). Prasad (5) has shown, when the energy absorption characteristics of individual car types derived from barrier tests are used to estimate collision speeds, that the accuracy of estimation is improved.

However in many cases the crush characteristics of the particular cars involved in a collision are not available to the accident investigator. In this paper it is shown that the root(2 x Specific Energy Absorption) or Equivalent Barrier Impact Speed (EBS) characteristics of the car population in frontal impacts can be described by a single equation which can be used to estimate collision speeds.

Frontal Crush Characteristics of Cars

The crushing force-deformation behaviour of cars is complex. The initial forces are frequently low, a large force pulse occurs when the deformation reaches the engine and the engine is decelerated while the general level of crushing forces increase as interaction with the occupant compartment takes place. Emori (6) indicated in 1968 that the deformation of car fronts could be approximated by a linearly increasing force characteristic. Lim (7) in 1972 showed that a particular car model could be represented as having a uniform crushing force independent of deformation. In CRASH (2) and related procedures (5) the vehicle structure is represented by the linearly increasing force model. Prasad (8) has shown that the energy absorption properties of cars can be equally well represented by constant force and linearly increasing force models. Strother (9) and Woolley (10) have shown that the linear force-deformation assumption used in CRASH is not valid for all car types particularly at high collision speeds when force saturation can occur.

In detailed parametric studies of vehicle crashworthiness Sakuri et al (11) showed that the crushing force-deformation relationship could be represented by two regions of constant force, an initial low force level and the second high force area which starts when the crush deformation reaches the engine.

In the context of collision speed estimation the predominant interest is in a method which can be used to reliably estimate the energy absorbed by the colliding vehicles over the full range of possible collision speeds. Fonda (12) has suggested that nonlinear force deformation models give an improved match with the barrier test data.

Normalised Deformation Model of Frontal Crush

The energy absorbed in crushing an idealised tubular structure equals crumpling force times crush depth. The crumpling force is stress times area while vehicle mass is density by area by length. Manipulation shows that

$$(E/Mk) = V^2/2 = (\sigma/p)\cdot(d/L) \tag{1}$$

Equation 1 shows that the energy of approach, E, of a vehicle divided by the mass of the vehicle structure, Mk, referred to as the Specific Energy Absorption of the vehicle, is related to the normalised crush depth (d/L) and the stress/density ratio (σ/p). This relation was originally proposed by Pugsley (13). This relationship can also be expressed in terms of the root (2 x Specific Energy Absorption). This is also called the Equivalent Barrier Impact Speed (EBS). Taking into account the more complex crushing behaviour of real cars and to allow for saturation effects at high speed the relation

$$(2E/Mk)^{1/2} = EBS = Const. + f(\sigma/p)\cdot(d/L)^n \tag{2}$$

is used. Wood (14) has shown that such a equation can be used to describe the specific energy absorption properties of individual car types for barrier impact speeds up to 66 mph.

Overall Car Population

Schmidt (15) shows that the kerb weight of cars is proportional to the wheelbase to the third power. This infers that the average density of unladen cars is independent of car size. Danckert (16) shows that the mean crushing force in 30 mph barrier impacts varies in proportion to the 2/3 power of kerb mass. This indicates that the mean crushing stress of the car population is independent of car size. These factors suggest that the Specific Energy Absorption characteristics of the car population can be represented by a single equation.

Figure 1 shows root(2 x E/Mk) data for 67 car types and 205 barrier tests (14) plotted against normalised crush depth (d/L) for cars produced between the mid 1950's and the mid 1980's. The figure demonstrates the nonlinear nature of the relationship. Wood (14) has shown that equation 2 can be used with exponent, n =2/3 to model the Specific Energy Absorption behaviour of the car population. Moore (17) has also shown that

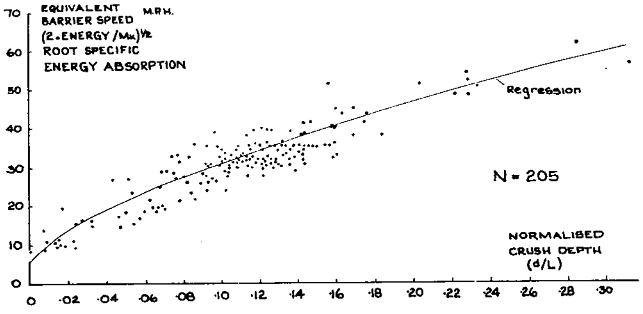


Figure 1. Root Specific Energy Absorption Versus Normalized Crush Depth (d/L)

impact speed is related to permanent crush to the 2/3 power. Regression analysis of the data shown in Figure 1 yields the following relationships,

1. 122 Barrier Tests of 26 Car Types from 1975 to 1986.

$$(2E/Mk)^{1/2} mph = 4.60 + 119.1(d/L)^{2/3} \tag{3}$$

Coef. of Determination = 0.854, Std. Dev. = 3.71mph.

2. 163 Barrier Tests of 59 Car Types from 1970 to 1986.

$$(2E/Mk)^{1/2} mph = 5.16 + 119.24(d/L)^{2/3} \tag{4}$$

Coef. of Determination = 0.756, Std. Dev. = 4.60mph.

3. 183 Barrier Tests of 66 Car Types from Mid 1950's to 1986.

$$(2E/Mk)^{1/2} mph = 5.05 + 119.2(d/L)^{2/3} \tag{5}$$

Coef. of Determination = 0.760, Std. Dev. = 4.50mph.

The regression is shown in Figure 1. 76% of the variance is accounted for by the regression. The remaining 24% of the variance not accounted for by the equation is due to the variation between the characteristics of individual car types and to the variation in the crush behaviour of individual cars within any given car type.

Application to Frontal Collision Speed Estimation

Equations 3 to 5 can be used to estimate, from the permanent crush damage of the cars, the energy of approach of the vehicles for collisions where in the course of the collision relative motion between the vehicles ceases in the area of mutual contact. The equations do not account for restitution effects. The specific energy absorbed by each vehicle is obtained by calculating the mean value of the normalised crush depth, (d/L) across the full width of the front of each vehicle, refer Figure 2, and substituting into equation 3, 4 or 5.

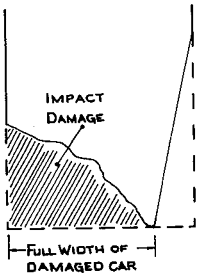


Figure 2. Typical Damage Profile

Staged impact tests by Ueyuma et al (18) have confirmed that the preimpact orientation and overlap of the vehicles can be reconstructed by matching the detailed damage profiles obtained for the collision vehicles. When the relative orientation of the vehicles is known, then, for frontal impacts, it is unnecessary to estimate the direction of the crushing forces applied to each vehicle as the impact equations can be directly solved from the relative orientation information, for example refer to Limpert (19). This allows the Collision Closing Speed (CCS) of the vehicles towards each other and the magnitude of Delta V of each vehicle (for e = O) to be calculated.

Missing Vehicle

Often only one of the two cars involved in a collision is available for measurement. In the collision both vehicles would have experienced equal and opposite momentum impulses from the collision process. As the estimation for crush energy of each vehicle is 0.5 x Mk x (EBS)2 the magnitude of the impulse can be estimated as being Mk1,2 x EBS1,2. This yields the total crush energy equation,

$$Et = E1 \cdot [1 + Mk1/Mk2] \tag{6}$$

where E1 is the estimated crush energy of the measured car and Mk1, Mk2 are the kerb masses of the measured and missing cars respectively.

Comparison with Staged Frontal Collisions

Prasad (4) used data from nine staged frontal collisions, five full width and four with typically 45% overlap to evaluate the effectiveness of both CRASH 3 and of his reformulation based on the characterisation of the energy absorption properties of individual car types. Five different car types were used in these tests. *No barrier test data for these five car types were used in the derivation of equations 3 to 5.*

In three of the staged 45% overlap tests only the crush measurements in the contact zone between the two vehicles were reported. Tumbas and Smith (20) have shown that it is necessary to include measurement of the induced damage when calculating the absorbed energy. Examination of real world frontal crashes shows that the induced deformation of the fronts of cars is generally triangular in nature and that the non contacted portion of the front bumper and its associated front wing act in a manner similar to two pinjointed members. Baumann (21) and Hight (22) confirm this deformation pattern. This allows the induced damage for the three staged tests to be estimated, refer Figure 3.

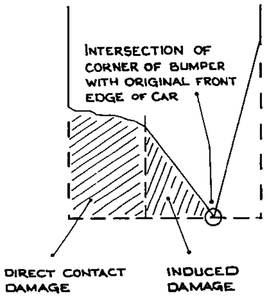


Figure 3. Induced Damaged Correction

Table 1 details the difference between predicted and actual Delta Vs as a percentage of the predicted value of Delta V for each car in the nine staged tests when using

1. Equation 3 of General Model
2. Prasad's Algorithm (4)
3. CRASH 3
4. Missing Vehicle Estimator with Equation 3 of General Model.

Table 1. Comparison of Percentage Difference between Predicted and Actual Delta V's in Nine Staged Car to Car Frontal Impacts using Various Prediction Algorithms

Algorithm Vehicles	Prasad(4)	CRASH 3	General Model	Missing Vehicle
Honda '84 Accord	2.65%	6.33%	6.33%	.40% / 13.33%
Chev '84 Celebrity	3.57%	7.45%	7.33%	1.33% / 14.39%
Renault '83 Fuego	2.84%	5.65%	5.92%	-6.13% / 17.98%
Chev '83 Celebrity	-1.57%	1.24%	1.24%	-10.20% / 12.90%
Honda '84 Accord	-5.69%	-3.33%	-1.47%	1.53% / -5.73%
AMC '82 Concord	-5.50%	-3.61%	-1.29	1.73% / -5.54%
Dodge '83 Omni	0.34%	-18.33%	1.40%	7.69% / -8.20%
AMC '82 Concord	-0.58%	-2.39%	0.44%	6.65% / -9.08%
Dodge '83 Omni	3.57%	-3.00%	-6.07%	7.93% / 4.17%
Dodge '83 Omni	3.47%	-3.34%	5.99%	1.14% / 0.77%
Honda '84 Accord	6.11%	-6.55%	-4.25%	-4.22% / -4.29%
Honda '84 Accord	0.00%	-11.58%	-9.96%	-9.93% /-10.06%
Renault '83 Fuego	3.90%	-5.24%	-9.41%	-9.17% /-10.28%
Renault '83 Fuego	-3.33%	-11.85%	-15.76%	-15.56% /-15.96%
Honda '84 Accord	9.73%	5.40%	15.87%	28.90% /-10.70%
Renault '83 Fuego	10.17%	6.13%	13.59%	22.40% /-13.68%
Dodge '83 Omni	6.13%	0.33%	-0.83%	-15.77% / 15.30%
Chev '83 Celebrity	7.11%	2.26%	0.67%	-14.48% / 17.03%

Statistical analyses of the results are shown in Table 2.

Table 2. Statistical Summary of Comparison between Predicted and Actual Delta V's

Algorithm Item	Prasad's Algorithm	CRASH 3	General Model	Missing Vehicle
No of Data	18	18	18	36
Mean Difference %	2.39	-1.91	1.22	-0.95
Standard Deviation %	4.63	7.14	7.95	11.91
Mean Absolute Difference %	4.24	5.78	5.99	9.85
R.M.S. Difference %	5.10	7.2	7.82	11.74

Comparison shows that the standard deviation obtained when using Prasad's algorithm is 4.63% while it is 7.95% when using the general model, 7.14% using CRASH 3 and 11.91% when using the Missing Vehicle estimator with the General Model. Variance Ratio tests show no significant difference between the General Model outlined in this paper and CRASH 3. Prasad's algorithm (4) is significantly better than both at the 5 level but not at the 1% level. The Missing Vehicle estimator is significantly worse than the General Model and CRASH 3 at the 5% level but not at the 1% level. The data shows that the 95% confidence limits for prediction of Delta V are,

Prasad's Algorithm	±10%
CRASH 3	±15%
General Model	±17%
Missing Vehicle + General Model	±24%

This analysis shows that the Specific Energy Absorption properties of the car population in frontal collisions can be represented by a single equation and that when applied to predict the Delta V's in nine staged collisions accuracies similar to CRASH 3 are obtained. When the energy absorption properties of the individual car types are known a significant improvement in Delta V prediction is obtained. However this data is not available for many, particularly European, car models. When only one vehicle is available for permanent crush measurement the Missin Vehicle estimator derived here can be used to calculate the total crush energy but gives a coarser prediction of Delta V than when both sets of crush measurements are available.

References

1. Campbell, K L "Energy basis for collision severity" SAE Paper 740565, 1974.
2. McHenry, R R "A comparison of results obtained with different analytical techniques for reconstruction of highway accidents" SAE Paper 750893, 1975.
3. Zeidler, F et al "Accident research and accident reconstruction by the EES accident reconstruction method" SAE Paper 850256, 1985.
4. Nilsson-Ehle, A et al "Evaluation of a method for determining the velocity change in traffic accidents" SAE Paper 826081, 1982.
5. Prasad, A K "CRASH 3 damage algorithm reformulation for front and rear collisions" SAE Paper 900098, 1990.
6. Emori, R I "Analytical approach to automobile collisions" SAE Paper 680016, 1968.
7. Lim, G G "Crash data analysis" SAE Paper 720496, 1972.
8. Prasad, A K "Energy dissipated in vehicle crush-a study using the repeated test technique" SAE Paper 900412
9. Strother, C E et al "Crash Energy in accident reconstruction" SAE Paper 860371, 1986.
10. Woolley, R L et al "Inaccuracies in the CRASH 3 program" SAE Paper 850255, 1985.
11. Sakuri, T et al "On the safety body structure of finite element method analysis" Proc. 12th. E.S.V. Conference, 1989, p. 327- 333.
12. Fonda, A G "Crush energy formulations and single-event reconstruction" SAE Paper 900099, 1990.

13. Pugsley, A "The crumpling of tubular structures under impact conditions" Proc. of Symposium on the use of aluminium in railway rolling stock, Instn. of Locomotive Engrs., London 1960, p. 33-41.
14. Wood, D P et al "Frontal collision speeds from damage—an empirical approach" Proc. of the Canadian M.R.S.Conf.7, p. 264-274.
15. Schmidt, R "Realistic compatibility concepts and associated testing" 6th. E.S.V. 1976, p. 234 -247.
16. Danckert, H "Development of crash energy management solutions" SAE Paper 760793, 1976.
17. Moore, D F "Minimization of occupant injury by optimum front end design" SAE Paper 700416, 1970.
18. Ueyuma, M et al "Determination of collision configurations from vehicle deformation patterns" SAE Paper 910127, 1991.
19. Limpert, R "Motor vehicle accident reconstruction and cause analysis" Publ. Michie 1989.
20. Tumbas, N S et al "Measurement protocol for quantifying vehicle damage from an energy basis point of view" SAE Paper 880072, 1988.
21. Baumann, K H et al "Frontal offset crash testing for approximately 15 years: results, experiences and consequences" SAE Paper 900413, 1990.
22. Hight P V et al "Barrier equivalent velocity, delta V and CRASH 3 stiffness in automobile collisions" SAE Paper 850437, 1985.

S1-W-29

Special Product/Person CVS-ATB 3-D Simulations

Donald Friedman
Donald Friedman Liability Research Group

Introduction

The versatility of the CVS-ATB 3-D simulation program is demonstrated by its use in varied product liability research. The power of this protocol is the scientific interpolation of the facts or witness marks and the time history of detailed accident events which make it far more accurate and reliable than popular illustrative animations. This paper describes the validation and qualification of hypotheses on injury accidents involving:

1. boat propeller/swimmers;
2. vision sensitivity;
3. football helmets;
4. rollovers;
5. ejection;
6. pedestrian impact trajectory; and,
7. asymmetrical seat back failure.

A brief description of a sample case history of each accident type is given, followed by the procedure used to reconstruct the accident/injury.

Case History Analyses

Boat Propeller/Swimmers

In the U.S., outboard motor propellers frequently injure thousands of swimmers at very low boat speeds. A long standing invention is the caged propeller whose edges are precluded from contacting swimmers. A recent case involved a young man whose leg was sliced to the bone from hip to ankle. To reconstruct the accident, a stuntman was overrun with a caged propeller without injury. Understandably, there were no volunteers for the open propeller, although the regularity of the victim's cuts needed no physical demonstration as to what happened.

We created a rotating propeller whose size and speed could be set on a shaft, attached to a boat, and we then floated a Hybrid III dummy under the boat so that it interacted with the blades of the propeller producing the injury as shown in Figure 1 at 0, 150 and 300 milliseconds.

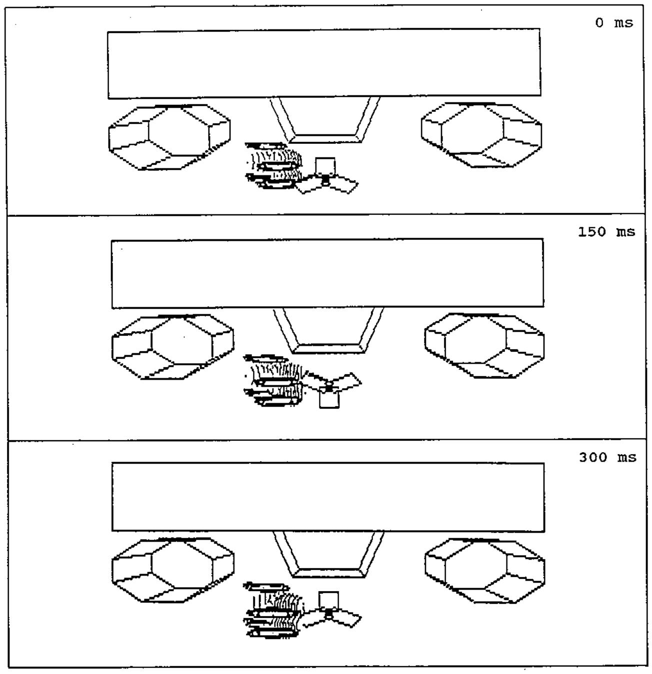


Figure 1. Rotating Engine Propeller on Pontoon Boat Contracting Hybrid III Swimmer at 8 mph, Viewed from the Rear

Then we caged the propeller and repeated the event. The differences in the kind and level of injury were obvious and identified by using GM HYBRID III Injury Measure Criteria. The following figure 2 illustrates the same scene intervals with a caged propeller from a camera position below the swimmer.

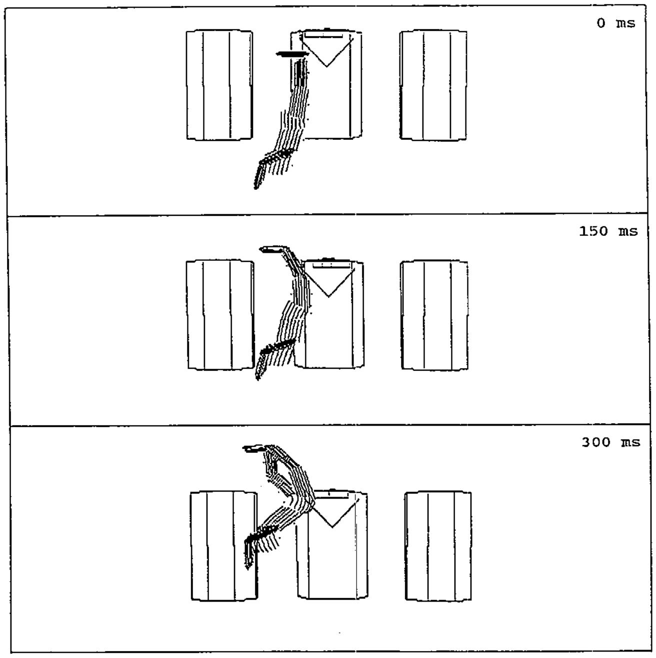


Figure 2. Caged Rotating Engine Propeller on Pontoon Boat Contracting Hybrid III Swimmer at 8 mph, Viewed from Below

Vision Sensitivity

A small child on a plastic "Big Wheel" tricycle rode a long driveway and into the road immediately behind a parked car. Low hedges, a tree and the parked car obscured the child from the driver of a Cadillac proceeding down the residential street at a moderate rate of speed. The driver claimed he couldn't see the child until it was too late to stop. The child was brain damaged by a strike from the right front bumper.

The manufacturer of the tricycle offered a visibility pennant on a 60" wand as an option. If attached, it would have substantially altered the conspicuity of the moving tricycle and child to the driver.

The scene was recreated with the parked car, hedges and driveway. A parametric study was done, based on the uncertainty of the speed of the car and the tricycle. Cameras observing the scene were located at the site of the stationary witness and the moving driver who were asked to judge which speeds best suited their recollection. Then, the tricycle was fitted with a fluttering pennant which made the tricycle motion clearly visible to the driver several seconds earlier than in the accident. Figure 3 and 4 show the scene in time sequence from the viewpoint of the driver.

Football Helmets

Several cases involving football player interaction during a game have resulted in quadriplegic neck injuries and have been modeled. The actual play scenes have always been documented in real time with game film cameras. In conjunction with player and witness testimony and the specific characteristics of the injury, this has been sufficient to recreate the kinematic interaction in detail as shown in figure 5.

By placing computer scene cameras at the sites of the actual game camera as well as at the location of witnesses, discrepancies with details could be resolved in individual recollections relating to the orientation of the players relative to the field markings and each other, which assisted in quantifying the contact impact orientation and velocity.

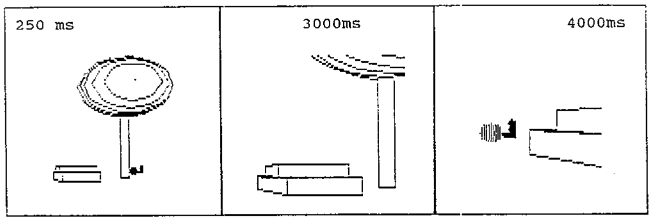


Figure 3. Child on Tricycle from Camera at Driver's Eye Point Emerged from Hedges but Still Behind Tree and Parked Car to Impact

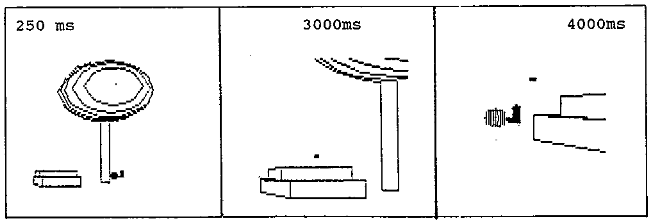


Figure 4. Child on Tricycle with Fluttering Pennant, from Camera at Driver's Eye Point Emerged from Hedges but Still Behind Tree and Parked Car on Impact

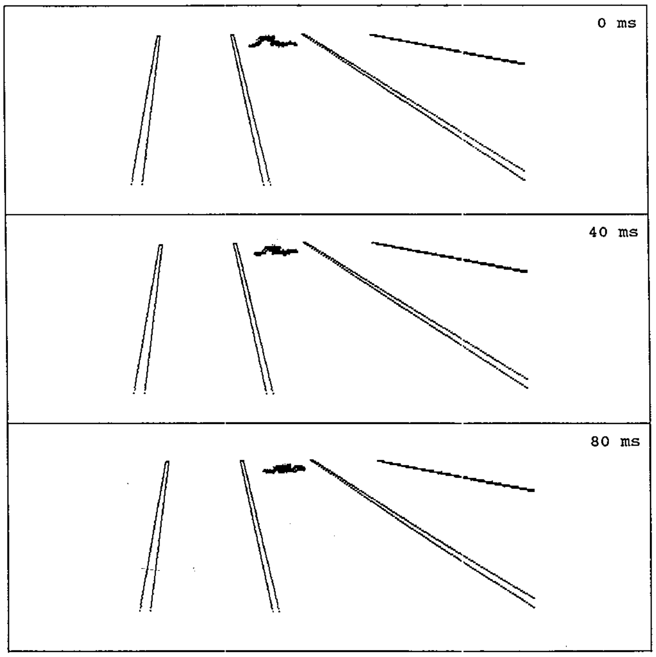


Figure 5. Motion and Interaction of Opposing Football Players from Game Camera Position Duplicating Injury Action

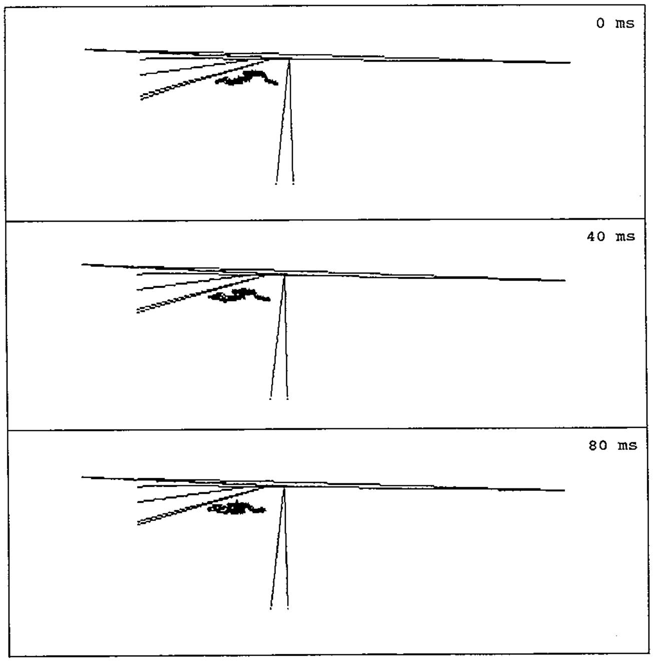


Figure 6. Motion and Interaction of Opposing Football Players from Far Side Witness Camera Position Duplicating Injury Action

In particular, this protocol moved the demonstration and performance of helmets from considering the effectiveness of a head/helmet into wall impact, to consideration of the mass effects (such as head to thigh) and to inertial and compliance effects (such as head to edge of abdominal torso).

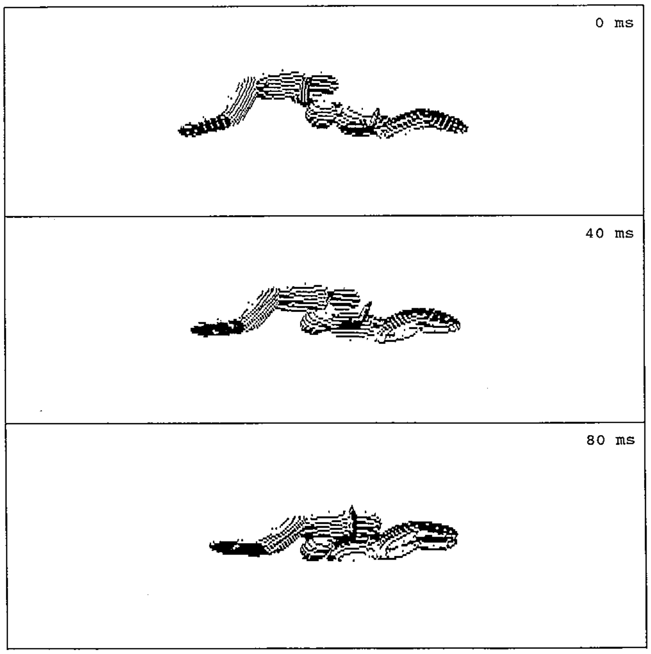


Figure 7. Motion and Interaction of Opposing Football Players from a Close-Up Camera

These considerations led to a more refined understanding of the effectiveness of the top of the head/helmet force/deflection characteristics. That in turn led to suggested modifications and improvements limiting the risk of quadriplegia.

Rollovers Involving Roof Crush Injuries

A variety of rollover accidents have been simulated from the initiation of yaw rotation to the lateral trip point and with the help of surface witness marks the touchdown points, orientations and time history of occupant events.

From the technical perspective, the SMAC program is generally used to relate vehicle planar motion and to establish the take off conditions at roll initiation and CVS simulation. The orientation of the vehicle in six displacement coordinates at several witness mark locations are estimated, and a spline fit is developed to connect the points; the spline fit is calculated not only in displacement, but velocity and acceleration as well.

Graphical plots of the motions are reviewed for reasonableness, comparison to test data, and empirical rules. The curves are reshaped and regenerated (iterated) to remove obviously impractical inflection points and excessive rates, as well as to enhance short term contact accelerations and/or deformations.

The process is not precise, but far more accurate and explicit than a verbal description and playing with model cars. And it is subject to validation by the occupant kinematics in relation to interior witness marks. Because having established the trajectory, we place the occupants in the compartment and observe their motion, interior contacts and the resulting forces on various body parts. Usually the major injuries are immediately evident or the adjustments are obvious.

Two technical observations are important.

1. The circumstances of an accident are so complicated, the number of variables so large, and the ability to know the unknowable so limited, that a adversary litigant almost always attempts to discredit the validity of the effort. One must agree with the limitations of precision, but there is only one recognized limitation to the claim of accuracy and that is the demonstration of an alternate reasonable interpolation of the factual evidence.

   Each time such an alternate scenario has been demonstrated (with accompanying photographic or instrumentation output), the ability to compare results makes the truth clear even to the lawyers, and the case settles (so far, always in favor of the victim). What this means is that the circumstances are so complicated and the number of pieces of factual (physical) evidence so great that there are no two ways to quantitatively describe it without making judgmental errors obvious.
2. There are times when the limitations of the model can cloud the issues. This is usually the case when vehicle component intrusion occurs during an occupant contact. Because CVS cannot normally

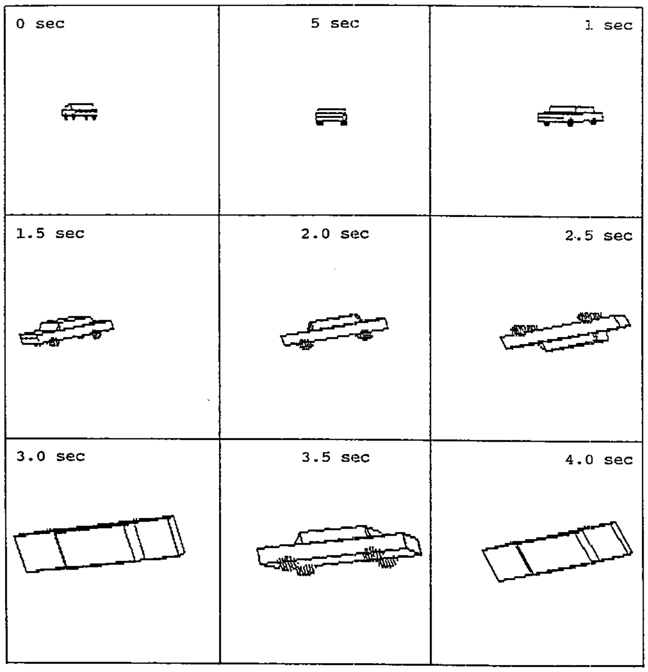


Figure 8. Vehicle Trajectory Motion from Leaving the Road and During Rollover from Stationary Camera in Front of Rest Position

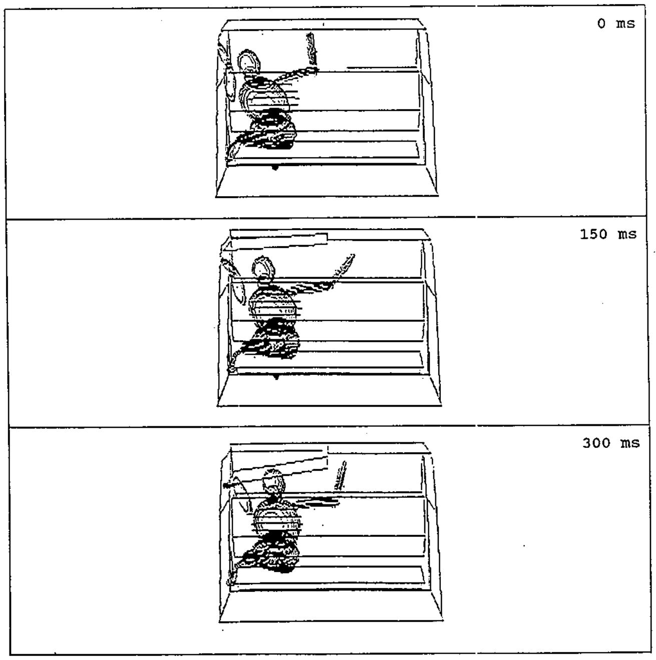


Figure 9. Rollover Roof Collapse on a Belted Occupant with Extensive Headroom from an Onboard Rear View Camera

move surfaces as a function of time during an event, we usually determine (and initially set) the positions of those surfaces relative to the point in time at which the occupant gets there.

However, if the impact is strongly dependent on the surface motion, we have developed a way to give that surface its own displacement pulse which parallels the vehicle until deformation takes place. This is usually important and therefore used in roof crush cases.

The illustration of Figure 9 is a vehicle with ample head room which has gone out of control, rolled one and a half times, ending up side down on the roof with the belted 50th percentile male a quadriplegic from roof collapse to the window sill during the 200 ms at final touchdown.

Rollover with Ejection

The rollover procedure previously described, and providing ejection portals, usually provides the answers directly. I am reminded of a case described in SAE 890382 ("Live Subject Safety Research") in which the time of ejection determined the time of belt release, and another case in which a small four year old unrestrained boy came out a rear side window after a left frontal offset impact induced a violent counterclockwise yaw prior to the initiation of roll.

But the case study here is an ejection during a roll. A young unrestrained woman driving friends on a dirt and gravel mountain road loses control and goes off the road. She goes out the open window as the roll is in process.

In considering countermeasures, the possibility of reducing the size of the side window by upper fixed laminated glazing would have significantly strengthened the roof and prevented the ejection. This was demonstrated with a window (outlook) input modification and rerun.

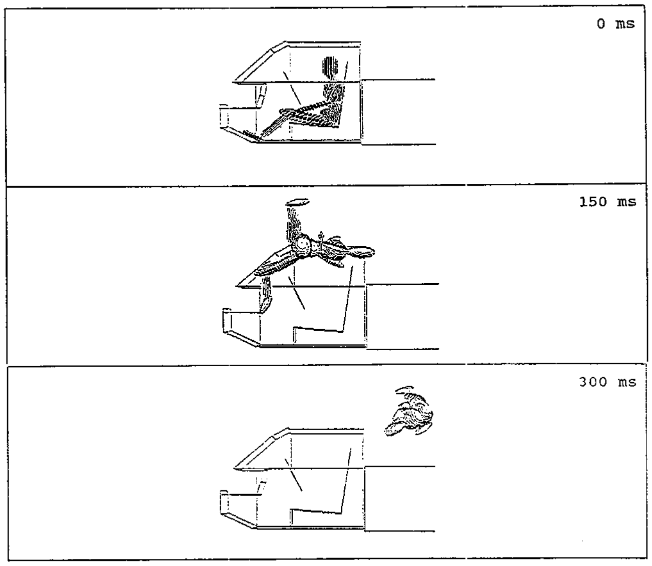


Figure 10. Rollover Ejection of an Unbelted Occupant from an Onboard Side View Camera

Nighttime Truck/Pedestrian Impact

An interesting analysis was required in the case of a pedestrian struck by a large semi-tractor truck at night on a rural road. The questions to be resolved were concerned with where the pedestrian was when he was struck, where on the vehicle was he struck, what was his trajectory to his place of rest on the shoulder, and could the driver have been taking evasive action at the time of contact.

The truck's right-front corner was particularly uniform in its radius of curvature, and its deformation, as a result of the impact, was clearly indicated. The driver's account established the impact point to be less than 100 feet from the pedestrian's point of rest due to his recognition of landmarks. This established the truck's velocity as more like 40 mph, as he claimed, than 50 claimed by the plaintiff witnesses.

A hybrid three dummy was placed standing erect at the right front corner of the truck moving at 40 mph, and the series of 50 millisecond impacts were developed to determine the effective body part injuries. The pedestrian had received severe brain damaging head impact, several fractured ribs on the left side, bruised left hip and thigh tissue with no other significant injuries. The injury measures identified for the Hybrid III dummy allowed us to move the dummy in one inch increments relative to the truck edge, right and left of the body centerline. Using this technique, we were able to identify the probable strike position within one inch and about 20 degrees of mid-sagittal plane rotation.

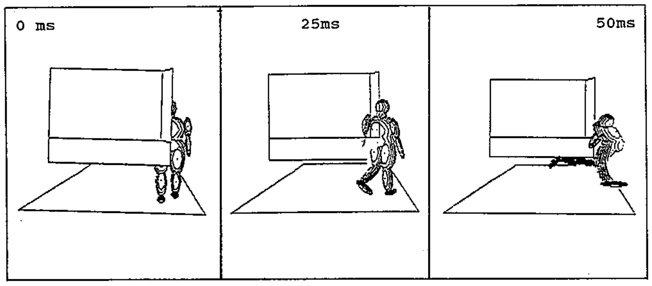


Figure 11. Pedestrian Impact on the Right Front Corner of a Tractor/Trailer to Locate Impact Position from Deformation and Injury

Having selected the strike position, we allowed the run to develop for three seconds during which time the pedestrian came to rest on the surface about eight feet to the right of the truck, about 70 feet from the strike position and oriented as the witnesses had found him.

Once having created the scene, it was possible to view it from cameras located on the truck, on the ground, overhead, etc. The tabular positions of each of the body parts also allowed the motion of the pedestrian after impact to be color-coded and overlaid with clothing and more realistic and recognizable features than the wire frame output, the technical mode of analysis, without losing science in favor of illustration.

Other features consisted of locating the camera at the driver's viewpoint prior to impact, and estimating, on the basis of conspicuity, the driver's reaction time and vehicle response characteristics.

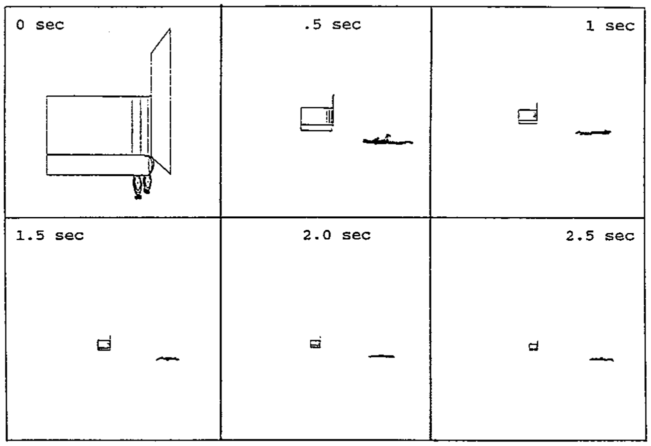


Figure 12. Pedestrian Impact on the Right Front Corner of a Tractor/Trailer and Propelled Forward and to the Shoulder of the Road from a Rear Mounted Vehicle Camera

Asymmetrical Seat-Back Failure

This case is a relatively low speed rear impact in which the seat back failed at the hinge point on the left, but not on the right. The consequence was to cause the driver to displace aft with a high angular rotation rate around his spine producing a torsional failure in his lumbar spine. This was compared with the lack of injury which would have resulted from the same circumstances had the left hinge not failed.

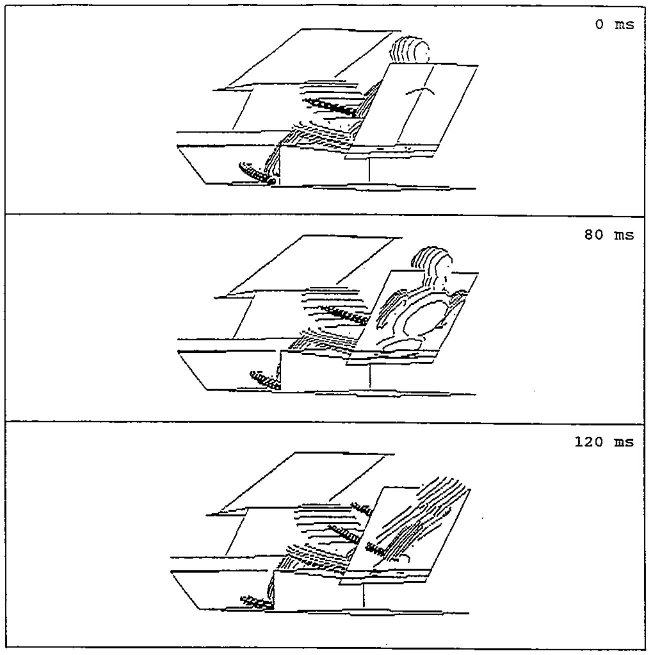


Figure 13. Asymmetrical Seat Back Failure Resulting in Lumbar Spine Torsional Injury from Left Rear Package Shelf Camera

Conclusions

The facility with which accident injury simulations can be conducted and iterated using the Hybrid III dummy (or a re-sized Hybrid III based on victim characteristics) is a powerful tool in relative terms and more effective than physical testing.

Establishing the interactive force/deflection properties presents a problem in absolute terms which can be resolved by duplicating a physical test; but the reality of litigation is associated with the correction of defects, a relative parameter. As such, the CVS model can be considered an ideal diagnostic tool for low cost analysis, validation and qualification of expert opinions in much the same way that it is used in adjusting designs to optimize performance in the original design process.

The CVS model forms the basis for a technical presentation of data based on the laws of physics. It is not only illustrative, but it has a potential graphical impact on the lay public.

References

1. "Live Subject Safety Research;" D. Friedman, S. Forrest, F. Gott, G. D. Dyne, SAE 890382. SAE 32nd STAPP Car Crash Conference in Atlanta GA, 1989.
2. "Reconstruction of Frontal Accidents Using the CVS 3-D Model," K. Diggs, SAE 840869.
3. "Prediction of an Occupant's Motion During Rollover Crashes," SAE 861876, L. Obergefell, I. Kaleps, A. Johnson.
4. "An Improved Three Dimensional Computer Simulation of Vehicle Crash Victims," Vols. I-IV. J. T. Fleck, Calspan Corp., April 1975; PB-241-692, DOT-HS-801-507.
5. "Development of an Interactive Computer Program to Produce Body Description Dara, GEBOD," L. Baughman, Air Force Aerospace Medical Research Laboratory, July 1983; AFAMRL-TR-83-058.
6. "Recent Improvements in Occupant Crash Simulation Capabilities in the CVS/ATB Model," SAE 880655, K. Diggs, NHTSA, March 1988.
7. "Improvements in the Simulation of Unrestrained Passengers in Frontal Crashes Using Vehicle Test Data," SAE 860605, K. Diggs, 1986.

Technical Session 2
Safety Improvements from Advanced Vehicle/Highway Technology

Chairperson: Claudio Schinaia, Italy

S2-O-01
Intelligent Vehicle Highway Systems—Safety Benefits and Public Policy

Eugene I. Farber
Ford Motor Company

Abstract

Autonomous Intelligent Cruise Control (AICC) will likely be one of the first applications of Automatic Vehicle Control Systems (AVCS) for motor vehicles. AICC is a relatively simple system which requires no breakthrough technology and no highway infrastructure or cooperative communication with other vehicles to function. AICC is an enhancement of conventional cruise control systems in that it can assume the task of longitudinal station keeping in traffic by automatically maintaining an appropriate speed-related following distance behind a lead vehicle. Although AICC is likely to be marketed as a convenience feature, it may have significant safety and mobility benefits. An analysis of the kinematics of car following indicates that an AICC systems has the potential to reduce the frequency of severity of rear end crashes. Concerns about risk compensation are discussed. A simple analysis suggests that net safety benefits can accrue even if drivers become somewhat less attentive because of reliance on the system for station-keeping in traffic. Tort liability is a major concern that could influence the timetable for deploying AICC and related AVCS applications. It is concluded that a broad industry consensus and the support of government agencies may be a necessary precondition for deployment.

Introduction

This paper addresses a number of issues relating to Automatic Vehicle Control Systems (AVCS) and safety. AVCS is one of the application areas included under the heading of Intelligent Vehicle Highway Systems (IVHS) in the U.S. and has the most direct connection with safety. The AVCS area generally corresponds to the PROMETHEUS topics: *Proper Vehicle Operation, Collision Avoidance, Cooperative Driving and Autonomous Intelligent Cruise Control.*

Although some of the points I will make are relevant to any AVCS feature having an influence on safety, the particular focus is on Autonomous Intelligent Cruise Control (AICC) and related applications of the underlying technology, namely front obstacle detection and collision warning and avoidance systems. This paper focuses on AICC because it is potentially the first production application of AVCS technology and as such will be the "test case" for the development of public policy in this area. While it is likely that the first AICC systems will be marketed primarily as a convenience rather than as a safety system, this paper is primarily concerned with the potential safety benefits of AICC.

AICC Functional Characteristics

The basic idea behind AVCS concepts is the application of advanced sensing, vehicle dynamics and data processing technology to perform some of the basic driving and control tasks, such as steering, braking and lane-and distance-keeping, that are presently wholly under the control of the driver. Existing conventional cruise control systems approach the AVCS concept. However, AICC goes beyond conventional cruise control by providing the capability for automatic following or "station-keeping." In an AICC system, front-mounted sensors measure the distance to and relative velocity with the vehicle ahead. This information is processed to drive brake and throttle actuators to establish and maintain an appropriate speed-related following distance even when the vehicle being followed speeds up and slows down. If the followed vehicle comes to a stop, the AICC vehicle will come to a stop behind it; when it starts again, the AICC car follows. When no lead vehicle is present, the AICC functions as a conventional cruise control system to maintain a preset speed.

Autonomous Intelligent Cruise Control may be one of the first AVCS applications to achieve practical implementation. There are several reasons for this. First, it appears that it may be possible to implement the system using relatively inexpensive sensor technology. Second, the sensing and computational requirements for AICC are relatively modest in comparison with accident avoidance systems. And finally, the system is autonomous—it requires no road infrastructure nor communication between vehicles to function.

AICC promises several benefits. Considered as an extension of conventional cruise control, it can provide a significant improvement in the ease and convenience of driving, especially in stop-and-go traffic. It is also anticipated that such systems, when widely deployed, will smooth traffic flow by damping perturbations and improve the capacity of intersections by reducing start-up delays. Moreover, by adjusting some of the control parameters, the system can be configured as a front obstacle detection and collision warning system or a collision avoidance system. However, as will be shown below, even in an AICC configuration, such a system may offer considerable safety benefits by anticipating and avoiding potential conflicts and by providing a compelling warning to drivers—the onset of automatic braking—when a conflict occurs. In particular, AICC has the potential to reduce the number and severity of rear-end collisions in traffic.

It needs to be emphasized that while prototypes AICC systems exist, the technology is still very much in the development stage and many problems remain to be resolved before it can be practically implemented.

Analytical Findings

A series of simple kinematic analyses of rear end collision scenarios was undertaken by means of computer simulation to develop an understanding of the nature and order of magnitude of the safety benefits that an AICC system might provide. The particular scenario studied was as follows: one vehicle is overtaking another in the same lane at some relative speed (ΔV). A rear-end collision may occur in this scenario if the overtaking driver is inattentive. Whether or not a crash actually does occur depends principally on four factors: (1) the distance at which the overtaking driver "wakes up" and observes that he is rapidly closing with a lead vehicle, (2) the rate of overtaking, i.e., the (ΔV), (3) the overtaking driver's reaction time and (4) how hard the overtaking driver brakes. In the analyses reported here, it was assumed that the following driver first becomes aware of the situation when the separation between the vehicles is 50 meters. The analyses were undertaken to explore the effect of an AICC system on the outcome.

AICC System Assumptions

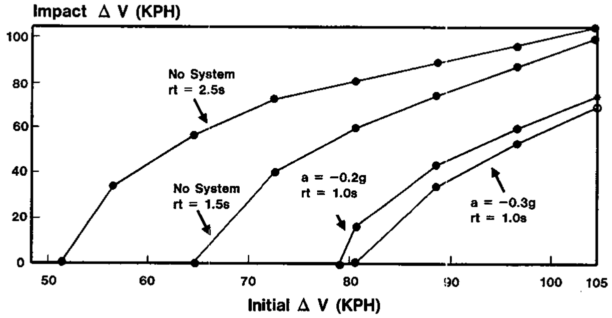
The assumptions about the AICC operating characteristics and the response of the driver were as follows:

1. The AICC system initiates braking as soon as the lead vehicle is within the operating range of the system and a positive ΔV is sensed.
2. The operating range of the AICC system is 50 meters.
3. The sudden onset of automatic braking acts as a strong warning signal to the driver and thereby reduces his reaction time to one second.
4. Following the driver reaction time interval, the driver brakes at up to 0.7g, overriding any AICC braking.

Results

Figure 1 shows the outcome, expressed as the impact ΔV as a function of the initial ΔV, for four different sets of conditions:

1. No AICC system, and a worst case driver reaction time (2.5 sec)
2. No AICC system with an average driver reaction time (1.5 sec),
3. AICC system present with braking authority limited to 0.2g, minimum driver reaction time (1.0 sec)
4. AICC system present with braking authority limited to 0.3g, minimum driver reaction time (1.0 sec)



Initial Separation: 50 M

Figure 1. Impact ΔV as a Function of Initial ΔV

For the first no-AICC case (2.5-second reaction time), a rear end crash will occur whenever the initial ΔV (the overtaking rate) is greater than 51 kph. The crash ΔV increases with increasing values of the initial ΔV and is equal to the initial ΔV when the initial ΔV is over 72 kph, i.e., the crash occurs before the driver has a chance to respond.

In the second no-AICC case (1.5-second reaction time), no crashes take place for initial values of ΔV less than 64 kph, and at higher initial ΔVs, the ΔV at impact is much reduced when compared with the first (2.5-second reaction time) curve.

The third curve shows the outcome when the overtaking car is equipped with an AICC system having 0.2g braking authority. The result is that accidents associated with initial ΔV values less than 79 kph are eliminated and those that are not eliminated occur at reduced crash ΔV's.

The forth curve gives the results when AICC braking authority is set at 0.3g. Increasing the braking level to 0.3g results in relatively little improvement because the automatic braking interval is only one second.

As is apparent from the figure, an AICC system offers the possibility of a significant safety benefit, even under the very conservative assumptions of a 50-meter operating range and braking limited to 0.2g. The results suggest that many rear end collisions might be avoided and in those not avoided, the impact speed can be considerably reduced. Since the crash severity increases roughly as the square of the ΔV, the net savings could be significant.

In the following paragraphs, I discuss a number of factors bearing on the feasibility of such systems and their deployment.

The Chicken and the Egg

An important advantage of AICC and related systems is that they are autonomous and thus can be implemented without regard to the development of a larger infrastructure. There is no doubt that an infrastructure-based system has a more far reaching potential than a collection of independent, non-communicating vehicles. However, systems based on the integration of vehicle and highway infrastructure components are subject to the chicken-and-egg problem, i.e., each component provider requires a commitment that the other will actually be deployed before its deployment can be justified. In practical terms, this means that it will be difficult for public or private organizations to commit resources to design, develop and deploy the infrastructure without a broad commitment from the auto industry to install the necessary vehicle components; by the same token, it will be difficult to convince auto companies to commit significant resources to design, develop and install the necessary vehicle hardware unless they are very sure a compatible infrastructure will be broadly deployed.

The problem appears to be especially difficult in systems that require communications between vehicles. In systems involving only vehicle-infrastructure communication, all system vehicles, even the first few, give their drivers access to the full functionality of the system. In systems requiring vehicle-to-vehicle communication, such as electronic platooning, system vehicles will have little or no functionality until a large number of vehicles are equipped. It is simply unrealistic to expect consumers to pay a premium for a system whose functionality depends on the purchasing decisions of others and is likely to be delayed for several years.

For these reasons, the development of motor vehicle AVCS features over the next 10 years or so will certainly emphasize vehicle-autonomous systems such as AICC, notwithstanding the vision of an integrated driving environment.

Catch 22

A routinely expressed concern about IVHS is that it is essentially self-defeating. This is the "Catch-22" argument: that improvements brought about by an IVHS deployment will merely stimulate the forces that brought about the problem in the first place. Thus it is argued that any reduction of congestion brought about by IVHS applications will soon result in increased demand, nullifying the gains. In the same vein the argument is made that safety improvements will lead to a compensatory increase in risk-taking on the part of drivers, resulting in an offsetting increase in accidents.

The extreme form of the risk compensation argument—that drivers vary their risk taking behavior so as to exactly counter any safety gains—has become known as "risk homeostasis" in traffic safety circles.

The concept of risk homeostasis has been aired at some length in the traffic safety literature over the last 10 years [Wilde 1982; 1986] and has been thoroughly discredited as a general principle [Evans 1991]. The more general concept of risk compensation is not so easily dismissed, however. It is reasonable to expect that drivers will take advantage of clearly perceived increases in driving safety margins by using up some of the margin. At the same time, it is important to understand that such feedback effects can occur without canceling all of the benefits. Thus, for example, speeds are higher on rural Interstate highways than on two-lane rural roads but the fatal accident rate on two lane roads is three times as high.

The risk-compensation argument when applied to AICC is that drivers will come to depend on the system for longitudinal station keeping and control to such a degree that the net result will be an increase in the probability of a rear-end crash. In fact, as the following analysis will show, it is possible to have some risk-compensation and still have a net safety benefit.

AICC System Reliability and Driver Risk—Compensation

Drivers are actually very reliable as longitudinal controllers in following situations, about 99.999,960%, or between "six and seven 9's" as a rough estimate (see insert below). What does this imply for an AICC system (or any AVCS application)? Must an AICC system be at least as reliable as a driver, i.e., at least seven 9's reliable, to be regarded as safe? As it turns out, the answer is no. What is important is not the reliability of the AICC by itself, but the combined reliability of the system and the driver. The overall probability of a rear-end crash in traffic in a vehicle equipped with AICC is the probability that the driver and the AICC system fail simultaneously. Since these are independent events, the probability of simultaneous failure is the product of the probabilities of driver and system failure. If the driver's reliability remains completely unchanged by the presence of the system, then even an AICC system with very poor reliability (e.g., one failure per 100 events) will produce a net improvement.

But we have acknowledged the need to consider the risk-compensation argument. Let's take an extreme case. Suppose that the presence of an AICC system produces a reduction of vigilance with the result that the driver's reliability decreases by a factor of 100. That is, the driver is 100 times more likely to have a crash, given that the system fails to work, than a normal ("non-compensating") driver. Suppose also that the AICC is only 1/100 as reliable as a longitudinal controller than the average driver. The net reliability (system plus driver) is given by

$$R(net) = 1 - P(d) \times P(s) = .999{,}999{,}999+$$

where

P(d) is the probability of driver failure

ESTIMATING THE RELIABILITY OF DRIVERS AS LONGITUDINAL CONTROLLERS

It is possible to make a rough estimate of the reliability of drivers as longitudinal controllers in following situations. Ford data indicate that drivers brake about 50,000 times per year on average. Most of these applications occur in routine stops and adjustments of speed in traffic. Even though these are very mild and routine adjustments, failure to make them in following situations would eventually result in a collision. This gives us a basis for making a rough estimate of driver reliability in station keeping. Assume that there are as many throttle adjustments to reduce speed as brake adjustments and that about half of these occur in following situations. Drivers in the U.S. average about one reportable rear-end crash every 50 years [NHTSA 1990]. This allows us to make the following estimates:

$$P = 1/(50 \times 50{,}000) \text{ or } 1/2{,}500{,}000$$

$$R = 1 - P = 0.999{,}999{,}600$$

where P is the probability of a rear-end crash, given the need to make a speed adjustment, and R is the reliability of an average driver as a longitudinal controller, where the definition of failure is a collision severe enough to be reported. These rough calculations suggest that drivers are very reliable in longitudinal control, somewhere in the range between six and seven 9's.

P(s) is the probability of an AICC system failure and
$P(d) = P(s) = 100 \times P$, i.e., 100/2,500,000
P is as defined in the insert above

The result is that even if both components of the larger system—the driver and the AICC—are considerably less reliable than a normal driver, the net reliability is much higher than that of a normal driver without the system.

Of course, the real concern with regard to the risk-compensation argument is not that driver reliability will decrease, but that it will go to zero or nearly so; that drivers will be so inattentive that the risk of a crash will actually increase.

I believe that this extreme form of the argument is difficult to sustain. Having a system that assumes a portion of the responsibility for station keeping will not permit a driver to withdraw his attention from the road. Driving a motor vehicle involves control tasks in addition to longitudinal speed and distance control. Drivers will still need to pay attention to the road ahead to steer, maintain lane position, follow the road, monitor traffic, attend to signs and signals, detect hazards, etc. Because their attention will continue to be externally focused, drivers will likely retain a high level of vigilance and will continue to be reliable detectors of situations requiring intervention. For these reasons it seems very unlikely that drivers would relax their vigilance to such an extent that an AICC system would produce a net reduction in safety.

Tort Liability Concerns and the Social Feasibility of AICC

AICC and related autonomous AVCS systems that might be introduced in the foreseeable future will not be 100% effective in preventing accidents. There are several reasons for this. First, these systems will not have anything approaching a general accident avoidance or warning capability, but will be effective primarily in rear-end collision situations.

Second, even in this limited application, AICC-type systems can reduce the likelihood and mitigate the severity of rear-end accidents, but they will not eliminate them. The need to keep false alarms to an absolute minimum and to minimize the consequences of false alarms when they do occur is a paramount consideration and imposes limits on the system's scope and range. Certain accidents may occur which arise from circumstances beyond the system's scope but which drivers are may regard as system failures.

Third, even assuming very high overall reliability, there still may be circumstances in which the system fails to prevent a preventable accident, either because of an actual malfunction or because of some unforseen operational circumstances.

Finally, there is the concern about risk-compensation raised earlier. Even if the overall number of accidents is reduced, it is possible that some accidents will occur because of driver over-reliance on the system. And of course, it is not beyond the realm of possibility that some drivers may blame the system for accidents caused by their own errors.

Tort liability is a major concern in the U.S., not only for auto makers, but also for public agencies which anticipate a significant social benefit from the deployment of IVHS. AICC is unique in that for the first time vehicle systems will perform longitudinal guidance and station-keeping functions, supplementing sensing, decision-making and control functions that have always been the responsibility of the driver. The introduction of such systems will be controversial no matter how well they perform.

These concerns raise a fundamental question about the social feasibility of AICC and AVCS in general. Will society permit the deployment of systems which may be fallible and limited in scope but which nevertheless offer significant net safety and mobility benefits? In particular, will concerns about tort liability delay or prevent the introduction of these systems? AICC will likely be the "test case" for the development of AVCS public policy on this issue.

The industry, the regulatory agencies and both private and public technical and social policy organizations should seek to establish a consensus regarding the deployment of AICC.

Conclusions

In summary, I offer the following conclusions:

- With continuing development, AICC offers the potential of useful safety benefits, improved ease of driving in congested traffic and improvements in traffic flow when the systems are deployed in large numbers.
- AICC is likely to the first AVCS application on the market and as such would be the pilot test for both public acceptance of AVCS and the development of public policy regarding AVCS.
- Tort liability is a major concern that could influence the timetable for deploying AICC and related AVCS applications. A broad industry consensus and the support of government agencies may be a necessary precondition for deployment.

References

Wilde, G. J. S. The theory of risk-homeostasis: implications for safety and health. *Risk Analysis* 2:209-255; 1982.

Wilde, G. J. S. Notes on the interpretation of traffic accident data and of risk-homeostasis theory: a reply to Leonard Evans. *Risk Analysis* 6:95-101; 1986.

Evans, L. *Traffic Safety and the Driver*. New York, NY: Van Nostrand Reinhold; 1991.

National Highway Traffic Safety Administration. *General Estimates System 1989—A Review of Information on Police-Reported Traffic Crashes in the United States.*

S2-O-02

Description of Three PROMETHEUS Demonstrators Having Potential Safety Effects

Daniel Jean Augello
Renault Research Staff
PROMETHEUS Project Manager

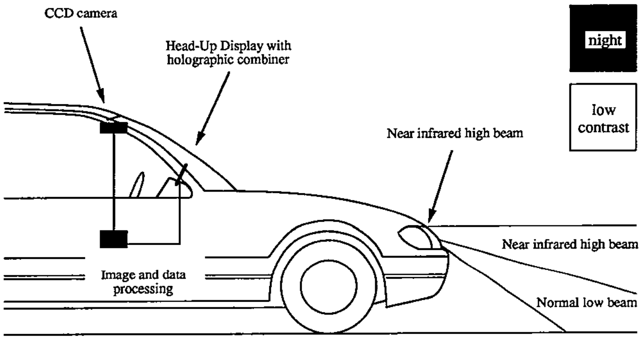
Abstract

The research program PROMETHEUS aims at improving road safety, traffic efficiency, comfort of road users, with less impact on the environment. We will illustrate in this paper the contribution of RENAULT to the objectives of PROMETHEUS through its work in the Common European Demonstrators program. More precisely 3 demonstrators already in test will be briefly described, namely: Vision Enhancement, Autonomous Intelligent Cruise Control and Cooperative Driving.

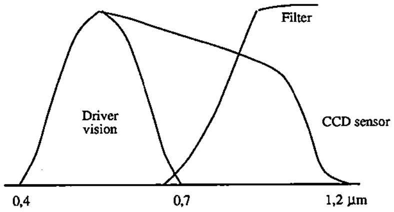
Vision Enhancement

Today travelling is essential, even at night and poor visibility conditions, but quite a high percentage of accidents can be attributed to the driver difficulty to cope with these situations. At night, driver's vision range is limited by the low beam range of normal head light.

The presence of oncoming traffic involves the blinding effect and consequently this situation becomes potentially very critical or dangerous. A first prototype car using a vision enhancement system had been implemented by RENAULT Research Center (Fig. 1).



NEAR Infrared Illumination of the scene and CCD Camera



Infrared headlamps

Cooperation Partners : THOMSON - PHILIPS LEP

Figure 1. Vision Enhancement

It is based on active near infrared high beam projectors and a CCD camera mounted inside the car at the level of the rearview mirror. The scene is illuminated in near infrared spectrum and CCD camera takes of the road scene an image which is presented to the driver on a Head-Up Display with an holographic combiner.

In the future, every car should be equipped with the same system and to avoid the problem caused by blinding effect to CCD sensor working on the same wave length region as NIR projectors (0,7 to 0,12 microns), polarizers have been mounted both on the NIR projectors and on the CCD camera with an angle of polarization of 45°.

By these means, the driver can see well over 300 meters in front and he can react in time to avoid dangerous situation. There are still open questions about this system, that need to be cleared in the near future: like presentation of information to the driver, investigation of possible side effects, product liability and low cost sensors.

Autonomous Intelligent Cruise Control (AICC)

AICC is an assisting system, it should be seen as an enhanced version of the existing Cruise Control system, not only keeping the selected speed but also a safe distance by adapting the speed of the own vehicle to that of a slower vehicle ahead in the same lane. As when using the present Cruise Control system, the driver remains fully responsible for the safe control of his car. The driver can override the system at any time by using the normal control devices.

When operating in AICC mode, all elements of longitudinal control (throttle and brake) are considered, but no element of lateral control. Although AICC may have the adequate sensing capabilities, it does not perform collision avoidance. Therefore the performance of longitudinal control is restricted to certain pre-defined limits.

AICC is autonomous in that it does not rely on communication between cars or with infrastructure but in the future its performance could be enhanced by the introduction of communication in the context of cooperative driving described later in this paper.

In the demonstrator developed by RENAULT the key element is the telemeter, an home-made infrared laser scanner (see characteristics in table 1).

Our demonstrator is now under test and benefits expected are:

- Safeguarding distance to car in front
- Provisions for smoother traffic flow
- Reduction of unnecessary braking and accelerating maneuvres
- Elimination of shortcomings in the use of present Cruise Control system
- Adapting speed automatically to demand of traffic flow

Table 1. Infrared Laser Scanner Main Characteristics

I.R. wave lengh	(n.m)	904
Laser power	W-pulsed	20
Detection range	(m)	200
Resolution	(m)	0.375
Accuracy	(m)	1
Angular field	(degrees) horizontal vertical	 -10 +10 3
Accuracy	(degrees)	0.17
Scan rate	(hertz)	10

Cooperative Driving

We all recognize that roadway traffic flow is an irregular and stochastic process. The driver's behaviour, choice of speed, distance and manoeuvres within the traffic system, exerts a large effect on the overall traffic efficiency.

The basic idea is that a mainly self-organized cooperation between vehicles which are influencing each other should significantly improve the safety and efficiency of road traffic. Variable strategies for solving local traffic problems autonomously, either by better information or by real-time advice or support, are a powerful complement to the more global and macroscopic measures applied by traffic management facilities. Cooperative driving is thus integrating vehicle and traffic control for mutual benefits for the driver and traffic. It ased on local mobile communication networks with dynamic membership. These provide short-range communication between vehicles and also include the bi-directional connection to fixed roadside communication services.

The PROMETHEUS working group dealing with cooperative driving have specified five basic applications:

1. Intelligent Manoeuvring and Control (Fig. 2) to perform cooperative manoeuvring in order to safeguard lane changes and overtaking
2. Intelligent Cruise Control (Fig. 3) to harmonize speed and distance on a single lane A reference speed can be communicated to the vehicle via a roadside beacon
3. Intelligent Intersection Control (Fig. 4) to optimize traffic flow through intersections
4. Medium Range Pre-information (Fig. 5) to provide advance static or dynamic information for adaptation to changes in traffic situation ahead
5. Emergency Systems (Fig. 6) to exchange emergency information via roadside beacons and to call

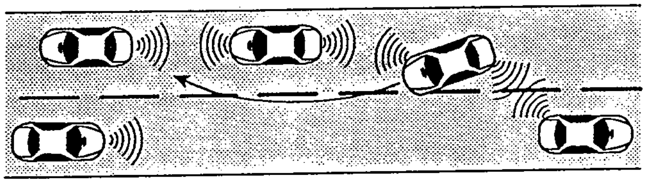


Figure 2. Intelligent Manoeuvring and Control

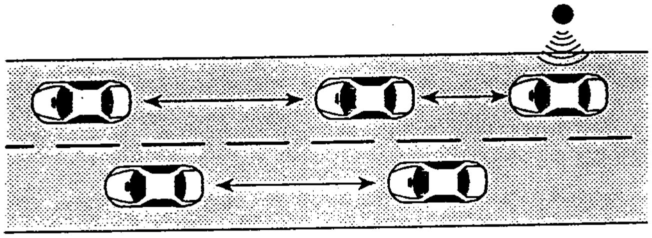


Figure 3. Intelligent Cruise Control

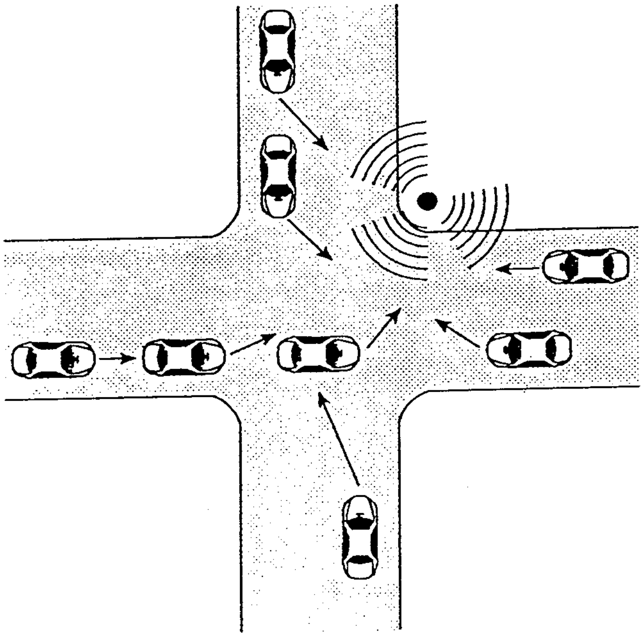


Figure 4. Intelligent Intersection Control

automatically for help by police or rescue operation centre

In a first round, our experts in traffic engineering have assessed the five basic applications. Table 2 shows some results of maximum potential benefits and reveals quite a difference between the advisory and the automatic intervention stage.

In this area the demonstrator developped by RENAULT consist of a network of driving simulators, SCANeR, running on Silicon Graphics workstation connected to an Ethernet network to simulate the inter-vehicles and vehicle infrastructure communication, each workstations representing a cooperative vehicle functioning in real time. Surrounding automatic traffic can be also simulated.

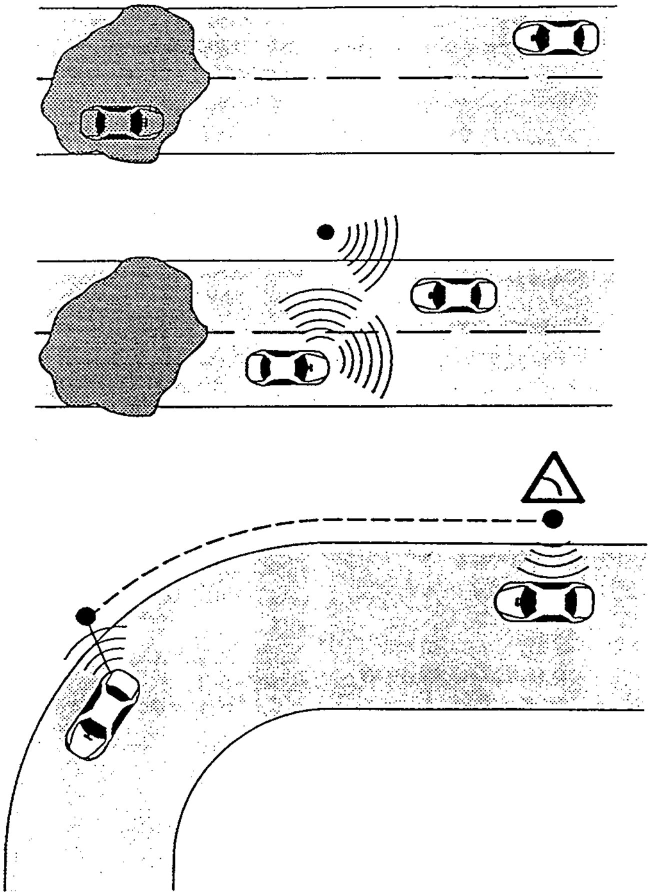


Figure 5. Medium Range Pre-information

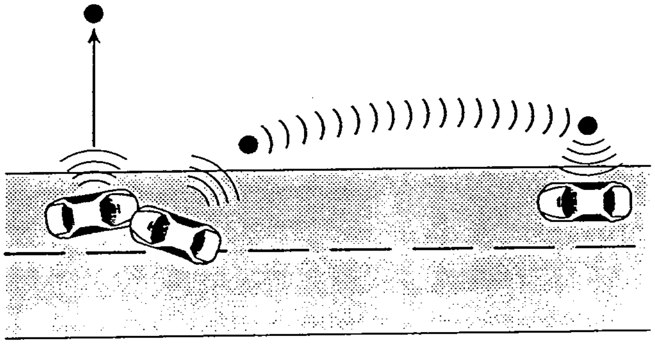
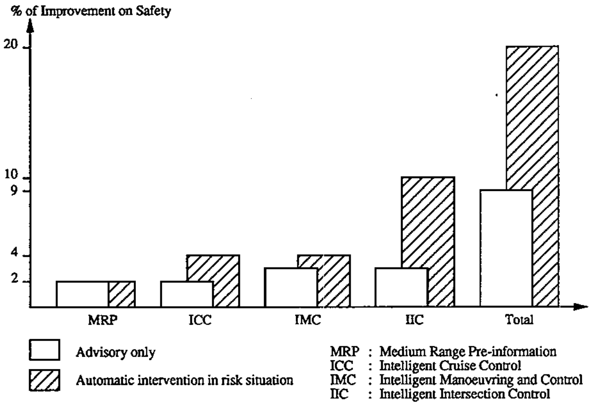


Figure 6. Emergency Systems

The goals of this research tool are:

- to evaluate the cooperative driving concept.
- to evaluate various strategies for the different applications.
- to test the driver acceptance.
- to test various solutions of man machine interface.
- to assess the requirements for the communication link.

Table 2. Cooperative Driving Applications Assessment on Safety



References

(1) "Night vision with near infrared projectors and CCD Camera" - H.G. NGUYEN Proceeding of the 4th PROMETHEUS Workshop held in Compiegne France October 1990.
(2) AICC PROMETHEUS Workplan - C. COUSON - E. MALDINEY Mai 1991.
(3) COPDRIVE - Progress Report - A. KEMENY Mai 1991.

S2-O-03

The First Practical Application of a Laser Radar Rear-end Collision Warning System in Production Heavy-duty Trucks

Itsuro Muramoto
Shigeru Okabayashi
Masao Sakata
Nissan Motor Co., Ltd.
Tohru Yasuma
Kiyoshi Minami
Nissan Diesel Motor Co., Ltd.
Todd Kohzu
Kansei Co., Ltd.

Abstract

A rear-end collision warning system for heavy-duty trucks using laser radar was put on the market in Japan in November 1989 with the aim of reducing highway traffic accidents. The basic concept of this system was formulated from the fact that about 70% of highway accidents involving trucks are caused by careless driving, although truck drivers are generally more skillful than ordinary drivers. Therefore, this system has been developed as a support tool for improving driving safety. Fleet tests were conducted by users for the purpose of determining suitable danger criteria matching human senses. The obstacle detection area and warning logic were optimized through these tests. Questionnaire were also given to 104 drivers to investigate the market response to the system. The responses included several examples of situations where an effective warning was provided under potentially dangerous conditions. The effectiveness of the system in preventing accidents was also confirmed statistically.

Introduction

The recent progress of optoelectronics has made it possible to fabricate high power pulse laser diodes at low cost and with high reliability, making these devices applicable to automotive use. This type of laser diode can be used in a laser system to measure the distance between vehicles based on the elapsed train from transmission of a laser pulse to reception of the reflected beam from the target vehicle. This laser technology is an important tool because it can be used to construct a collision warning system that advises a driver of potential danger when following a preceding vehicle too closely. It could also form the basis of a collision avoidance system or an automatic driving system.

The role of trucks in transporting freight has become increasing more important to the economy and society over the year. Traffic accidents involving trucks, however, can result in large loss of life and material goods. There has been a strong demand by transport companies and society in general to develop the required hardware that would resolve this issue by preventing accidents through effective driver support.

It was thought that laser radar could be used to build a collision warning system at a sufficiently low cost to allow application to heavy-duty trucks. It was felt that regular maintenance by users would overcome the drawback of laser radar that its detection performance is degraded by contamination. Based on this conclusion, a laser radar collision waving system for heavy-duty trucks was developed and released in the Japanese market in November 1989. The system is sold under the trade name of Traffic Eye and it is intended to reduce the number of highway traffic accidents caused by heavy-duty trucks.

This paper presents the system concept, basic specifications and subsequent improvements made to the system based on information obtained in experimental use under real-world freeway driving conditions. It also describes the response of 104 transport company drivers to a questionnaire concerning the uses of the system and its effectiveness. The transport company surveyed had 73 trucks equipped with the system as of the end of 1990. A comparison of the accident rate of trucks with and without the system confirmed statistically the effectiveness of the system in preventing accidents.

System Concept Based on Traffic Accident Statistics

Table 1 presents the results of research and analysis done by the Japan Trucking Association concerning the causes of freeway traffic accidents involving trucks(1). Typical accident patterns of heavy-duty trucks can be seen in these results. Many accidents stemmed from careless driving or drowsiness on straight section of freeways under clear weather conditions. These results indicated that some accidents could be prevented or the damage mitigated by simple alerting drivers to the potential danger of a collision when following too closely.

Table 1. Investigation of Rear-end Freeway Collisions Involving Heavy-duty Trucks on Highways

Causes	Drowsiness,inattention	57.6%
Load	More than 50%	72.8
Road surface condition	Dry	67.1
Danger perception distance	Less than 50 m	73.6
Vehicle speed	71 - 90km/h	54.0
Road configuration	Straight	73.4
Object	Truck	67.9
Speed of object	Stationary	45.5

In formulating the system concept, it was decided to limit its use to freeway, which are typified by long straight sections and curves having a large radius. The system would be installed only on heavy-duty trucks operated by trained professional drivers. The objective of the system would be to assist drivers in operating their trucks safely. The system would be designed to alert drivers to the potential danger of a collision when following the vehicle ahead too closely, such as while driving on straight sections of freeways under good weather conditions.

Development of the collision warning system

The aim was to develop a system with a simple construction that would be highly effective in preventing traffic accidents. It was concluded that a simple radar system would be better than a complicated scanning device in term of cost and reliability. A single-beam system or an equivalent would not require any complex operation. In addition, it was decided that the data to be processed would be limited to the distance between vehicles and the speed of the system equipped vehicle. That would keep the cost down by reducing the number of sensors required.

The system would require a data processing cycle of considerably less than one second and maximum detection range of around 100. That performance would be needed because trucks normally travel on freeways at a speed of 80km/h (22m/sec) or more. In view of the required performance, it was reasoned that laser radar would provide the best headway sensing system. At present, low-cost ultrasonic sensors are available but their detection range is limited. Microwave radar is much more expensive and its usage is restricted by law.

Laser radar also has its weak points. If the optical elements become dirty, for example, the system cannot detect distant objects. It was felt that this problem could be overcome by limiting the target use of the system to transport companies where drivers could be expected to perform periodic maintenance to keep the system clean. Another drawback is the decline in detection capability in a heavy rain or thick fog. It was reasoned that this would not present so serious a problem because under such conditions drivers must be more attentive anyway and would be less likely to become drowsy or inattentive.

Basic system specifications(2)(3)

The collision waving system has been designed to advise the driver when the distance to the vehicle ahead is less than a standard distance calculated with an equation given in advance. The standard distance is refereed to as the safe distance and is calculated on the basis of distance data, the speed of the laser radar vehicle and relative speed of the two vehicles. The basic concept of the system is shown in Fig. 1.

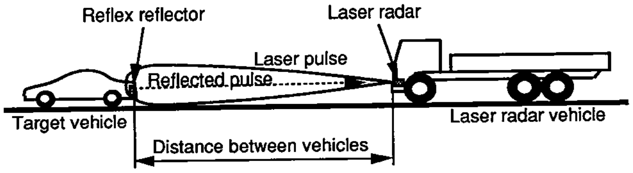


Figure 1. Basic Concept of the System

The system must provide a reliable warning at the moment when individual drivers would perceive potential danger. To meet the requirement, it was necessary to determine a suitable detection range to the vehicle ahead. It was also necessary to formulate an equation for calculating a safe distance between vehicles so that a waving would be issued at the point when drivers themselves would sense a potential danger.

Detection range of laser radar

The laser radar used in this system is a simple pulse radar method which cannot distinguish among several objects or measure the azimuth angles to them. This means the system could issue unnecessary warnings during concerning as a result of detecting road side objects or a preceding vehicle in an adjacent lane.

Preliminary tests were conducted using a prototype system to determine an appropriate detection range that would assure a sufficient detection capability while reducing the possibility of false alarms. The prototype system allowed the transmitting lens to be changed so that various detection ranges could be examined. The tests were conducted on different freeways sections including straight stretches of road and curves having various radii. The candidate detection ranges were determined on the basis of the following considerations.

1. The maximum possible detection range should be achieved.
2. The system should not detect vehicles in adjacent lanes on straight sections of the road.
3. The system should detect a vehicle cutting in as quickly as possible.
4. The lane width of freeway in Japan is 3.5m.
5. The detection width should be as wide as possible to allow detection of two or more roadside objects simultaneously on curves. This would make it possible to obtain distance signals with definite sawtooth-shaped waveforms which could be used to distinguish roadside objects from other things.

The frequency of detection for roadside objects and vehicles in adjacent lanes was investigated and analyzed. As shown in Fig. 2, the results indicated that the maximum detection range should be 100 with a detection width of 3.5m.

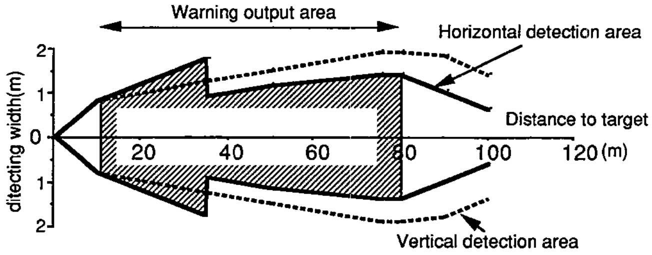


Figure 2. Detection Area of the Laser Radar

Calculation of safe distance

The following equation was formulated for calculating the safe distance to the vehicle ahead.

$$Dr = V_f(T_d+T_x)+V_f^2/2\alpha_1+V_a^2/2\alpha_2 \qquad (1)$$

This equation was derived by solving an equation of motion for a rear-end collision as shown in Fig. 3. The equation includes three variable parameters, decelerations and a time margin. Relative speed is found as the slope of an approximation of the change in distance to the vehicle ahead which is calculated using the least-mean-squares method. The speed of the vehicle ahead is found as the sum of the relative speed and the speed of the laser radar vehicle, the latter being obtained with a vehicle speed sensor. These data are substituted into Eq. (1) to calculate safe distance. If the actual distance between vehicles is shorter than the calculated result, the system issues a warning to advise the driver of the potential danger of a rear-end collision. Processing is performed at cycles of 0.1 second following the logic flow shown in Fig. 4.

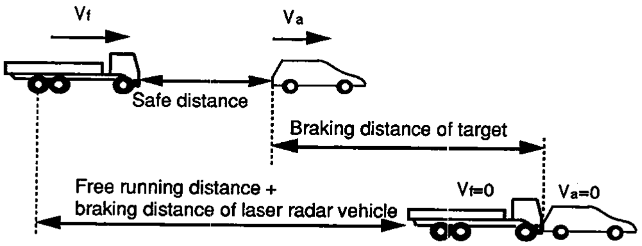


Figure 3. Safe Distance

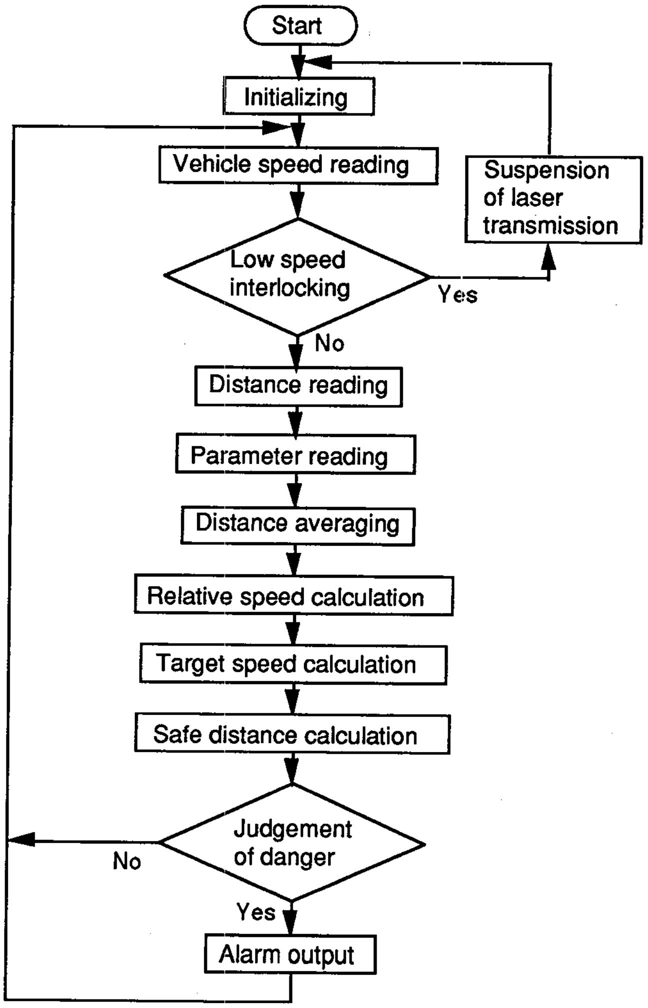


Figure 4. Calculation Flow Chart

Detailed system specifications

Construction of laser radar

Figure 5 shows the construction of the laser radar system which consists of a transmitter, receiver, signal processing circuit and power source circuit. The transmitter emits an infrared laser light at a wavelength of 904nm. These laser beams are used to achieve the detection range shown in Fig. 4. As this reduces the output per beam, it extends the service life of the laser diode and improves system reliability. The detection range of the left and right beams is limited by the control software in that data on objects detected at a distance of over 35m are ignored.

Reflex reflectors for automotive laser radar system are required by law to be attached to the rear-end of vehicles. The use of these reflectors having high reflexive reflectivity results in the construction of a cooperative laser radar system for automotive use. The size of the receiving lens and the gain of the preamplifier in the receiver were designed using a laser radar equation. As a result, the receiver is capable of detecting feeble laser light reflected from an object at a distance of 100m.

The receiver adopts a honeycomb filter and an infrared filter to prevent false alarms triggered by unwanted light. The combination of an infrared filter and a PIN photodiode provides ideal spectrum sensitivity for detecting reflected laser light at a wavelength of 904nm and thereby avoids misprision caused by the reception of light at other wavelengths. The signal processing circuit calculates the distance to the detected object using a reference clock to count the elapsed time between laser beam transmission and reception. This system uses two clocks whose frequencies differ by around 15MHz. A statistical processing operation is performed to obtain distance measurement accuracy of 0.35m. Figure 6 shows an example of the distribution of 1000 measurements when the distance to the target object was 50m.

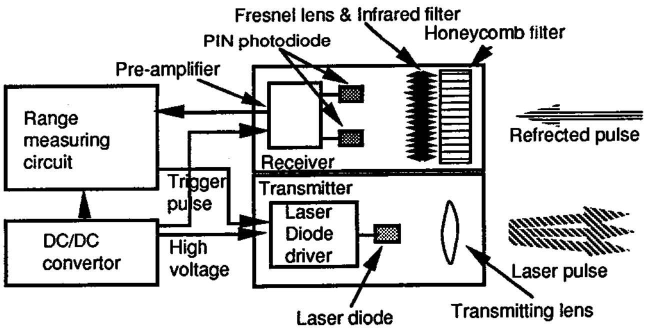


Figure 5. Laser Radar Head Configuration

Assurance of eye safety(4)

The transmitted laser beam must be safe for pedestrians or the drivers of other vehicles. Japan Industrial Standard (JIS) C6802 prescribes the safety performance of laser products in Japan and conforms to ANSI Z136.1-1713. A rear-end collision waving system must meet the requirements of the class 1 laser products regulated by this standard.

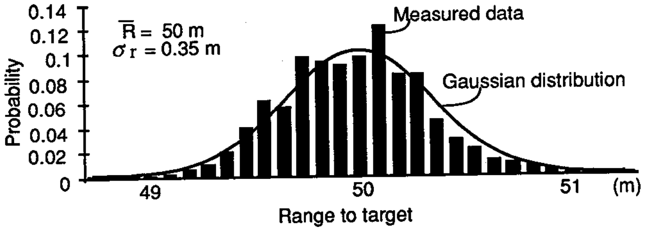


Figure 6. Distribution of Range Data

It is impossible that pedestrians would look into the laser light source from a distance of one meter when a truck is being operated on the road. On the other hand, the energy density of a laser beam decreases rapidly with increasing distance from the light source because of divergence angle of the beam. Using the calculation equation specified by JIS, it was found that a laser output of 8W would provide a safe energy level at a distance of one meter or more from the light source. It was concluded that eye safety could be assured by controlling the emission of the laser beam according to the vehicle speed. An interlock mechanism has been built into the system to prohibit laser emission at vehicle speeds under 35km/h.

Improvement of reliability and mountability

A custom made integrated circuit was built for signal processing to achieve a more compact size and light weight. The package of laser radar head measures 200x75x117M and weights 1.5kg. The compact size helps to avoid interference with other parts when the system is installed at the front of the vehicle.

The following steps were taken to improve reliability for practical use.

1. The aluminum case is filled with dry nitrogen gas and hermetically sealed to avoid moisture condensation on the optical elements due to changes in the external temperature.
2. The detection capability of the laser radar declines when the optical elements become dirty. In such case, the system detects the scattering of the laser light and advise the driver that the detection performance has dropped.
3. A current of several ten amperes is applied to the pulse laser diode to produce the laser light. The detectors must be able to detect the feeble reflected light. Each unit is shielded in an aluminum case so that its electronic circuits will not be affected by noise from other electric components.
4. Range signals are transmitted from the laser radar head to the signal processing circuit via plastic optical fiber to ensure that data are transmitted reliably without being affected by noise generated by the engine or other parts.

5. Laser radar tends to detect rain drops or fog instead of actual objects in a heavy rain or thick fog. To prevent false alarm from being issued under such conditions, a Sensitivity Time Control (STC) circuit is used to suppress the detection sensitivity lowering the detection amplitude in the near field.

Calculation of relative speed

Simple differentiation of distance data to obtain the relative speed can give rise to variation in the safe distance because it has the same effect as a high pass filter and emphasizes noise. As a result, waving may be issued intermittently, which can lead to uncertain judgment about the potential danger of a rear-end collision. Increasing the number of distance data used to calculate relative speed would be one way of reducing the variation. However, this method is not effective in situations where distance data change suddenly, such as what occurs when a vehicle cuts in front. In such case, the longer time is needed to calculate the relative speed could cause the warning to be delayed.

In this system, the relative speed obtained by differentiation is filtered to assure stable calculation of the safe distance in a short interval. Filtering is done with a low-pass filter having a cut-off frequency of about 0.3Hz. This figure was determined from the characteristics of the relative speed as shown in Figure 7. The noise reduction effect of the filter was confirmed in road tests.

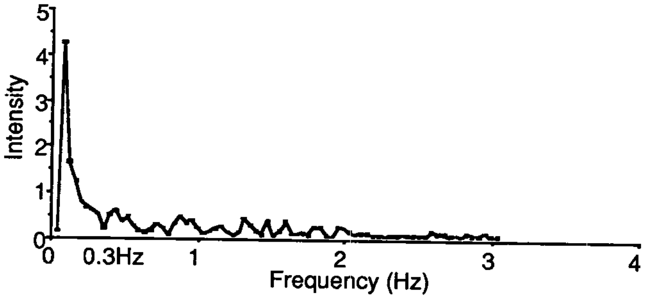


Figure 7. Spectrum of Relative Speed

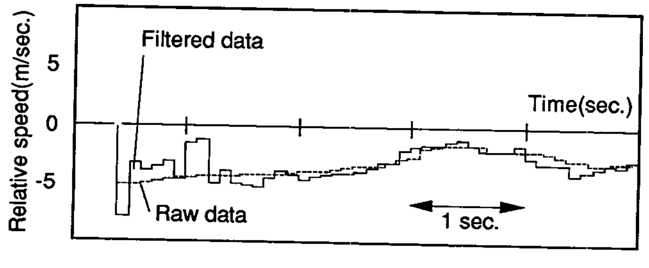


Figure 8. Effect of Filtering

Improvement based on tests results

Driving tests were conducted with heavy-duty trucks equipped with the system to confirm its effectiveness in issuing warnings at the moment when drivers would perceive the potential danger of a rear-end collision. The participants were all professional drivers employed by transport companies. Subjective tests were carried out in the following three stages.

In the first test conducted on test course, a small number of drivers were used to investigate the distance at which the participants felt the potential danger of a rear-end collision. A second test, also involving a small number of drivers, was conducted to determine suitable parameters for using the system in freeway driving. Finally, a third test was carried out under real-world driving conditions with a large number of unspecified drivers to identify problems that valid hay to be resolved before the system could be put on the market. Based on the results obtained, improvements were made to the system.

When the relative speed was small, the drivers tended to use the speed of their own truck as the criterion for judging whether the distance to the detected object was dangerous or not. It was found that the safe distance determined by Eq. (1) changed more than the drivers expected while the relative speed changed only a little. As a result, the system gave the drivers a strange, disconcerting feeling. With regard to stationary objects, it was found that the driver's perception of danger was influenced by the speed at which the object drew nearer.

The feeling of strangeness stemmed from the inconsistency between the supposition in Eq. (1) that the two decelerations, α1 and α2, have equal and constant values and natural driving behavior that a person displays under ordinary driving conditions. In other words, under real-world conditions the relative speed is small when a driver is following a preceding vehicle. The driver tries to maintain a constant distance to the vehicle ahead by adjusting the speed of his vehicle according to that of the preceding vehicle. In this case, the second and third terms of Eq. (1) cancel each other out, and the safe distance is determined by the first term only. On the other hand, when a stationary object suddenly appears in front of the driver, the relative speed is too large to be adjusted by the control rate of deceleration, as the object has a velocity of 0km/h. Accordingly, the second term of Eq. (1) has a large effect on the safe distance and the third term becomes zero.

These results indicate that moving objects would have to be distinguished from stationary ones. The warning logic was thus designed so that the safe distance to a moving object would be proportional to the speed of the laser radar vehicle and that to stationary objects would be determined from the physical conditions of a collision, including consideration of deceleration. The equations used to calculate the safe distance are given below.

$$Dr = V_f\ (T_d+T_{x1}) \qquad (2)$$

$$Ds = V_f\ (T_d+T_{x2})+V_f^2/2\alpha \qquad (3)$$

Equation (2) is used when the relative speed is less than 50km/h and the speed of the preceding vehicle is greater than one-fourth the speed of the laser radar vehicle. In all other cases, Eq. (3) is used to calculate the safe distance.

The number of parameter combinations for adjusting the safe distance calculation proved to be too many and the drivers did not know which combination to select. Varying the parameters did not seem to change the safe distance applicably and so the effects were not clear. To resolve this problem, three distance mode—far, middle and near—have been provided to make the effects of parameter changes clearer (Fig. 9). Drivers can select the made the prefer according to their own driving skill or the traffic conditions at the tone.

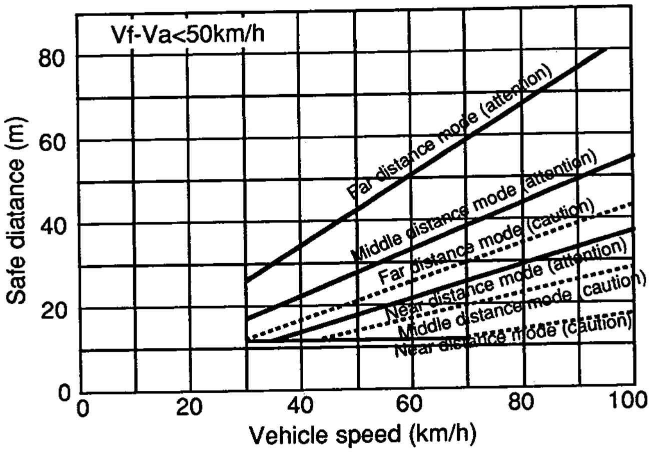


Figure 9. Safe Distance Calculated from Equation (2)

It was found that the drivers became accustomed to the waving sound and its effectiveness was diminished because the same sound was given regardless of whether the preceding vehicle was far away or very close. This problem has been resolved by providing two different warning sounds, an attention alert and a caution alert. The former is issued when the distance to the vehicle ahead is shorter than the safe distance. The latter is issued when the distance is less than one-half the safe distance. The caution warning is 8dB louder than the attention warning.

Heavy-duty trucks often travel in convoys on freeways at night. It was found that the system was annoying in this driving situation because warnings were issued continuously. As a result, some drivers stopped using the system altogether. This problem was solved by modifying the system so that attention warning are not issued when a vehicle is traveling at a constant speed and maintains a constant distance to the vehicle ahead, even if that distance is shorter than the safe distance.

Continuous warning were also issued in traffic jam when vehicles were very close together. This has been solved by suspending the transmission of the laser beam at speeds slower than 35km/h, which eliminates unnecessary warning.

False alarms were triggered frequently by roadside objects and disturbed the drivers. This problem was solved by using the sawtooth waveform to distinguish roadside objects from other items. In addition, when the system recognize a sawtooth waveform, it suspends the issuance of a waving for 25 seconds. It is assumed that drivers can maintain sufficient alertness during an interval of this duration.

Response from the market

The collision waving system was put on the market in November 1989 under the trade name of Traffic Eye. The system is priced at $2200 and projected sales volume is 1000 sets per year. By October of 1991, approximately 500 trucks were equipped with the system. This is the first time in Japan that a system of this type has been used in such large number in the field. It is thought that further investigation of actual uses of the system and demonstration of its effectiveness in preventing accidents will be very valuable in promoting further penetration and development of the system.

A large transport company in Japan decided to install the system on many its trucks. At present, the system has been installed on 73 of the 250 heavy-duty trucks operated by the company. An investigation was conducted at the company to examine whether there was any difference in accidents rates between trucks outfitted with the system and those that were not. A survey was also conducted among the drivers concerning their experience with the system. Responses were received from 104 drivers who had driven trucks outfitted with the cistern.

Investigation results

Figure 10 shows the frequency at which the drivers used the three distance modes and Fig. 11 gives their reasons for selecting a particular mode. The middle distance mode seems to be best suited for the traffic conditions typically found in Japan. It is presumed that the far distance mode may not be very practical under real-world conditions because warnings are issued too frequently.

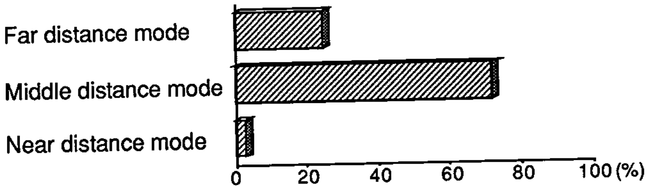


Figure 10. Frequency of Use of Distance Modes

The results in Fig. 12, 13 and 14 indicates that the drivers have some dissatisfactions with regard to the conditions under which warnings are issued and the timing, loudness and sound quality of the warning. Some of the dissatisfactions expressed would be difficult to

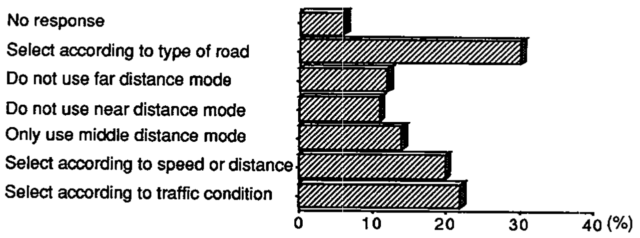


Figure 11. What is Your Criterion for Selecting the Distance Mode?

resolve because of the limitations of the system. Other items mentioned may be allowable to some extent because the drivers were all professional. However, it will be necessary to resolve these points if the system is to be used in passenger cars driven by ordinary drivers.

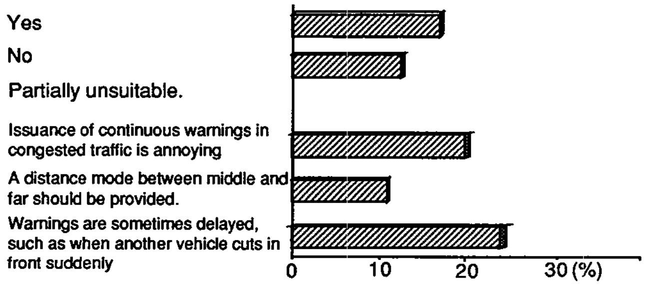


Figure 12. Do the Conditions for the Issuance of a Warning Seem Suitable to You?

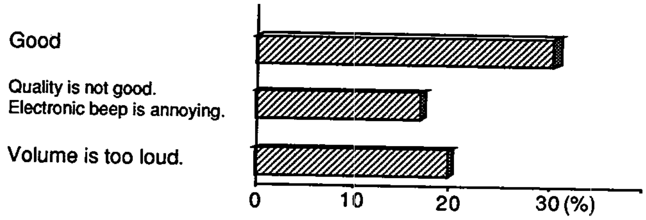


Figure 13. What Do You Think About the Audible Alarm?

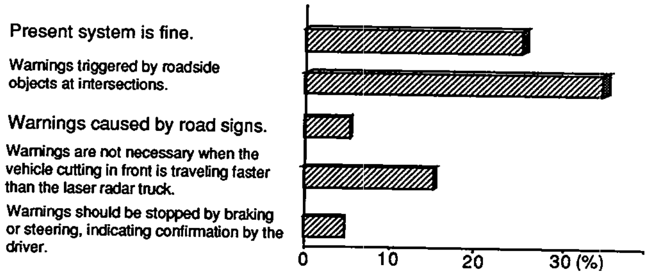


Figure 14. What Kinds of Warnings Should Be Eliminated?

Figure 15 shows that drivers are more relaxed when they drive a truck equipped with the system because they know the actual distance to the vehicle ahead and obtain concrete numerical information on their approach to the preceding vehicle. Figure 16 indicates the effectiveness of the system. 31% of drivers responded that they had experienced a waving while driving inattentively. Figure 17 shows that the installation of the system made a large number of the drivers more conscious of driving safely, which, in effect, also contributes to accident prevention.

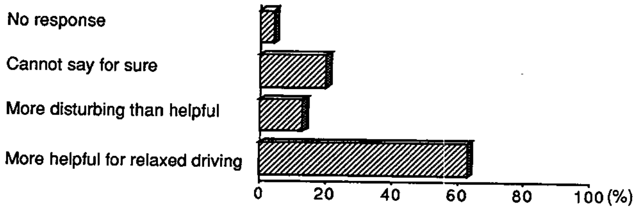


Figure 15. Does the System Contribute to Safer Driving?

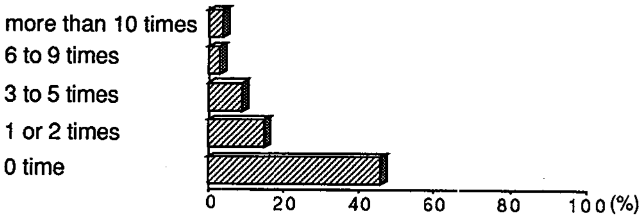


Figure 16. How Many Times Are You Alerted to Potential Danger by the System

- Displayed distance reading becomes a guidline for safe driving.
- The system helps to correct bad driving habits, such as not driving in the center of the lane or following too closely.
- With laser radar trucks, drivers tend to drive more safely than usual because they are more conscious of notcausing an accident.

Figure 17. Other Effects of the System

Figure 18 and 19 indicates that 80% of the drivers, including those expressing partial agreement, thought the system should be installed on all trucks operated mainly on freeways. They also said they preferred to drive a truck equipped with the system over a vehicle without.

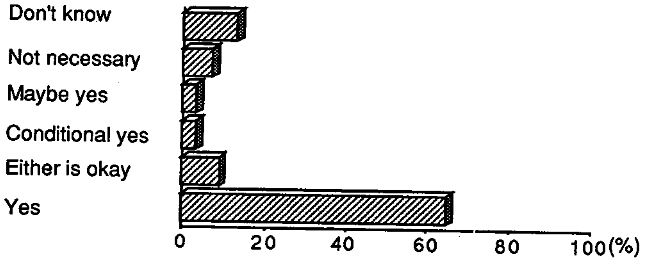


Figure 18. Do You Think All Trucks That Are Mainly Operated on Freeways Should Be Equipped with the System?

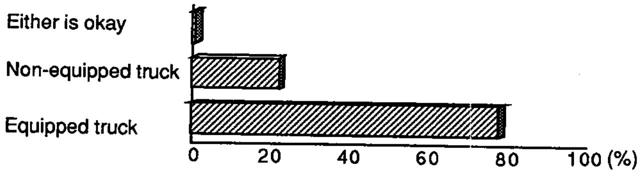


Figure 19. Which Do You Prefer to Drive on Freeways, a Truck Equipped With the System or One Without?

Verification of the effectiveness of the system

The transport company mentioned in the previous section experienced eleven traffic accidents between

April and September 1990. All of the accidents involved trucks that were not equipped with the system. A statistical hypothesis test is employed here to examine whether the system is actually effective in preventing traffic accidents(5).

The hypothesis, H0, is given as follows:

H0: There is no difference between trucks with and without the system with regard to the probability of an accident occurring.

It is assumed that drivers are selected at random and that there is no difference in their driving ability. It is also assumed that there is no difference in the operational conditions of the two groups of trucks, including the mileage driven. It is also assumed that the number of trucks are large enough, so that a binomial distribution can approximate to a normal distribution. We will let n denote the number of trucks with the system, n2 that of trucks without and n that of total trucks. We will also let P1 denote the probability of an accident occurring with the trucks equipped with the system and P2 the corresponding probability for trucks not equipped with the system. Using the number of trucks and accidents at the foregoing transport company we obtain

$$P1=(n1-O)/n1=73/73=1$$

$$P2=(n2-11)/n2=(177-11)/177=0.934$$

Since the hypothesis H0 posits that

$$P1=P2$$

we can estimate the probability of an accident occurring, P, as

$$P=(n-11)/n=(250-11)/250=0.956$$

Accordingly, the value of the standard deviation $\sigma p1\text{-}p2$ can be estimated as

$$\sigma p1\text{-}p2=(P1(1-P1)/n1+P2(1-P2)/n2)^{0.5}=0.0285$$

In this case, the opposite hypothesis of H0 is

$$P1>P2$$

The region in which H0 is rejected at a confidence level of 95% is

$$1.64\sigma p1\text{-}p2=0.0467$$

Here,

$$P1-P2=0.066> 1.64\sigma p1\text{-}p2$$

which indicates that the hypothesis H0 is rejected as being invalid. In other words, there is a significant difference between the accident probabilities of the two groups of trucks. It can be concluded, therefore, that the collision waving system is effective in preventing accidents.

Conclusion

This paper has presented a laser radar collision waving system for heavy duty trucks. This system has been developed as a user-friendly tool intended to improve driving safety and aimed specifically at professional truck drivers The waving logic was improved on the basis of results obtained in road tests. In addition, the user-friendly nature of the system was further enhanced by making it easier for drivers to understand the capability and limits of the system.

A large transport company in Japan has installed the system in many of its trucks. An investigation of the actual use of a questionnaire given to drivers at the company indicated that installation of the system enabled them to drive in a more relaxed manner and they also drove more attentively. The effectiveness of the system was also confirmed statistically using the company's recent accident record. The following conclusions can be drawn from the present work.

1. The collision waving system is effective in preventing traffic accidents.
2. A system which is intended to prevent or reduce traffic accidents under limited conditions can also be sufficiently useful.
3. It is important for drivers to be known the functional limits of the system and the conditions under which it is most effective.

Acknowledgement

The authors wish to express their appreciation to the Ministry of Transportation and the Japan Trucking Association for their coordination. They also wish to thank Professor Tsutomu Suzuki of the University of Electrocomunications for his helpful discussions and suggestions. They are also due to thank Seibu Transport Co., Ltd.

References

(1) Japan Trucking Association, "An Investigation on Preventing of Rear-end Collision Accidents on Highways," May 1986, May 1987, May 1988.
(2) H. Kept, e a., "A Study of Laser Radar," 10th International Technical Conference on Experimental Safety Vehicles, July 1985.
(3) M. Sect, e a "Laser Radar Rear-end Collision Warning System for Heavy-duty Trucks," International Symposium on "Future Automotive Microelectronics," December 1988.
(4) JIS-C6802, "Radiation Safety Standard of Laser Products."
(5) Paul G. Hoel, "Elementary Statistics," John Wiley & Sons, Inc., 1976.

S2-O-04

The Anti-Collision Radar in the DRIVE-SMILER Project

Pascal Deloof
INRETS-CRESTA[1]
Nathalie Haese and Paul Alain Rolland
CHS-USTLFA[2]

Abstract

This article presents an important part of the DRIVE-SMILER project which is the evaluation of the feasibility of an *anti-collision radar* for road vehicles. In a first step, the main specifications of the radar are drawn from a bibliographic survey. Then the feasibility study is summarized: several mock-ups, realized by the partners, are presented. Finally, a new possibility of radar front end integration is described, which is using the quasioptical technique on active antennas. This technology, compatible with MMIC process in millimeter-wave applications, allows to suppress all the microwave links needed in the classical integration concept, in order to reduce the cost and the complexity of the radar front end.

Introduction

Inside the European Research program DRIVE, the SMILER (V1002) project was devoted to the evaluation of the potentialities of microwaves for the realization of transmission links envisaged in the RTI field, for automatic tolling, beacon-supported navigation system, exchanges of data between vehicles, and anti-collision radars.

The "Work-Packages" which were particularly concerned by the anti collision radar are the Numbers 1, 6, and 8. A short synthesis of these different activities is following.

WP1. State of the Art

Starting from a large literature survey and completed by visits to industrial firms, WP1 has contributed to yield a good knowledge of all the achievements and researches on the applications of microwaves in the RTI field and particularly about the anti-collision systems (110 articles).

Anti-collision radars have already been studied in 1968 in USA and in 1972 in FRG, in United Kingdom and in Japan; and after 1980 in Sweden and in France.

The used frequencies are rather high, most of them work in the 35 GHz band, a few need higher frequencies at 56, 60 or 94 GHz.

There are two main approaches for the design of radar system:

- American approach: to limit the false alarm rate, the chosen solution consists to reduce range down to 50 m on freeway, and 35 m in curves, and associate an automatic braking system
- German approach: the radar systems have longer range, between 100 and 200 m, but are non-automatic, only giving to the driver informations about the distance of the preceding vehicle, and generating alarms in case of critical situations. The false alarm rate is higher than in the preceding approach and requires a more sophisticated signal processing.

Concerning the choice of passive or cooperative systems, only a few radars are cooperative (involving a transponder on other vehicles). The danger of not detecting a non equipped vehicle can be a sufficient argument for eliminating this solution.

The radar systems generally use two main types of modulation: Frequency or Pulse one. For the time being the Frequency-Modulation based systems are cheaper than Pulsed ones, but they are less efficient in the presence of several targets in front of the radar.

Then, the signal processing is more complicated and can increase the cost of FM radars. If the Pulsed systems can resolve these problems by "multitarget" algorithms, however they need a microwave head which is more expensive than the FM one.

The other characteristics of existing anti-collision radars are given in the technical Table 1.

Table 1. Main Characteristics of Radar Systems

Firm & Country		Date of report 19..	A: Automatic or M: Manual C: Cooperative or NC:Non "	Frequency (GHz)	Mean Power (mW)	Modulation FM, Pulsed or Bi frequency	Number of antennas	Antenna Aperture H*V (degrees)	Range (m)	Price ($)
AEG TST	FRG	79	A-NC	35 (60) 80 & 94	300	P 20 ns FM	1 2	2.5*3.6	120 200	
Auto-Stop	USA	73	A-NC	10.5 24	50 175	2F P 20 ns	2	2.5*5.5	100	350
Bendix	USA	77	A-NC	22.1	25	2F	1	2.5*4.5	100	200
GM	USA	78	A&M-NC	8-12		P 1 ns	2			
Lucas	GB	78	A-NC	32.6	25	FM	2	5	100	
Munich TUniv.	FRG	88	M-NC	94 imaging	200	P 1 ns	1 Scan.	1.5/360 * 20	50	
Nissan	J	70	M-NC	24	20	P 20 ns	1	3.5*4	100	
Rashid	USA	80	?-NC	24.5	20	FM	1		120	558
RCA "	USA	77	A-C&NC	10.5 17.5	15 100	FM	1 or 2 printed	3*5	30 50	
RCS	USA	78	M-NC	33.4	5	2F	1	4	100	875
SEL	FRG	80	M-NC	35	20	FM	1	2.5*3.5	100	1500
Sperry	USA	74	M-NC	1.75		P 2 ns	3	eq.2.5	45	
Toyota	J	78	?	50	30	FM	2	2.5*4	60	
TRW	USA	78	A-NC					2.5	30	288
VDO "	FRG	80	M-NC	9.3 35	200	P 30 ns	2	2.5*4	120 200	875
Following mock-ups belong to some partners of the consortium DRIVE - SMILER - V1002										
IM	S	90	M-C & NC	17 (60)	100	FM	2	14*6	300(c)	
INRETS-CRESTA	F	90	M-NC	10 35	15 40	FM "	1	4*4.5	75 50	
SMA	I	89	M-NC	35	100	P	1Scan.	2±20*4	160	
CHS-USTLFA	F	90	M-NC "	10 (80) 10	100 "	FM P 40 ns	1 "	4*4 "	75 200	

---

[1] Institut National de Recherche sur les Transports et leur Sécurité—Centre de Recherche et d'Evaluation des Systèmes de Transport Automatisés.

[2] Centre Hyperfréquences et Semiconducteurs—Université des Sciences et Techniques de Lille-Flandre-Artois.

WP6 Feasibility of a Low Cost Front End for Anti-collision Radars

After the first analysis, it was determined that the aim of the radar system to be developed would be in conformity with the "German approach" i.e. to reduce reaction time in dangerous situations, mainly upon conditions of bad visibility (fog, rain) or of reduced vigilance (night driving) when driving on motorways or main roads with low or moderate traffic.

Some SMILER's partners have developed their own mock-up using different techniques. Field trials have been done on single targets in order to determine the distance measurements, the RCS (Radar Cross Section) of cars, and also to analyze the multipath effects.

Some experiments have also been conducted in multi targets environments, because this type of environment is generally at the origin of perturbations, particularly for fixed beam radars.

The activities of each partner can be summarized in the following paragraphs.

CHS-USTL's Mock-up: A Pulsed Bistatic Radar

The block diagram of a 80 GHz version of the front end is shown in the Figure 1, but trials have been carried out at 10.7 GHz.

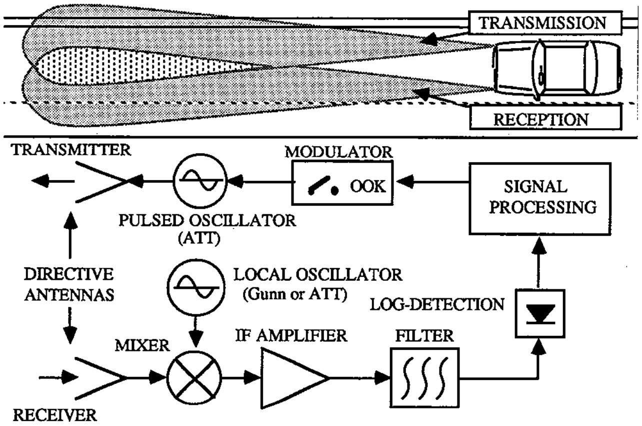


Figure 1. Mock-up of Pulsed Radar USTL

Preliminary trials were realized using an X-band (10.7 GHz) laboratory prototype with a parabolic reflector using FM/CW modulation on an active antenna and a parabolic reflector as it is described in the WP8. They have pointed out two problems:

- a system problem due to multitargets;
- heating problem in the front end integration due to the constant dissipation in FM/CW.

Further trials have been undertaken with a pulsed radar, which appears to be more adapted to multi targets environments and also resolves the thermic problem because the mean power is low.

The accuracy in distance measurement of the signal processing unit without microprocessing is illustrated in Figure 2. The error in distance is less than 4 % for distances up to 200 m.

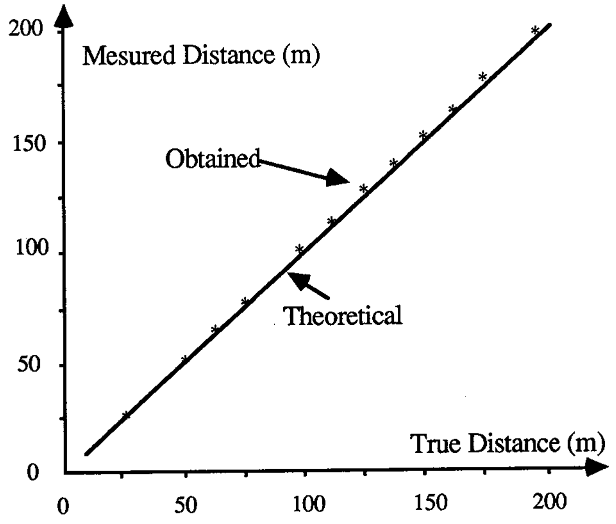


Figure 2. Accuracy of the Radar USTL

Moreover the relative error is quasi constant and could be corrected by microprocessing. The minimal range of the pulsed radar is closed to 4 m when the pulse duration is reduced to 20 ns.

INRETS-CRESTA's Test Bench: A 10 & 35 GHz FM/CW Radar

The block diagram of this test bench is presented on the Figure 3. Two mock-ups have been built using commercial transceiver and parabolic dish antennas operating at 10 and 35 GHz.

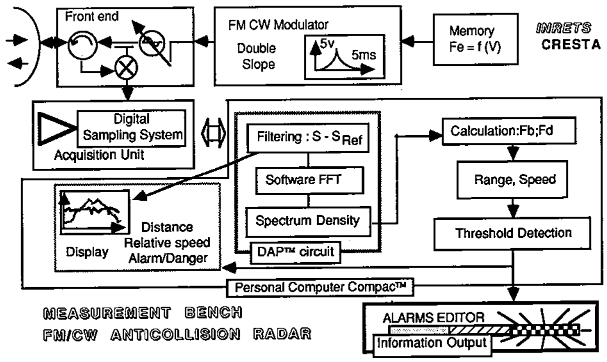


Figure 3. Block Diagram of the INRETS-CRESTA's Test Bench

Trials have been done in static on real scenarios, using typical targets (man, car, metallic plate). The results of distance measurements with both sensors have generally shown good results except several values out of the usual edge of 10% for specific distances around 30 and 35 meters. A possible explanation is the ground clutter effect.

These measurements have shown different kinds of problems due to the poor characteristics of the commercial front ends which were not really made for this application.

However the effectiveness of signal processing has been shown and some coherent results have been obtained in several real road scenarios. An example of results on the 35 GHz radar is given on Figure 4. The target can be rejected even when it is in the far line of sight of the radar.

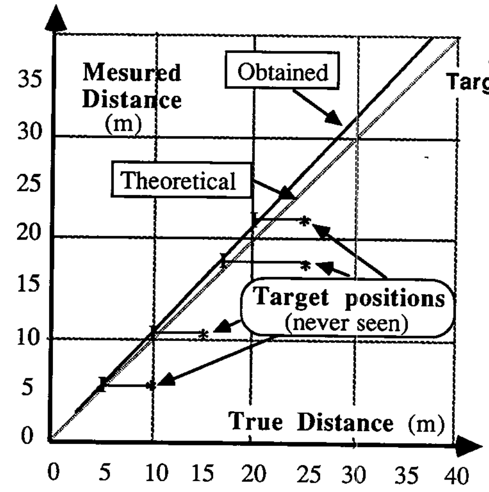


Figure 4. Measured Distances of a Car with the Rejection of a Metallic Target

IM's Mock-up[3]: A 17 GHz Cooperative/Non-cooperative Radar

An overview of the basic block system is shown in Figure 5. The microwave and IF blocks are integrated in one unit, while the signal and data processing block mainly consist of a digital oscilloscope or an instrumentation tape recorder and a computer.

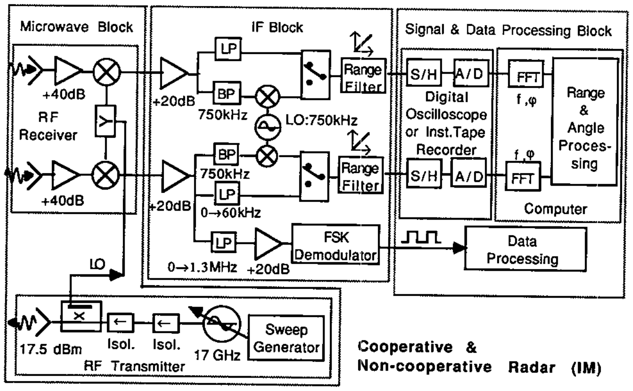


Figure 5. IM's Cooperative/Non-cooperative Radar Test Bench

Range and angular measurements were carried out using a structure able to work with cooperative as well as non cooperative systems.

Three types of measurements have been performed:

- Static measurements of range, accuracy and reproducibility with cooperative radar under ideal and not ideal conditions, i.e.with other objects in between the radar and the target.
- Comparison between cooperative and non-cooperative techniques.
- Dynamic measurements, with cooperative radar, to observe the influence of multipath and other phenomena when the link is moving, i.e. the cars are rolling.

The results of the first series of measurements show that the FM/CW method applied to cooperative radar system gives a quite sufficient accuracy, under open area conditions, for anticollision applications. The comparative measurements were performed under similar conditions. The results illustrate the possibility of combining both systems in the same transceiver.

The signal from the non-cooperative radar has stronger amplitude fluctuations than the one from the cooperative equipment. This is due to the characteristic of the RCS of a car which is strongly related to the incident angle. Also, clearly illustrated is the clutter level of the non-cooperative radar which is considerably higher than for the other one. Figure 6 shows an example of the FFT spectrum obtained at a distance of 100 m with both system.

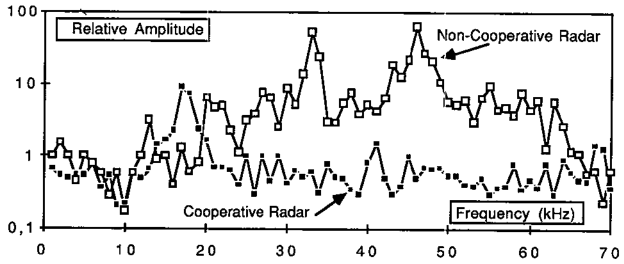


Figure 6. Example of F.F.T. Measurements on Cooperative & Non-cooperative Radars at a Distance of 100 m (IM)

Dynamic measurements have shown that the influence of multipath effects seems to be limited to short interrupts. Most of these are single values with large errors which can easily be filtered out. The behavior of the distance meter and the relative speed calculation look promising. Speed fluctuations of around i 0.5 m can be explained by variations in the up and down sweep.

SMA's Mock-up:[4] a 35 GHz Scanning Radar

SMA has been working—together with FLAT—on anti-collision radars since 1987. Several mock ups have been built up to now. The objective of this work has been the realization of an autonomous radar system with a scanning antenna and a non automatic braking system.

Figure 7 shows the system block diagram of one prototype which operates at 35 GHz with a pulsed radar technique and a rotating antenna.

---

[3] IM: Swedish Institute of Micro electronics, Kista, Sweden.

[4] SMA: Segnalamento Marittimo ed Aero, Florence, Italy.

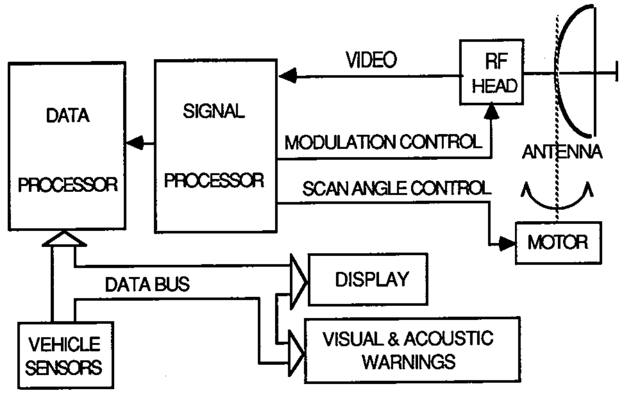


Figure 7. Block Diagram of the Radar (SMA)

Functional trials and measures on real scenarios have been carried out. RCS on typical targets (man, car, truck) and propagation phenomena (multipath) have been investigated.

Figure 8 shows the RCS measurements on a car: deep nulls are due to the multipath effects, while the decrease of the mean at lower range is due to the sparkling effect. Sparkling effect appears with the use of short wavelengths, when the target can be perceived as a set of scattering centres. Multipath effects appear when the beam propagates near reflecting surfaces: if the surface is a good conductor at operating frequency, the energies of direct and indirect signals can be comparable. At 35 GHz, in real conditions, most of the typical targets are scarcely affected by this effect.

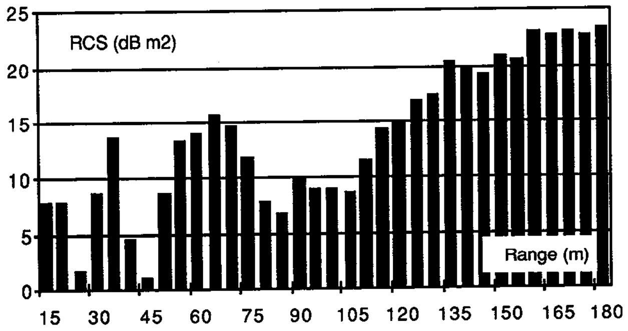


Figure 8. Radar Cross Section of a Car (SMA)

WP8: Unified Microwave Link Designed for Low Cost Components

The RTI functions envisaged in DRIVE program will require a number of communication links between vehicles or between ground and vehicles. To reduce the cost of on-board equipments, it seems reasonable to reduce the number of transmitter/receiver front ends required for all these links, or at least to standardize them in an unified design.

This work has demonstrated the feasibility of a new concept: the quasi-optical integration. The principle of this technique is summarized in Figure 9. All the necessary functions for a T.R. module are integrated on an active patch antenna which illuminates a directive passive antenna.

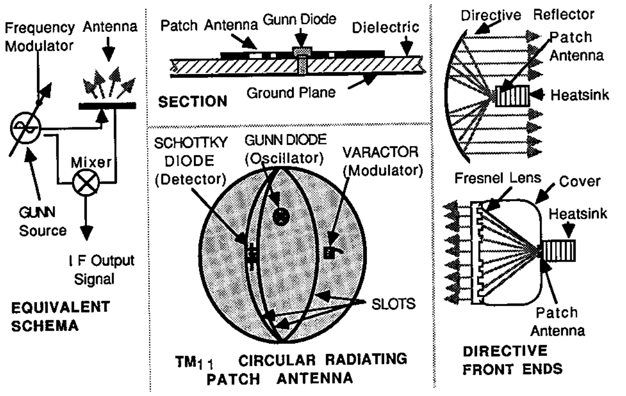


Figure 9. Principle of the Quasi-optical Integration (USTL)

Indeed, all the physical microwave links needed to interconnect the various devices in a conventional design can be suppressed since the energy transfer in this technology is achieved by radiation and coupling. This technique leads to an efficient low-cost solution quite compatible with monolithic integration (MMIC). This feature is even more attractive in the mm-wave range because the size of both lumped and distributed circuit elements decreases. The validity of this concept has been demonstrated up to 85 GHz.

The quasi-optical integration is well suited for FM/CW and pulsed front end as well.

Depending on the kind of active device used (Gunn or Impatt diode), the radiating power measured ranges from 15 to 33 dBm. According to the low patch antenna gain this power radiated level is quite sufficient for short and medium range civilian applications since this low gain active antenna is designed to illuminate a high gain directive passive antenna, such as planar Fresnel lenses.

Such planar lenses used in transmission offer three major advantages:

- low-cost housing without radom design,
- high directivity with reduced size and low-cost at millimeter-wave frequencies,
- a possibility of putting a large heat-sink for Continuous Wave operation.

First field trials performed at X-band on such a quasi-optical FM/CW radar front end have demonstrated a range in excess of 100 m with a low power Gunn device and a non optimized design.

Such a design could constitute the basic building block of generalized Transmitter Receiver units.

Recommendations and Conclusions

Although the SMILER program was concentrated on the conception and evaluation of quasi-optical front ends, as several members were interested before in anti-collision radars, a number of mock-ups of different design and technologies have been tested.

At the end of this work, a reflection allows us to emit some concrete recommendations:

a) *Functionally:* Anti-collision radars should be used, at least initially, without automatic braking, to enhance the driver's perception.

The best solution appears to be the non-cooperative radar for safety reasons. However the use of passive transponders placed on some selected targets and on vehicles could improve the system performances and open up new interesting possibilities for RTI applications. By a combination of the both features, the radar should be able to detect passive targets, as well as to receive response signals from transponders, but the cooperative concept should be seen as a complement rather than an alternative to non-cooperative radar technology.

b) *Technologically:* Among the two main modulation modes, a preference is given to pulsed radars, even if the front end is a little more expensive, due to the less complex signal processing and to the greater facility for multi targets detection.

A scanning or multibeam antenna is necessary for false alarm limitation. Although mechanical scanning antennas are already feasible, it is recommended to develop a low cost electronic scanning antenna for reliability and cost considerations.

Frequencies used up to now for anti-collision radars have been 35, 60, 80 and 94 GHz. Now the 76 GHz band is suggested by the Frequency Committee of CEPT. A sufficiently large bandwidth, up to 2 GHz, is needed, in order to allow pulsed modulation, and a frequency distribution which could give a protection against the risk of interferences between cars.

Quasi-optical devices appear as a good and feasible alternative for the realization of radar front ends. In this way there are good hopes to reduce the costs of components through the use of quasi-optical and MMIC technologies in a near future.

Even if Anti-collision radars have been under study for nearly 30 years, no one operational application is known, and there remains still a long way before the generalization of such equipments on board road vehicles. V1002 SMILER could only bring a partial contribution to this long development.

References

[1]V1002-SMILER WP9: Synthesis Report; Final Report; Ref. RD1-26-12-1990; DRIVE Office CEE DGXIII, Brussels Belgium.

[2]"A Low Cost Approach for a Low Cost Anti collision Radar Front End"; P.Deloof & al (INRETS); Ref. 910 051; 24th ISATA Congress; 20-24th May 1991, Florence, Italy.

[3]V1002 SMILER WP1: State of the Art. Report Ref.1-2RD1-30-8-89; DRIVE Office, Brussels Belgium.

[4]V1002 SMILER WP6: Study of the feasibility of a low cost radar front end. Report Ref. WP6-MF6-22-10-90; DRIVE Office Brussels Belgium.

[5]V1002 SMILER WP8: Unified microwave links for low cost design. Report Ref. WP8; DRIVE Office Brussels Belgium.

[6]"Anti collision radar: State of the Art"; G.Preti (SMA); DRIVE Conference Session 11; Brussels 4-6th February 1991; Belgium.

[7]"Recherche bibliographique sur les radars de prevention des collisions"; P.Deloof, N.Haese, S.Baranowski. Recherche Transports Securite N. 26, INRETS, June 1990.

S2-O-05

Improved Active and Passive Safety by Using Active Lateral Dynamic Control and an Unconventional Steering Unit

Per Bränneby, Bo Palmgren
Saab Automobile AB
Anders Isaksson, Torbjörn Pettersson
Mecel AB
Stig Franzén
Saab-Scania AB

Abstract

The goals for this work are to investigate possible improvements in active and passive safety by active lateral dynamic control and an unconventional steering unit. The ideas have been implemented as a running prototype in a SAAB 9000 car. The unconventional steering unit uses ideas from the development of Saab Scania As's latest military aircraft J39 Griffin. The system safety and reliability of the system are also taken in consideration and discussed in the paper. The test results indicate that it is possible to achieve an extended controllability and a higher degree of active and passive safety by using steer-by-wire and a joy-stick.

Introduction

Saab-Scania and Saab Automobile AB has a long lasting tradition to work with active and passive safety in vehicle design. Very often this work have been supported by the synergy effects of the diversified Saab-Scania organization. The Saab Aircraft Division has been a contributor with their deep interest and experience of the man and the aircraft total system performance. Their experience of how to tackle the problems of dynamic interaction between pilot and aircraft as an important part of a system approach in the design have been very valuable over the years in vehicle applications.

Figure 1. Steer-by Wire and a Joy-stick Installed in a Saab 9000

Saab-Scania is involved in the European Eureka research program on future road traffic systems called PROMETHEUS. The main objectives of PROMETHEUS are to accomplish increased safety, increased efficiency and reduced environmental impacts in road traffic by means of solutions based on information technology. The application oriented areas are safe driving, harmonization of traffic flows and travel and transport management. The Saab-Scania organization is involved in all of these areas. One project in the area of safe driving was started in 1987 [Aartojarvi et al. 1990] and is called Driver Assisting Copilot, DAC and will be reported in this paper.

The main objectives of the DAC project have been to improve safety by optimizing the following relationships:

- driver-vehicle cooperation (driver feedback)
- vehicle-environment interaction
- the total system performance (closed-loop information flow)

A sub-goal has been to investigate how the basic ideas of joy-stick algorithms from the military aircraft J39 Griffin [Nordstrom, 1982] can be used to improve the driver-vehicle-road interaction.

Another sub-goal is to secure the safety and reliability of a steer-by-wire system in a passenger car. The driver must be able to control the vehicle even if a component fails.

The project is in line with a well established tradition at Saab Automobile AB to make use of the knowledge gained from the development of modern military and civilian aircraft at the Saab Aircraft Division and combine it with experiences from other parts of the Saab-Scania organization [Franzén, Ilhage 1989].

The main activity in the project has been to develop and test an experimental Saab 9000 car with an active steering system using an unconventional control unit and steer-by-wire principles. The problems addressed, the principle applied, the details of the realization work and the evaluation studies performed will be presented in the following sections.

Driving Situation

A description of the handling properties should be done by considering the closed-loop of driver-vehicle-road as a dynamic system (Figure 2). Methods to analyse dynamic systems have been developed in the area of control theory. When the driver changes the steering input, the response of the vehicle can theoretically be described as a superposed steady-state response and a transient response. Under normal driving conditions, the vehicle response should accurately follow the driver's steering input with smooth lateral force build-up.

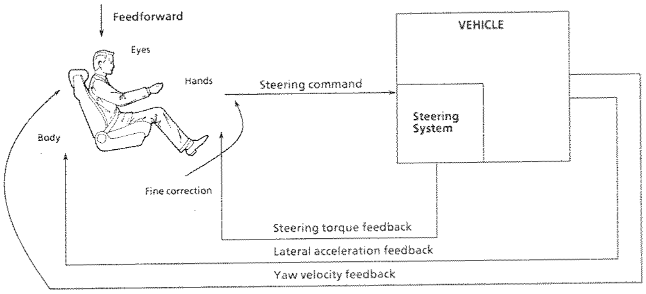


Figure 2. Driver Vehicle Closed Loop System

The steady state response is dependent on the steering input and the vehicles stability properties. The transient behavior is mostly dependent on the vehicles steering properties, such as steering response time and steering gain, and the control properties of the chassis, e.g. a neutral, oversteered or understeered vehicle, roll steer, side force steer and the ratio between the radius of gyration and the wheel base.

In general good handling properties can be achieved at all road surfaces with a neutrally steered vehicle. In a wide range of velocities and road surfaces, the control properties of the chassis is a compromise between road holding, handling, steering properties, track sensitivity, the information from the vehicle-road to the driver etc.

The driver is of vital importance in the driver-vehicle road system. When controlling a vehicle the correct decision should be taken in all driving situations, so it is essential that the information is of high quality and at the right time. The driver has a superior capacity to adapt to different driving situations and to change control strategies in a very short time. But to control the vehicle with high precision, the vehicle must support the driver and give him/her very accurate information from the vehicle and road. The driver can then convey the vehicle with high active safety.

The driver uses feedback signals such as visual impressions through the wind screen, steering wheel torque and lateral accelerations to do steering corrections and follow the ideal course (Figure 2). The driver is very sensitive to those signals. An unskilled driver uses principally visual impressions to control the vehicle during course tracking and lane change manoeuvers. A skilled driver can include steering wheel torque and lateral acceleration signals to a higher extend and reach accurate lane keeping.

By using visual impressions, the driver can plan the driving. The velocity can be reduced and early steering corrections take place if for example an obstacle appears in front of the vehicle. When the driver detects a deviation between the vehicle heading and a desired course he will compensate to reduce the deviation.

The force variation between tyre and road feeds back torque through the steering system to the steering wheel which informs the driver and enables him/her to decide the next steering command. The driver needs a distinct and noise-free signal to avoid unnecessary lateral movements. To achieve a very precise and immediate response, the chassis system must have well-tuned kinematic and elasto-kinematic characteristics accurately adapted to the steering system characteristics.

A skilled driver uses the lateral acceleration signal to a higher degree to control his vehicle. The lateral acceleration acts as a force on his hips. The driver and the passengers are very sensitive to lateral acceleration.

A New Steering System

In the Saab PROMETHEUS project driver assisting copilot, one of the aims has been to investigate if driving safety can be improved by replacing the conventional steering system by a steer-by-wire system in combination with a joy-stick as the steering command unit (Figure 3).

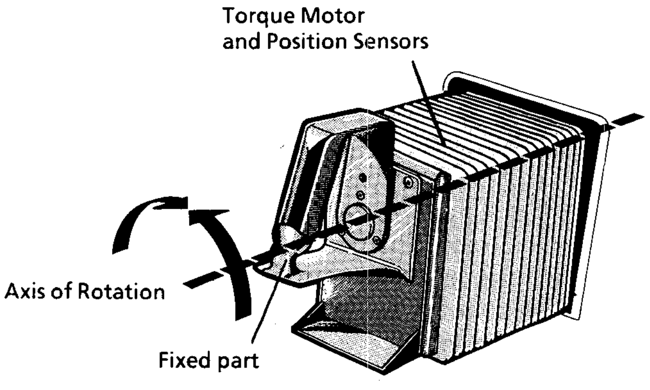


Figure 3. Joy-stick

When using a steer-by-wire system the mechanical link between the driver and the wheels is removed. A computer collects the necessary information and controls the steering servo.

The steer-by-wire system will allow a change in the steering characteristics and adapt them to other properties of the driver and vehicle e.g. the steering ratio and the force feedback from the tyre/road to the driver can be made velocity dependent.

When introducing a steer-by-wire system the steering wheel solution is not necessarily the best driver command element. It opens the possibility of using a joy-stick. The steering wheel is a good compromise of steering strategy when there is a direct mechanical coupling to the wheels and full wheel travel of ±40 degrees is needed in parking manoeuvers and precision for small wheel travel of ±5 degrees is needed in normal and high speed driving.

In an aircraft, the pilot uses a joy-stick to control the aircraft with small movements of his wrist. He can fully use the sensitivity and motoric functions of his wrist to achieve a very precise response.

The combination of a joy-stick and a steer-by-wire system gives a possibility to minimize the lateral deviation from the desired course.

The joy-stick feedback to the driver is computer controlled and generated from a torque motor in combination with spring and damper. The programming of the computer is a very important task to create genuine joy-stick-feeling, high fail-safety and good handling characteristics.

By using sensors in combination with a steer-by-wire system, active steering can also be used to automatically steer the wheels to compensate for disturbances which affects a smooth driving path, e.g. a track in the road surface or cross-winds.

Realization

System Layout

A block diagram of the prototype implementation of the DAC system is shown in Figure 4. The DAC system is a full steer-by-wire system i.e. no mechanical connection from steering input to wheel angle output exists. The joy-stick is the driver interface to the DAC system. When the driver applies a steering command by use of the joy-stick, the computer calculates a modified wheel angle command as an input to the electro-hydraulic servo. The joy-stick unit includes a torque motor for an un-linear force feedback to the driver.

The DAC system includes an analog backup channel. At startup the system is working from the analog backup channel, just to make sure that this channel is working before switching over to the computer channel. The analog backup channel and the computer channel are both working in parallel, feeding the corresponding redundant servo valve with servo commands. If a failure is detected by the computer channel or if the driver

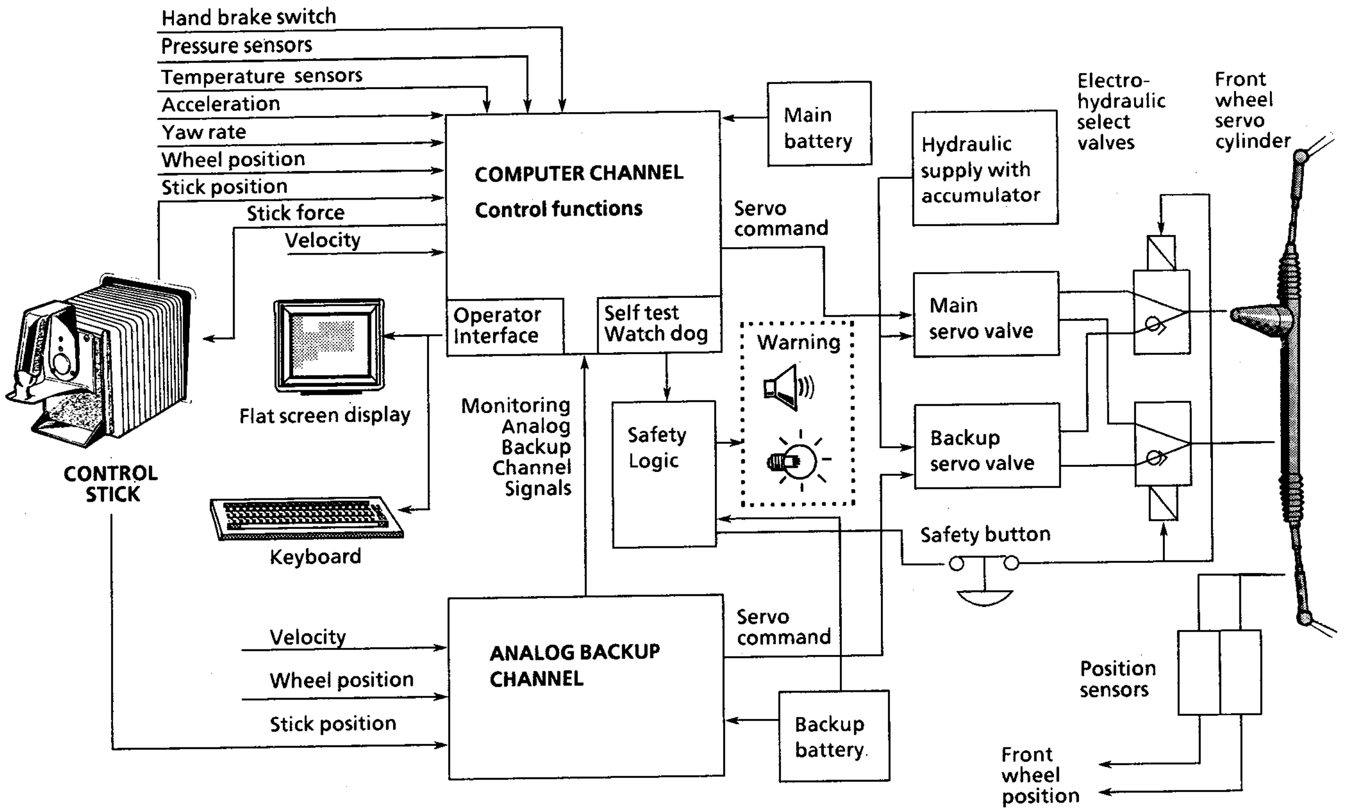


Figure 4. Block Scheme of Front Wheel Control System

pushes the safety button, the electro-hydraulic selection valves will be switched off and the backup servo valve will be connected to the front wheel servo cylinder.

Individual or group of parameters in the software are easily adjusted from an operator interface with keyboard and flat screen display. For demonstration and development test purposes any one of ten different parameter groups can be selected by one key stroke and transferred to running software, during driving.

Position sensors for the joy-stick position and the front wheel position are doubled. This redundancy can be used to detect transducer failures. The system includes also a hydraulic accumulator which will keep the hydraulic pressure for about 30 sec. or three full wheel deflections. This is enough for the driver to stop the vehicle at the roadside in a safe way in case of hydraulic pump failure or an engine stop. Signals from pressure sensors at the pump as well as the accumulator are available for early detection and warning.

Joy-stick

Different joy-stick configurations have been investigated. One has two joy-sticks mechanically coupled to each other and placed in front of the driver. Another configuration uses a single joy-stick placed by the side of the driver in front of an adjustable arm rest. The last one is implemented in a SAAB 9000 car.

The design of the joy-stick is of great importance for the controllability of the car. The joy-stick is divided into two parts. The lower part is fixed to support the hand against lateral and vertical forces and to give the driver a rigid reference for the hand (Figure 5). The upper part of the joy-stick has the axis of rotation just below the center of the hand parallel to the forearm.

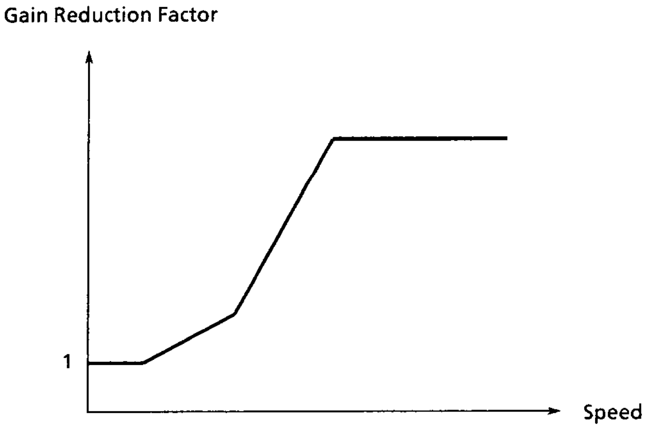


Figure 5. Speed Dependent Stick to Wheel Angle Gain

In a good man-machine system, information must be transferred in both directions. In our case the driver does not only apply the steering command to the joy-stick but he also gets force feedback. The joy-stick feedback is composed of a force generated from a computer controlled torque motor superimposed on the feedback of a passive springs and damping system.

Control algorithms

When using full steer-by-wire the steering strategy can be freely selected. Ideas from the aircraft development work supported the idea that a yaw velocity proportional to the stick angle should be used as a steering strategy. To achieve this, the stick-to-wheel angle gain has been made velocity dependent. At high speed the gain is decreased and thus the yaw velocity is maintained. At low speed a full stick angle gives a full wheel angle. The stick to wheel angle gain reduction curve has two break points and an upper limit (Figure 5).

The stick-to-wheel angle control function is non linear with a low gain for small changes and a high gain for large changes in the stick angle input. The force feedback is matched to the steering function above. In the same "fine steering area" where the gain from stick-to-wheel angle is low, the gain for force feedback is high (Figure 6). The "fine steering area" is not fixed to the center but follows the stick angle input. Hence, fine corrections while cornering is performed with low stick-to-wheel angle gain (No 2 in Figure 6) and high stick force gain (No 1 in Figure 6). All transfer function slopes and gains are changeable via the operator keyboard and screen. A change in force function will, if needed, automatically introduce the correct change in the stick-to-wheel function to keep the two functions matched.

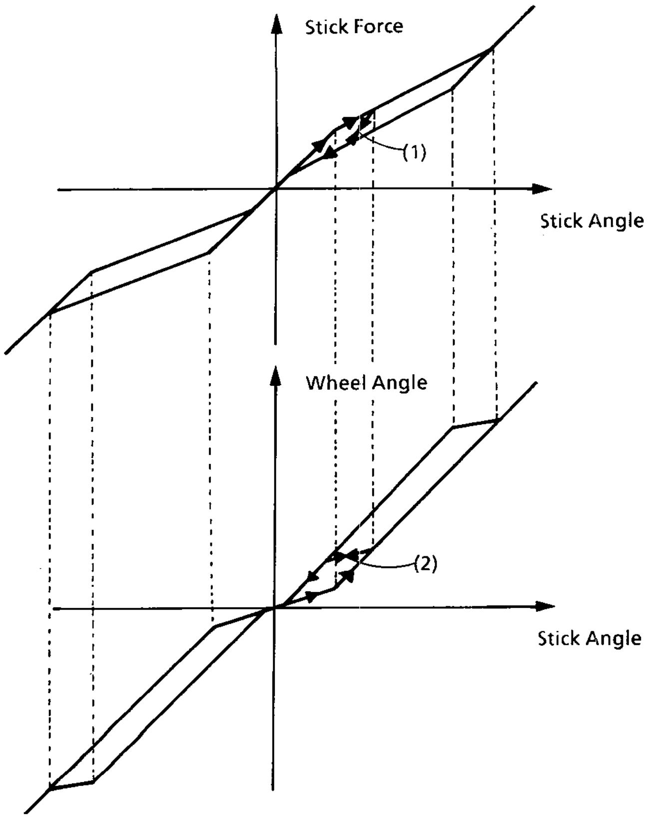


Figure 6. Joy-stick Algorithms

Hardware

The servo cylinder is a modified standard front wheel servo. At the normal steering input a housing with two redundant servo potentiometers are mounted. The electro-hydraulic servo valves, one for the computer channel and one for the analog backup channel, are connected to the servo cylinder via two electro-hydraulic select valves. The hydraulic pump supplies, via a non return valve, a constant pressure of 100 bar to the servo valves and the accumulator.

The computer is PC-AT compatible with Intel 287 math coprocessor. All input and output signals are interfaced to the computer via a standard G64-bus. This solution is not compact but very flexible for development and test purposes.

The joy-stick is mounted in front of an adjustable armrest. Two joy-stick position sensors are included, one resolver for the computer channel and one potentiometer for the analog backup channel. The joy-stick angle resolution for the computer channel is 14 bits or 0.022 degrees.

Software

The software has been developed in Turbo C and assembler and is loaded into the vehicle from a 3.5 inch floppy disk. As mentioned before all control parameters can be modified changeable via the operators interface. A specific group of control parameters can be saved on a disk for repeated use.

The sampling frequency is 120 Hz. All control calculations are performed at this frequency. The settling demand for this frequency is the force feedback control loop. The human hand is very sensitive and with the prototype joy-stick assembly a 120 Hz sampling frequency was needed to get a smooth feeling.

Methods for Reliability

When full steer-by-wire is considered for passenger cars, safety and reliability questions are of major concern. The vehicle must be steered and handled in a safe way even if a component fails. The reliability of electronic subsystems must be very high and the necessary fault tolerance can be achieved by employing redundant sensors, electronic sub-systems and serve valves.

The system layout chosen for the full steer-by-wire demonstrator vehicle is a result of trade off studies performed early in the project, with the objective to design a system with adequate safety for the successful demonstration of the project goals.

The resulting implementation (Figure 4) is a redundant active/standby system, where redundancy is used to form a "fail safe" system, rather than to achieve enhanced availability.

The active channel has a digital implementation, built around a microcomputer. The program code contains, algorithms to control the vehicle as well as software for functional monitoring. If the monitoring system detects a serious failure an automatic switch-over to the standby system will be take place.

The standby or back-up channel is analog and it is operated from a separate power source. The basic idea is to keep the back-up channel simple for the highest possible reliability. A speed dependent gain control has been implemented to better match the gain of the primary channel and thus reduce the transient if a switch-over should occur during dynamic control.

A hydraulic actuating system has been chosen in the demonstrator vehicle mainly because its maturity in comparison with electrically operated power actuators. The use of standard Saab 9000 parts also simplified the installation in the test vehicle. A high pressure accumulator serves as a temporary hydraulic back-up system.

An extensive automatic and partly operator assisted test of the system is performed at every start-up, in order to detect dormant failures in redundant functions and to reduce the exposure time for failures not detected by the functional monitoring scheme.

The steer-by-wire system has been certified for use in the demonstrator vehicle through various analyses methods such as; Fault Tree Analyses (FTA) and Failure Mode Effects Analyses (FMEA). Limited failure mode testing (FMET) was also performed as part of system validation. Experiences from the safety concept gained to date are encouraging.

Test and Evaluation

To be able to investigate the joy-stick layout and the joy-stick characteristics a simple driving simulator has been built. The driving simulator was based on low cost standard equipment. The driving simulator includes an interface to the driver for the steering, the trottle pedal and the brake inputs and a two dimensional video screen which shows the vehicle position to the driver. The software includes a vehicle velocity model, steering strategy equations, a vehicle model, a road map and conversion software for conversion from vehicle position on the map to the screen.

The prototype built from the experiences achieved from the driving simulator has been used for extensive evaluations by experienced test drivers in different driving situations and tests conditions. The driving conditions covers everything from dry tarmac to winter tests on icy roads.

To achieve the different steering properties computer control is necessary. The testing includes optimization of the control algorithm parameters, total a number of 12 parameters, over the whole vehicle speed range.

The test driving have resulted in different enhancements of the system, such as adding damping through an electric damper for better low speed performance. A small amount of filtering have also been added in the low speed region. Furthermore have control algorithms been optimized in the whole speed range.

Future Outlook

Steer-by-wire

One logical question is; Can we ever expect to see a steer-by-wire system in a production car?

We believe the answer is "Yes" !

For similar reasons that fly-by-wire systems today are the preferred design approach in modern commercial and military aircraft's, they may also become attractive to the automotive market in the future. But we do not believe in full automatic driving. The driver must keep the responsibility for driving the vehicle.

In the aircraft world, the following factors have influenced the fly-by-wire evolution:

- Easy and flexible to install
- Enhanced performance (active steering)
- Easy to adapt (software changes)
- Low weight
- Low volume

These parameters are also important in automobile design but the low cost requirements, the very different driving situation and the much greater variation among drivers makes the introduction in cars much more difficult.

Steer-by-wire systems in cars, will when first introduced likely use a conventional steering wheel as a control unit.

Use of one or two mini joy-sticks is deemed to be attractive together with a more integrated driver environment, where graphic display units of "head on" type are used to inform the driver about the traffic situation. The various driver support systems such as intelligent cruise control that will be available will further justify the deletion of a sight line distracting steering wheel. Independent development of high voltage electrical systems (48VDC) and multiple winding high torque electric motors for cars will support the maturity process for steer-by-wire systems.

A high supply voltage will be required to keep control currents low, and to keep the overall efficiency up. The conventional battery system can act as a redundant supply for safety reasons. The battery will operate over a separate motor winding and provide adequate steering characteristics in case of a failure in the ordinary supply.

In order to present a cost effective solution, it is mandatory that supply and actuating components of the system have reached a mature state and has been proven reliable. The electronics required in the system can already today be designed with required redundancy and produced at cost levels that would not prohibit introduction of steer-by-wire systems in automobiles.

Four Wheel Steering

To gain full advantage of a steer-by-wire systems it is necessary to include four wheel steering (4WS). The goals for a 4WS system is to reach:

- Better manoeuverability at low speed
- Improved high speed stability

- Reduction of disturbances caused by external forces
- Higher degree of controllability in evasive manoeuvers
- Easier and more restful control task for the driver in normal situations
- Neutral steering behavior, independence of load etc.
- Increased grip

The approach for a SAAB 4WS system is to have a system that will adjust to the control strategy and the driving situation. This means that the strategy for "normal" driving situations should aim to making the drivers task easier and more comfortable. Irrelevant information should be reduced or eliminated, while relevant information to the driver should be clear and consistent.

When the vehicle comes close to the limit of adhesion a control system should take over. It should act on its own (c. p. an ABS system) or give the driver the opportunity to cope with the situation.

The reliability criteria is somewhat lower for the rear axle since the effects on the controllability of the vehicle are limited. In case of power fail to the rear actuators they may be locked and the passive elements in the suspension can take over.

Conclusions

We have found that combining the joy-stick and the steer-by-wire system leads to a more relaxed and comfortable driver. That is because of it gives:

- a better steering precision as the driver can use the sensitivity of his/her wrist
- a more ergonomically designed driving position, since the arm rest protects the drivers from doing undesired movements
- an improved possibility to utilize the instrument panel for new information purposes to the driver
- improved safety when injury caused by the steering wheel is eliminated

References

Aartojarvi, R., Branneby, P., Franzen, S., Isaksson, A. and Palmgren, B.: "A Driver Assisting Copilot For Active Lateral Control", PROMETHEUS Proceedings of the 3rd Workshop pp 5-15, April 1990, Torino Italy.

Nordstrom, L.: "A Mini-Size Aircraft Manual Control", European Annual Conference on Manual Control and Human Decision-Making, May 1982, Bonn, BRD.

Franzen, S. and Ilhage, B.: "Active Safety Research on Intelligent Driver Support Systems", The 12th International Technical Conference on Experimental Safety Vehicles (ESV), May 29-June 1, 1989, Gotborg Sweden.

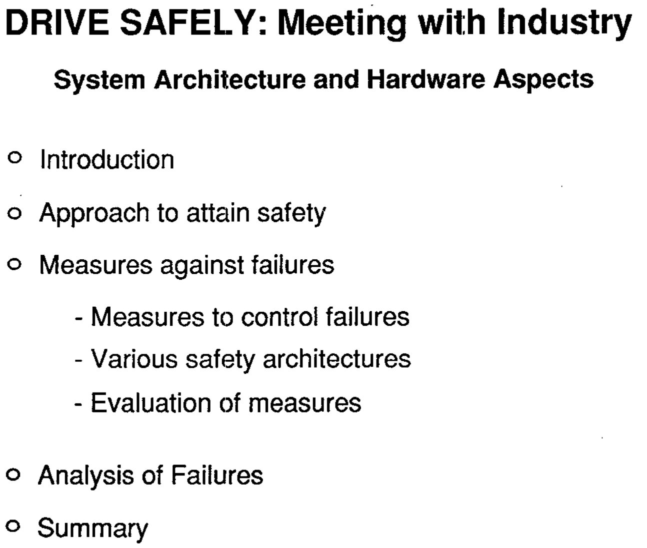
S2-O-06

Proposal for a Guideline for Safety Related Electronics in Road Transport Systems (Drive Project V1051)

Winfried Asmuth, G. Heuser,
H. Trier, J. Sonntag
TÜV Rheinland

Today more and more safety related vehicle subsystems are equipped with programmable electronics. Current research programs—in Europe DRIVE and PROMETHEUS—are thinking about high tech systems such as automatic distance control, steering by wire, etc. which have all a very high level of risk. The project V 1051 of the DRIVE programme is intended to ensure a high safety standard in road transport systems. The main task is to specify a guideline for developing and production process as well as for the certification procedure of hard- and software of porgammable electronic systems.

This presentation is mainly concerned with measures against random hardware failures as well as with methods of analysis used to detect weak points in the design of Road Transport Informatics (RTI) systems (Figure 1).



DRIVE SAFELY: Meeting with Industry

System Architecture and Hardware Aspects

- ○ Introduction
- ○ Approach to attain safety
- ○ Measures against failures
    - - Measures to control failures
    - - Various safety architectures
    - - Evaluation of measures
- ○ Analysis of Failures
- ○ Summary

Figure 1. Structure of the Report

Firstly the general approach to attain safety of RTI systems will be explained, followed by measures against failures. The main emphasis is on the measures to control random failures. We look at both the various architectures for different safe situations and at an approach to assign measures to integrity levels. Following that, methods to analyses and to detect weakpoints in the design will be considered. Finally there is a short summary of the presentation.

Approach to attain safety (Figure 2)

In order to ensure safe operation of safety critical electronic systems, it is necessary to recognize the various possible causes of failures and to ensure that adequate precautions are taken against each.

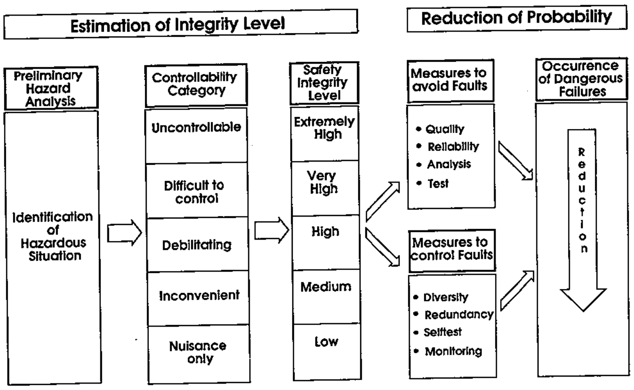


Figure 2. Approach to Attain Safety

The main safety objective is to avoid hazardous malfunction of the electronic system with sufficient probability for a particular application. This goal could be attained, if the following approach is applied:

In a preliminary hazard analysis the hazards must be identified and evaluated.

The degree of probability to control the dangerous situation by the road user places each hazard into one of five controllability categories from nuisance to uncontrollable.

Assigned to these categories are safety integrity levels which are ranged from low to extremely high.

According to the integrity level a combination of measures with suitable effectiveness must be taken to avoid and to control faults.

By quality measures which are applied during the development process, faults can be avoided.

By structural and fault detection measures, faults can be controlled during the operation phase.

The controlling measures are necessary, especially at higher integrity levels, because the reliability of electronic systems is often limited. Both the measures to avoid and to control faults increase safety by reducing the probability of the occurrence of dangerous failures.

Measurement Failures (Figure 3)

Precaution must be taken against both random hardware failures and systematic failures in hard- and software. Suitable measures must be taken to avoid faults during the development and production phase and to control faults during the operation phase of the system.

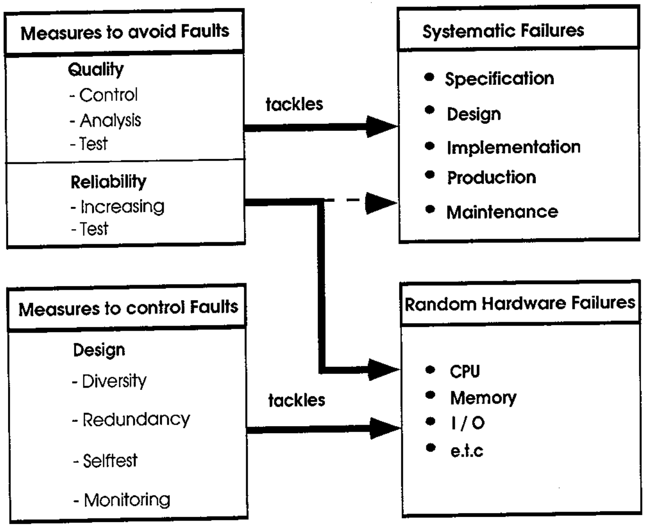


Figure 3. Measures Against Failures

Software faults always result in systematic failures. They can only be avoided by quality control measures during the development process and controlled by diverse redundancy during operation.

Hardware failures can be caused by both systematic faults made during the development and productions processes, as well as by random faults in components. Systematic hardware faults can be avoided through quality measures. The occurrence of random hardware failures can be reduced by improving reliability, but this is often limited, especially with complex programmable electronic systems. Therefore additional design measures are necessary to control these random failure.

The measures against failures can be summarized into three safety elements:

- Quality---> tackles mainly systematic failures
- Reliability---> tackles mainly random failures
- Design---> tackles also mainly random failures

Measures to control faults (Figure 4)

If safety cannot sufficiently be attained by quality and reliability measures, then measures are necessary to control failures during the operation phase.

The first basic safety requirement on RTI systems for all levels of integrity is, that a single fault may never lead to a dangerous situation. To attain this goal faults must be detected and an appropriate protection measure must be carried out. The second requirement is, if a fault is undetected, it should never lead to a dangerous situation even in combination with one or more other faults.

These safety requirements can mainly be fulfilled with the aid of two methods: The first method uses comparison of results of redundant systems. The second method uses test procedures to detect faults in systems.

If quality + reliability < safety
then measures are necessary to control faults.

The objective of the control measures is to ensure that faults never lead to a dangerous situation.

To achieve this faults must be detected and an appropriate protection measure must be carried out.

Fault detection measures

- System structure (Comparision of the result)
- Test routines to recognize faults
- Inspection, maintenance

Figure 4. Measures to Control Faults

In addition to these technical measures, periodical inspection and preventive maintenance should be carried out to detect faults.

Faults detection measures (Figure 5)

In the first place the designer has to specify a system architecture which is related to the integrity level and the predicted safe state of the process in the event of a failure.

System structures

- One channel with selftest and monitoring
- Two channel with comparison of the result
- Three channel with voter
- etc.

Test routines

- CPU-, RAM-, ROM-, I/O-Test
- plausibility check of Input/Output data
- watchdog
- etc.

Organizational Measures

- Periodical Inspection
- Maintenance
- etc.

Figure 5. Fault Detection Measures

The following structure are feasible:

- One channel with selftest and monitoring
- Two channel with comparison of the result
- Three channel with voter etc.

Secondly, he has to select adequate test methods to recognize faults in each channel. Possible test routines are:

- CPU-, RAM-, ROM-, I/O-Test
- Plausibility Check of Input/Output data
- Watchdog

Thirdly, he has to determine organizational measures to detect failures during the operation phase of the system. Inspection and maintenance should be performed periodically.

Architecture of Safety-Related Systems (Figure 6)

Modes of safe design

We have to distinguish between fail safe, fail soft and fail operational design.

Modes of safe Design	Required safety function	Modes of operation	Possible System Structures
Fail safe	Emergency cut out (operation terminated)	- Protection/ Monitoring system - Control system	- One channel with fault detection measures - Two channel with fail safe comparator
Fail soft	Emergency operation (Limp home)	- Safety Monitor with Limp home function - Control system	System with redundancy for "Limp home"
Fail operational	Continue operation with full function	Control system	Two out of three voting system

Figure 6. Architecture of Safety-Related Systems

Required safety function

In the first case the process can be transferred into the safe state after the detection of dangerous failures, for example by switching off the energy supply (**Emergency cut out**).

In the second case the operation must be continued by degraded functional capabilities or performance in case of failures (**Emergency operation**).

In the third case the operation must be continued by full functionality of the process (**Continue operation**).

Modes of operation

A safety related system can be used as a protection system or can be part of a control system.

Protection systems get several inputs from the monitored process and their sole purpose is to transfer the process into a *safe state* (Emergency cut out) if they recognize a potentially dangerous state of that process.

Control systems use information from the process to influence process operation. In this case we have to distinguish between the following safety functional requirements in case of failures:

- Emergency cut out
- Emergency operation (limp home)
- Continue operation with full functions

Possible System Structures

Fail safe can be attained by:

- One-channel system with selftest and external safety monitor
- Two-channel system with fail safe comparator

Fail soft can be attained by one-channel system with redundancy for "limp home."

Fail operational can be attained by a two out of three voting system.

Competition between Reliability and Safety (Figure 7)

Safety and reliability can be found in competition in certain applications.

Modes of safe Design	Relation between Reliability and Safety	Safety Requirements on the availability of the	
		system function	safety function
Fail safe	Safety and reliability in competition System reliability is limited by safety	none	depends on the integrity level
Fail soft	Safety and reliability in competition System reliability is limited by safety	conditional required for the "Limp home" system	depends on the integrity level
Fail operational	Reliability and safety have the same objectives	equal to the safety function	depends on the integrity level

Figure 7. Competition Between Reliability and Safety

By **fail safe** and **fail soft** design reliability of the system will be reduced, because parts of the system or their functions are no longer available. In these cases safety and reliability are in completion; system reliability is limited by safety. Only if the part of the system under consideration is designed to **fail operational**, are safety and reliability achieved by the same measures. In this case reliability and safety have the same objectives.

Safety requirements on the availability of the system function must be made only if the system is designed "**fail operational**" and conditional for the Limp home function if the system is designed "**fail soft.**" Availability of safety function is required for all modes of safe design, but the degree of availability depends on the integrity level.

Required Effectiveness of Measures (Figure 8)

A set of measures is necessary to avoid and to control hardware failures of (programmable) electronic systems. A combination of measures with suitable effectiveness must be selected according to the estimated integrity level.

Three classes are proposed:

- little effectiveness
- average effectiveness
- great effectiveness.

The effectiveness classes are established for each integrity level. The required effectiveness of the measures to avoid systematic and to control random hardware failures ranges from little to great. Measures to control systematic failures are only required at higher integrity levels. Lower integrity levels only require measures with little effectiveness.

Hardware Measures to		Safety Integrity Level				
avoid (Development)	control (Operation)	Low	Medium	High	Very High	Extremely High
Systematic failures		little	little to average	average	average	great
	Systematic failures	--	--	--	average	great
	Random failures	little	little to average	average	great	great

Figure 8. Required Effectiveness of Measures

These measures are able to tackle failures with relatively high probability of occurrence. In contrast, higher integrity levels require measures with great effectiveness which are also able to tackle failures with low probability of occurrences.

Assignment of Structural Measures to Integrity Levels (Figure 9)

Possible measures to avoid and to control failures are listed and evaluated in the draft of the proposed standard. The list should be an aid for the developer to find suitable measures for a particular application; however other adequate measures with the same effectiveness could be applied. Different combinations of measures are possible for a safety integrity level, where the selected combination for a particular application depends strongly on the considered process. The total

Structural Measures	Safety Integrity Level				
	Low	Medium	High	Very High	Extremely High
One-channel structure					
- with selftest	X				
- with selftest and monitoring		X			
Two-channel (fail safe)					
- homogenous			X	X+	
- diverse				X	X+
Three-channel (fail operational)			X	X+	X+

X required
X+ required with additional high value measures

Figure 9. Assignments of Structural Measures to Integrity Levels

effectiveness of all measures should be examined carefully to ensure that the safety requirements are fulfilled.

An example is given for structured measures (see Figure 9).

Failures Analysis (Figure 10)

To prevent dangerous situations of a system in case of failures all thinkable modes of component or sub-system failures and their effect must be considered. Many standardized analysis methods exist.

Two of these are:

- Fault Tree Analysis (FTA)
- Failure Mode Effect Analysis (FMEA).

To prevent dangerous situation failures of items must be considered.

Useful analysis methods are:

- Fault Tree Analysis (FTA)
- Failure Mode and Effect Analysis (FMEA)

FTA is applied to identify combination of failures and to identify safety-critical items (top-down approach).

FMEA is a qualitative evaluation of failures, especially to detect weakpoints in design, construction and production of systems (bottom-up approach).

Both are applied to complement each other during safety analysis.

Figure 10. Failure Analysis

The objective of the FTA is to identify all possible combination of component or sub-system failures, which could lead to the undesired event. The FTA is a top-down method and can be started before a detailed design document is produced. This method can support the hazard analysis process to identify safety critical items. The output of this analysis is a clear reviewable diagram(s).

The objective of the FMEA is the qualitative evaluation of component or sub-system failures of a system. The FMEA is a bottom up approach, whereby the various failure modes and effects of components or sub-systems will be analyzed, especially to detect weakpoints during the design, construction and production phase of a system.

The methods are not applied in competition, on the contrary the will be applied to complement each other. During safety analysis the FTA is used to identify safety critical components/sub-systems and the FMEA is used to detect weakpoints of these items.

FMEA of Complex Electronic Devices (Figure 11)

The FMEA will be performed to give an answer of the question: "What happens if a sub-system/component fails in a particular failure mode"?

FMEA should answer the questions:

What happens it a sub-system/component fails in a particular failure mode.

General approach

- Failure mode of items must be identified
- Failure effect must be analysed
- Failure with very low probability must be excluded

Approach for complex electronic system

- It is economically unjustifiable to evaluate all failures of complex electronic design.
- Therefore FMEA should preferably be performed on module level of complex electronic unit and on component level of actuators, sensors, electric and simple electronic circuits.
- The electronic unit itself must be constructed according to the prescribed measure against failures.

Figure 11. FMEA of Complex Electronic Devices

Firstly all failure modes of components/sub-system must be identified. Secondly the effect of the failure must be analyzed. To design safety devices it is necessary to excluded failures with very low probability.

Another problem occurs where applying the FMEA on complex (programmable) electronic systems, because it is impossible or economically unjustifiable to evaluate the very high number of failures and their resulting effects. An applicable approach is to perform the FMEA on module level of complex electronic systems and of component level for actuators, sensors, electric and simple electronic circuits. The electronic unit itself must be constructed according to the prescribed measure against failures.

Consideration of Multiple Failures (Figure 12)

The standard FMEA regards only the consideration of a single failure. In standards on road traffic signal system, electric signalling systems for railroads, burner control systems, press control devices etc. multiple failures are considered according to a particular fault flow chart.

For RTI system an appropriate fault flow chart is proposed. The chart begins with the "1st failure" (e. g. emitter-collector of any transistor short circuit). Verification that after each *"1st failure" no hazardous situation may occur* must be made. If so, what else happens after the "1st failure"?

- The automatically detected "1st failure" immediately leads to the "safe situation." If all first failures run

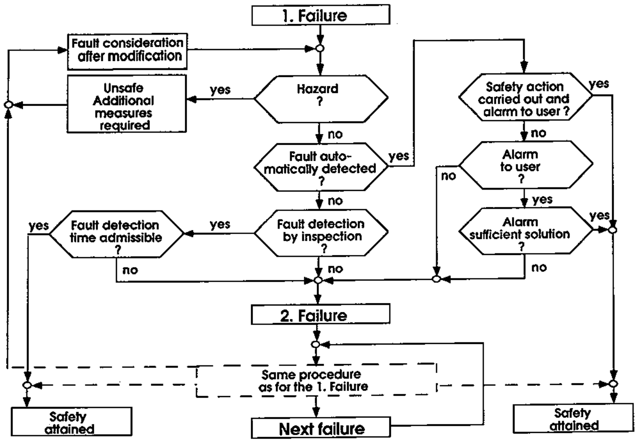


Figure 12. Consideration of Multiple Failures

If safety cannot be achieved sufficiently by quality and reliability measures,
then measures are necessary to control failures.

This is usual if electronic systems are applied.

The control measures must be able to detect faults and to carry out a safety action with sufficient probability

The different safe situation must be considered when designing the system. These are:

- Emergency cut out	(fail safe design)
- Emergency operation	(fail soft design)
- Continual operation	(fail operational design)

Figure 13. Summary

this course, the safety device is fail safe to the highest possible level. Only relay switching circuits or small discrete electronic systems can be designed this way.

- The automatically detected "1st failure" leads to an alarm signal for the user. If this solution is not sufficient further failures must be considered or the system must be modified in order to ensure a switch over to the "Safe Situation."
- The "1st failure" will be detected during the next system inspection (automatic check or manual test). In general it is not assumed that during the interval between failure appearance and failure detection any "2nd failure" will occur and thus, in combination with the "1st failure" create a hazardous situation. It is often a question of probability calculation whether or not this assumption is permitted. If this solution is not sufficient further failures must be considered or the system must be modified in order to ensure a switch over to the "Safe Situation."
- The "1st failure" will not be detected at all (not detected by routine inspections).

In the last mentioned case, or if the alarm signal and inspection is not a sufficient solution, the "1st failure" has to be combined with any "2nd failure" and the flow chart is followed for the same routine. According to the level required, this may be repeated infinitely.

S2-O-07

Influence of Electromagnetic Fields Radiated by Lighting Discharges on Automotive Electronic Components

S. Ficheux
UTAC
M. Klingler, M. Heddebaut
INRETS

Abstract

An overview of the automobile field shows a more and more frequent resort to electronic systems on vehicles. Improvement of mechanical functions, comfort, driving information and safety are now some of the current applications. However, functioning of electronic systems can be modified by electromagnetic perturbations generated by sources such as on-board transmitters, AM broadcasting, CB, or radar emissions. The radiated fields produced by the lightning discharges form also intense sources which are apt to disturb the functioning of electronic systems or eventually to destroy them. In such conditions vehicle safety can be altered if systems (e.g. electronic injection units, ABS or future multiplexing systems) are perturbated. Results obtained during different tests performed on two vehicles: a passenger car and a truck, disposed on the lightning research station at Saint Privat d'Allier, France are presented and discussed.

Introduction

Natural lightning phenomenon constitutes the most important natural source of electromagnetic perturbation that often affects functioning of telecommunication systems and transmissions.

The national center of telecommunications in France CNET (1) has been studying for a long time the influence of the lightning discharges on telecommunication systems.

In 1990, it was decided by CNET to re-activate the privileged site of Saint Privat d'Allier in order to perform experiments to directly appreciate influence of lightning discharges on telecommunication systems and transmission lines.

French automobile group constituted of PSA (2), RVI (3), ECL (4), INRETS-CRESTA (5) and UTAC (6), was invited to join the working group of Saint Privat d'Allier as well as other companies and research laboratories (3,7).

1) CNET: Centre National d'Etudes des Telecommunications
2) PSA: Peugeot Societe Anonyme
3) RVI: Renault Vehicules Industriels
4) ECL: Ecole Centrale de Lyon
5) INRETS CRESTA: Institut National de Recherche sur les Transports et leur Securite—Centre de Recherche et d'Evaluation des Systemes de Transport Automatises
6) UTAC: Union Technique de l'Automobile, du Motocycle et du Cycle
7) CEA-CENG: Commissariat a l'Energie Atomique—Centre d'etudes nucleaires CENG de Grenoble.

The Saint Privat d'Allier station provides effectively the possibility to initialize artificial lightning discharges with full control of their impact points and it gives a certain flexibility to perform tests with well determined conditions.

A passenger car was equipped with a simplified multiplexed system and a numerical survey of the dialogue was implemented during each of the artificial lightning discharges. The engine speed of the vehicle was also controlled.

In relation with these points we have developed also coupling measurements performed on the different electric wiring harnesses. These ones were mounted on each of the two vehicles, in order to appreciate the risks run by electronic systems regarding induced current amplitude produced by high field strength levels.

Triggered Lightning Phenomenology

Triggered lightnings are achieved by creating an artificial conductive channel between earth and the thunder cloud. This is done by firing a rocket unrolling at it's rear a thin copper-kevlar cable connected to the base of the firing platform. Lightning discharges are then characterized by a first current stroke, followed by several return strokes which magnitudes can be greater than the first stroke. By using this method, it is possible to obtain amplitudes between 5 and 50 kA, whilst typical natural lightnings can reach current levels of 100 kA. These currents create intense electromagnetic fields which can influence electronic implemented systems aboard vehicles. This technique has been used with success for several years by the CEA-CENG in France and overseas.

Wiring Implementation

Two vehicles, a truck and a passenger ear Peugeot 405 MI 16 were disposed at approximately 50 meters from the lightning impact point. On each of these vehicles were laid out several cables with different technology in a view to study both destruction and coupling aspects. Functioning and coupling aspects were complementary dealed in these experiments. Figure 1 shows the two vehicles and the lightning platform.

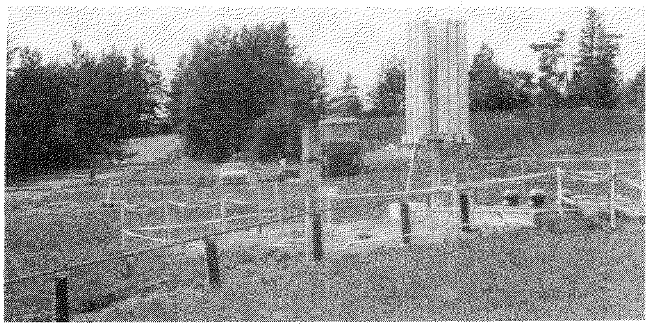


Figure 1. View of the Saint Privat Station, Vehicles and Launching Platform

A first set of communication harnesses were installed between the front and rear of the passenger car, designed to support a simplified communication link which will be detailed throughout the next paragraphes. The different types of cables composing this set were the following:

- a twisted shielded bifilar harness,
- a four lead ribbon cable.

Two experimental communication modules were installed at each end of the passenger ear, the first one under the front left wing, the second in the trunk. These prototypes, enclosed in a plastic box, insured a communication dialogue respecting the first ISO layers of the VAN (Vehicle Area Network) standard proposition. The vehicle's motor speed was also controlled during these experiments.

Two simple wires were laid out along with the communication harnesses, one of the two placed above the chassis and short-circuited at it's end by a connection to the vehicle chassis, the other under the chassis connected at one end to the chassis and the other end on a 50 ohms load.

Initially planned to perform two current measurements, experimental circumstances conducted us to choose this configuration: an induced current measurement on the inner cable and a voltage measurement on the external cable's load.

To end, induced currents on several supply cables on the truck were done, one of these being exposed further in this paper. Figure 2 summarizes the wiring implemented on each vehicle.

Our measurement philosophy has lead us to place all the acquisition and survey instruments near the vehicles. The presence of intense electromagnetic fields produced by the lightning discharges obliged us to protect the instrumentation by double shielded containers. The

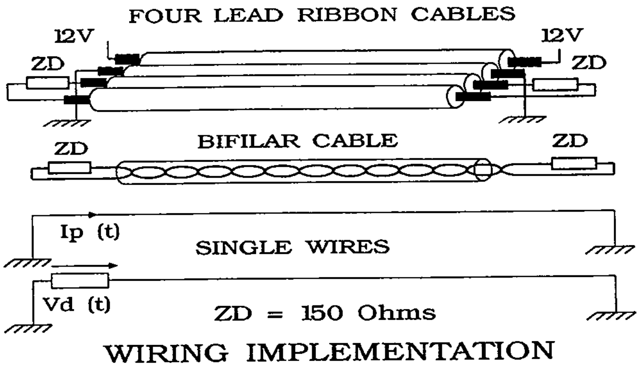


Figure 2. Wiring Implemented in the Two Vehicles

control, downloading and storage tasks were done from a control center protected by a faraday cage 75 meters away from the vehicles by means of optical A 488 modems and buses connected between computers and instruments.

Digital functioning survey of the simplified communication network was achieved by using a logic analyses and a Tektronix 2430A numerical scope. The analyses was connected by digital optical HP interfaces to the module under the front left wing, supposed to be the module the most exposed to the lightning discharges. The digital scope was used to measure the differential voltage across the communication harness through a 10 MHz analog optical interface giving supplementary information on data levels.

Concerning analog electromagnetic coupling measurements, fast numerical scopes functioning in a sequence mode were needed to capture separately each pulse corresponding to a lightning return stroke. Current probes, connected by plain copper shielded coaxial cables to the scopes, were chosen to measure the different induced currents.

Multiplex System Survey

Description

Two identical communication modules were connected at each end of one of the bifilar harnesses. In a view to achieve functioning diagnostics, digital readings were done on the module placed under the front right wing, supposed to be the one the most exposed to radiated electromagnetic fields. Synoptic of the communication circuit is given in Figure 3.

In order to distinguish and analyse the different origins of dysfunctions, the entire system had to be kept relatively simple as well on the hardware as on the software aspects. In this regard, the communication modules included only common and well known components. In the same idea, galvanic separation was achieved between the module and the car battery supply by the use of a DC-DC converter. Isolation between the module and the communication harness was realized by a pulse transformer.

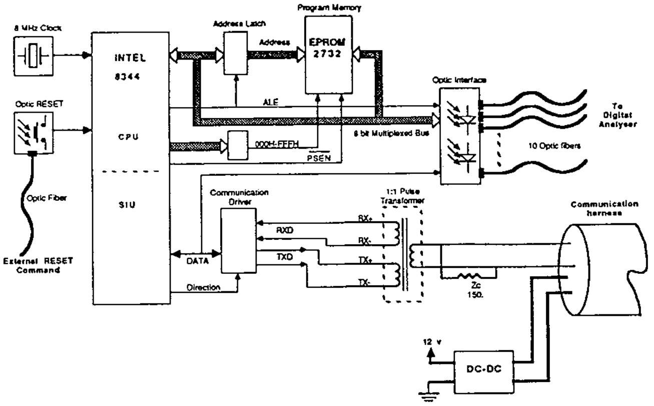


Figure 3. Communication Circuit Synoptic

For the communication purpose, an Intel 8344 microcontroller was used, essentially for it's programming flexibilities and it's serial interface transmission rates compatible with rates envisaged into the vehicle network systems. Although originally designed to handle high level HDLC (High Level Data Link Control) protocol, these SIU (Serial Interface Unit) functions were not required.

The frames transmitted at 125 kbps are identical and contain a 511 bits pseudo-random binary sequence coded in a Manchester format, giving to the frame a large frequency spectrum covering the entire Manchester spectrum. To preserve the frame's spectrum, no further information blocks were included, such as CRC block or Information block normally established in the VAN standard.

In order to avoid complicating the circuit and the software, the frame is already coded in it's Manchester format in memory and sent at a rate of 250 kbps.

An external EPROM is needed to observe the microcontroller's CPU steps. Several signals were to be read, enabling us to reconstitute it's functioning during the lightning discharge. For this purpose, a set of ten optical fiber transmitters were connected to different points of the circuit, chosen as being the most representative test points:

- the CPU's 8 bit multiplexed Data/Address bus, enabling to recover each step accomplished by the CPU during the lightning discharge,
- the Address Latch Enable pin, in order to separate~ Data and Address information occurring on the multiplexed bus,
- the SIU's Data pin, giving the levels received and transmitted by the microcontroller's SIU.

Reset operations after each triggered lightning is performed by using an additional optical receiver connected to the microcontroller's Reset pin.

No error checking is done after receiving the frame, this task giving only little information. On the contrary, serial data received is sent back on the microcontroller's Address/Data bus where it is analysed amongst the program data.

Results

Although no physical destruction was observed during lightning discharges, permanent dysfunctions were noticed on the module under test.

By analysing the digital recording, it was shown that no modifications appeared on the Central Processing Unit's functions, whilst the Serial Interface Unit presented a permanent dysfunction state corresponding to a sticked output level either in a low or high state. The different steps accomplished by the Central Processing Unit seem to show that the Serial Interface Unit acknowledges commands but does no longer execute them.

To achieve deeper investigations concerning the module's dysfunctions, further tests were carried out in a TEM cell driven by a 200 Watt power amplifier, generating electric fields reaching 160 V/m for different types of signals. Using this bench, no permanent dysfunctions were encountered in pulse mode, but only momentary random levels corresponding to each electromagnetic pulse. In a continuous mode, permanent software failures were recorded due to electromagnetic coupling on the CPU circuits.

Electronic Injection Unit

The survey of the vehicle motor's speed was achieved in measuring the voltage at the primary circuit of the coil ignition by means of an optical link. During each lightning discharge no faults were observed. All the results presented hereafter are obtained from a 6 kA peak current lightning discharge.

Coupling

Coupling results are exposed Figures 4 to 6. To improve their representation it was necessary to smooth them to remove the measuring noise, mainly due to the low dynamic of digital oscilloscopes and also in some cases to the low amplitude of the signals measured. Signals have been digitalized with 2000 points on a 2 µs window duration.

Shielded twisted bifilar cable

The current's evolution flowing through the 150 n impedance connected at one end of the cable situated in the car's boot is given in Figure 4-a. A 5 mA peak to peak amplitude is reached.

Figure 4-b shows the evolution of the same parameter measured through the 150 Ω impedance connected at one end of a similar but longer cable, placed along the left girder of the truck. We observe an equivalent peak to peak amplitude. It seems that the length factor does not influence result. These results have to be considered carefully. We have to notice that the connections to the vehicle's ground have been done with a certain length of metal wire which is able to deteriorate efficiency of the shielding. At last, even if these results announce a low induced current value, they necessitate further investigations to precise the real effectiveness of the cables.

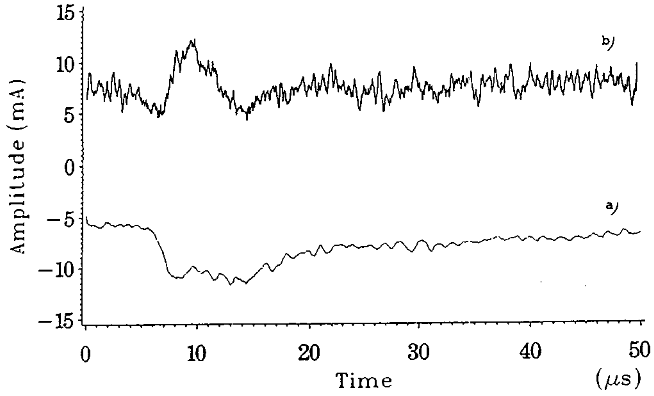


Figure 4. Induced Current in the Twisted and Shielded Bifilar Cable Situated in: a) the Passenger Car and b) the Truck

Simple short circuited wire

This cable was laid under the passenger car's floor and short circuited at both ends. Figure 5 gives the evolution versus time of the induced current measured in the car's boot near short circuited termination.

An important peak current value of 2 A has been measured. The wiring implementation and termination conditions create a favourable coupling with the magnetic fields.

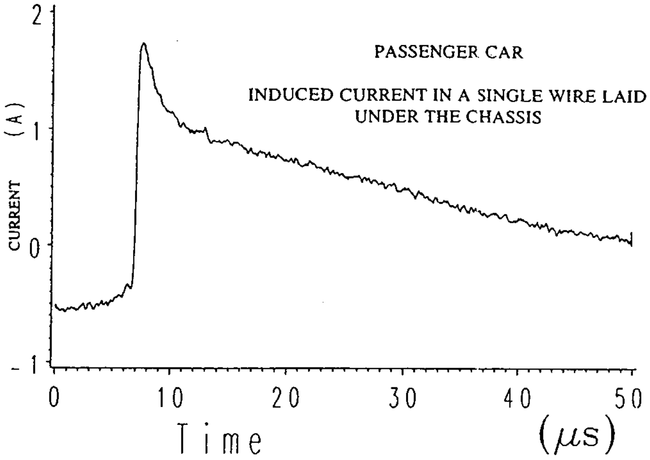


Figure 5. Induced Current in a Single Wire Short Circuited at Both Ends Situated Under Passenger Car's Chassis

Supply cable

A similar investigation was achieved for a 12 V supply cable on the truck. Figure 6 shows that a 16 A peak to peak amplitude is obtained.

Supply cables are often the most sensitive cable to which electromagnetic perturbations can be coupled to. In fact, they are present everywhere in a vehicle and generally have low impedance terminations in the frequency range covered by the lightning spectrum. This situation can explain this result.

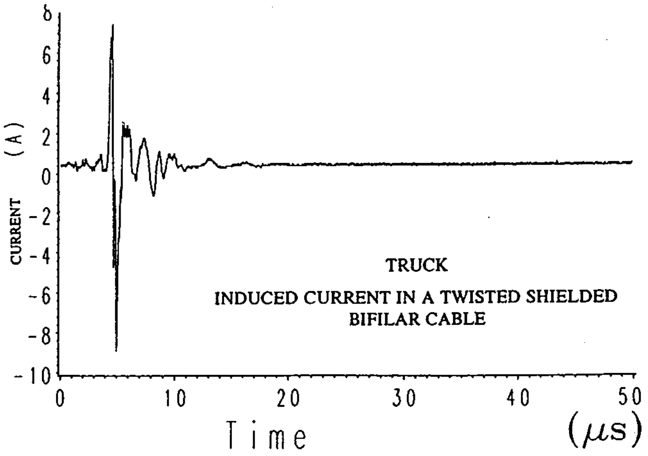


Figure 6. Induced Current in Supply Cable in the Truck

Conclusion

Lightning phenomenon can produce intense electromagnetic fields that are able to induce high current amplitudes in automotive wiring harnesses, and alter functioning of electronic equipments. Coupling results show that for some particular wiring harnesses, high induced current amplitude can be expected. We have to notice that maximum lightning current amplitude obtained during this campaign was 19 kA. This is a quite low level comparing to those that can produce natural lightning discharges (100 kA).

Dysfunctioning observed on the prototype multiplexed system has been correllated in laboratory with TEM cell tests with low pulsed levels comparing to those radiated by lightning discharges. Nevertheless, permanent malfunctions have been registrated for continuous wave signals. We need to precise their real action. Is it a direct coupling influence on electronic modules or does it act in using the wiring harness as a vector?

Extremely high induced current was also been found in simple wires and supply cables.

Results obtained by French automobile group during this campaign, are continuing to be studied, and we are looking forward to an other measuring campaign in some cars.

Simulations have been computed to predict current evolution in wiring, from lightning current discharges. First numerical results seems to be in accordance with experiments.

References

1. Zeddam, A., 1989, "Couplage d'une onde électromagnétique rayonnée par une décharge orageuse à un câble de télécommunication," *Thèse d'état, 768,* Université de Lille, France.
2. Leteinturier, Ch., *1990 Revue Phys., 25* 139-146.
3. Klinger, M., Szelag, M., "Effet d'une décharge orageuse sur les systèmes électroniques embarqués bord de véhicules routiers," *Inrets report*-NOV. 1990, 136.
4. Draft standard VAN R13-708, ISO/TC22/SC3/WG1 Nov. 1989.
5. Wheat G.C. and Evans N.J. "Vehicle Multiplex Wiring—An Implementation."
6. Fieheux, S., 1990, "Susceptibilité électromagnétique des véhicules et comportement des dispositifs électroniques soumis à une onde de foudre"—Phase 1 et 2. DA 890050—UTAC Report.
7. Klinger, M. and AL, 198 1, "Influence of Electromagnetic Fields radiated by lightning discharges on a vehicle multiplex wiring system," ISATA.
8. Mareehal, C., 1991, "Les effets d'une décharge orageuse sur un faiseeau de câbles intra-véhicule," *DEA*, UTSTL Flandres—Artois.

S2-O-08

Improving Vehicle Safety Under Bad Weather

Joop P. Pauwelussen
TNO Road-Vehicles Research Institute

Abstract

As one of the projects within the European Programme DRIVE, CROW (acronym for Conditions of Road and Weather) deals with the development of a system architecture and improved data acquisition techniques for an integrated road and weather monitoring system. The objectives include the collection of reliable data about present and future road and weather conditions, with distinction between low-friction (icy, aquaplaning), poor visibility (fog), lateral disturbances (cross-wind) and combinations (such as stormy weather). The CROW approach consists of specification of safe driving limits and the prediction of traffic risk level, where weather, traffic characteristics and the road-configuration are taken into account.

This requires new sensor concepts, algorithms for risk assessment (the CROW algorithm), traffic- and road databases and a system architecture (special purpose road processor) for combination of all of these aspects. The results, reliable information and risk assessment under bad weather, can be used to select appropriate actions yielding a higher level of safety and road transport efficiency.

Introduction

Bad weather is one of the main causes for interurban accidents. Drivers are not capable to estimate the effect of bad weather on driving performance. Moreover, some dangerous weather conditions are difficult to predict with sufficient reliability, such as fog.

The CROW project (Conditions of Road and Weather monitoring) deals with these subjects and tries to find means to enhance traffic safety under bad weather. It is part of the EC programme DRIVE I, carried out in the period from 1989 to 1991.

Within CROW, reliable sensors and forecasting systems have been developed, together with and linked to a prototype road station offering the road manager information about present and future road condition, and the safe driving speed.

The consortium consists of the following partners:

TNO Road-Vehicles Research Institute (coordinator)
TNO Physics and Electronics Laboratory
KNMI Royal Netherlands Meteorological Institute
CETE de l'Est
TZN Forschungs- und Entwicklungszentrum Unterlues GmbH
SIAP SPA
FISBAT - C.N.R.
INRETS.

Why CROW?

There is a safety problem in Europe: $1.7x10^6$ people are injured and $5.5x10^4$ people are killed yearly in the European Community. The annual costs for traffic unsafety for the whole EC are estimated at more than 3 Billion ECUs.

A large amount of the traffic accidents are related to bad weather. Accident statistics indicate that between 25 and 35% of all interurban accidents occur during adverse weather conditions. The risk of having accidents increases under bad weather with a factor between 2 and 5. Eliminating this risk increase would prevent between 12 to 24% of all accidents. For Canada some results are shown in fig. 1. Similar results are obtained for other countries.

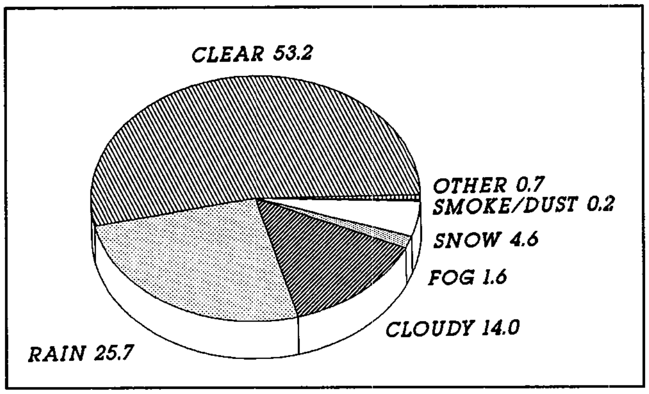


Figure 1. Accident Conditions

Most of these accidents occur for a wet road. Other dangerous weather types are fog or cross-wind. They can lead to severe consequences and respectively involve usually several cars in one accident, and lead to strong lateral deviations or even roll-over for high-sided vehicles.

Bad weather is experienced by the driver through a reduced friction on the road, poor visibility or a sudden unexpected lateral disturbance. Hence, there is a need for measures to prevent such accidents. However it turns out that the credibility of existing road signs is rather low, having only a minor effect on traffic and individual vehicle behaviour. Winter maintenance activities are a good alternative but are expensive, contribute to environmental damage, and are still more based on human experience than available meteo data. No objections against that, but it demonstrates the lack of credibility of these systems.

In order to cut down the total number of accidents significantly, one has to present information to the driver about forthcoming bad weather induced unsafe conditions which is reliable, accurate, easy to understand, and the driver must be aware of these properties and, more important, be able to understand the safety consequences. This last point requires that the presented information or recommendations should correlate with his or her own insufficient subjective assessment of safety margin. This requires that, in order to modify driver's behaviour under bad weather and with that to enhance traffic safety, one needs to understand driver's perception on bad weather conditions and on selected warning strategies.

Furthermore, not only weather or road conditions are considered but traffic behaviour and specific road configurational data have to be taken into account.

Summarizing, successful safety enhancement under bad weather requires reliable data acquisition, integration between weather-, road condition- and traffic information, understanding of driver behaviour and safety margin assessment.

This paper lists the results of CROW over the last three years. More detailed information can be found in the different reports, derived within this period, and more specific in the Executive Summary [7].

Outline of the Project

The intention of the DRIVE project CROW is to develop a system architecture and to improve data acquisition techniques, for an integrated road and weather monitoring system, and to demonstrate its benefits for traffic control and management.

The main elements of CROW are:

- A technique to predict the onset of aquaplaning based on extrapolation of radar imagery.
- A knowledge based system to provide fog warnings.
- Prototype microwave, infrared and laser based sensing systems for monitoring the conditions of road surfaces.
- An improved integrating nephelometer to assess road visibility.

- CROW road/weather Control Centre, denoted as the CCC.
- An algorithm to define safe traffic levels in bad weather conditions, based on road, weather and traffic data.

They are schematically shown in fig. 2.

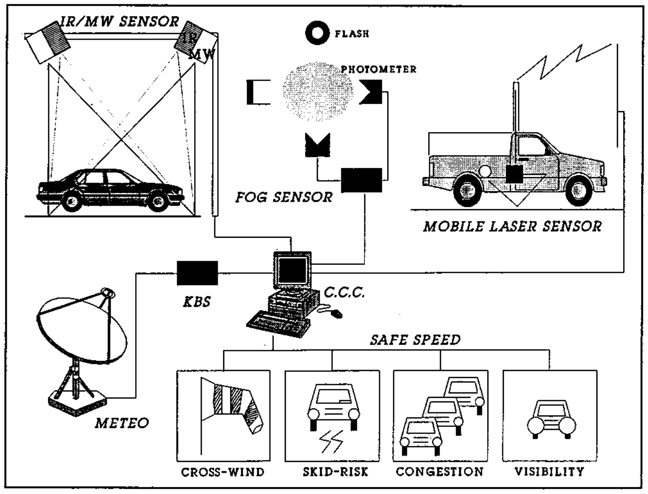


Figure 2. The CROW System

The CCC consists of a processing unit, a sensor/system interface, a simulator to bypass the sensors/systems with realistic scenario's, and user interfaces.

Road-side installed monitoring tools such as the sensors and systems developed within CROW can be interfaced with the CCC. Results are presented through different screens, from warning message display up to sensor data versus time.

In the future, the CROW system, including CCC and sensors, will be implemented along the road, to study its feasibility in a pilot project. Until that time, the CROW achievements are demonstrated within the framework of an artificial CROW miniworld. This miniworld simulates a road containing locations which might be critical with respect to bad weather conditions, such as black ice on a bridge, aquaplaning on a highway, cross-wind due to sharp transitions in the motorway-sheltering (near a bridge, forest), local fog stimulated by the presence of a nearby industrial area, towns, etc. The layout of the CROW Miniworld is schematically shown in fig. 3. The variation of weather parameters and traffic in the miniworld is extracted from real measurements, carried out in France.

As indicated earlier, one of the intentions of CROW is to specify and predict traffic risk levels, as a function of weather, road-condition and traffic parameters. This information is necessary for local processing, to inform the road-users, to inform the road authorities, and for feed-back to regional meteo stations.

These risk levels refer to a general situation of combined bad weather hazards, i.e. the CROW approach consists of taking into account bad weather conditions in an integrated manner.

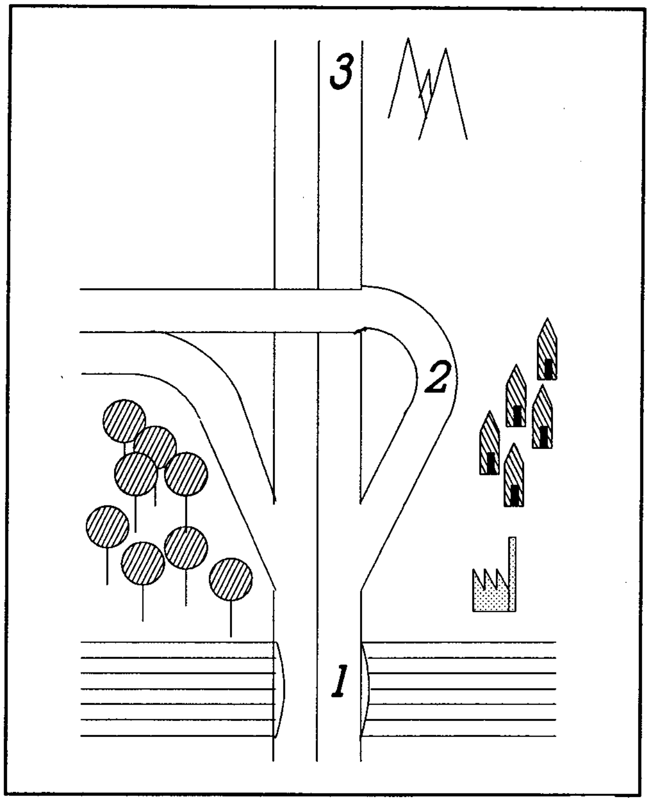


Figure 3. The CROW Miniworld

This last point may require some explanation. Assume as an example the situation of severe thunderstorms. In that case, there is a risk of aquaplaning, strong cross-winds and on top of that poor visibility, see fig. 4.

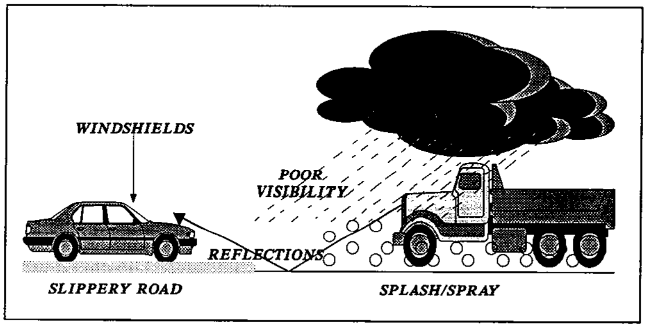


Figure 4. Rain, Cause for Accidents

Usually, the situation is not stationary but varies in time. Traffic parameters as flow and speed will respond to these variations, in addition to the dependence on rush hours. Consequently, traffic safety is a result of a complex of inputs, all occurring at the same time.

These should all be taken into account simultaneously (the CROW approach), which differs from existing approaches.

The Results of CROW

CROW has dealt with sensor development, meteorological aspects and forecast methods, traffic engineering requirements and recommendations, and a pilot demo to demonstrate the feasibility of the overall CROW system concept and sensors. These four parts are referred to as CROW SENSOR, CROW METEO, CROW TRAFFIC, and CROW DEMO, respectively. They are treated separately in this paper.

CROW sensor

Surveys have been carried out for cross-wind sensors, visibility sensors and road condition sensors, yielding three different sensor prototypes.

For road condition warning systems, distinction is in general made between three different kinds of systems:

1. Black ice detectors, "reading" the road.
2. Warning systems, using indirect information such as humidity, wind, etc. Usually mainly based on local data.
3. Predictive, using meteorological information over a large area and of a more general nature.

The appropriate CROW sensor systems are of type 1. CROW has focused on non-contact sensors, which have the advantages above other types of low installation costs, location flexibility and higher reliability.

These sensors are:

(a) An IR/MW sensor

Preliminary investigations have shown that:

- Microwave (MW) reflections enable the distinction of water levels up to 10 mm, with reducing accuracy for lower frequency.
- Microwave reflection is not suitable for identification of icy road conditions.
- The three road surface conditions dry, wet and icy can be clearly distinguished, from the infrared (IR) reflection characteristics.
- Both waterlevels (tested up to 2 mm) and ice thicknesses can be clearly distinguished from infrared reflection characteristics.

Both concepts, IR and MW are used simultaneously in one sensor for road condition, to be installed at a gantry above the motorway (see also fig. 2). A working prototype is available, tested in- and outdoors.

(b) A laser based sensor

A laser based road condition sensor has been developed, where image identification techniques are used to distinct between different road conditions. The laser reflection approach only scans the road surface and is therefore not suitable to determine water heights. On the other hand a large number of different surface conditions might be distinguished such as starting rain (viscous aquaplaning), different types of snow, etc.

The sensor has been installed in a service vehicle of a French road authority, and tested up to a speed of 80 km/hr to distinguish between wet, dry and icy.

A third sensor has been developed for visibility monitoring.

A review of available visibility monitoring instruments led to the conclusion that a relatively compact, low-cost instrument, being free of specialized maintenance and where measurement readings are only slightly effected by set-point loss, does not exist. Main problems are the setting of the instrument in continuous use, and the effect of droplet size.

Promising concepts are (1) a transmissometer (based on attenuation of a light beam), for small path and in combination with laser as a light source, and (2) the integrating nephelometer (3D scattering), improved to reduce the offset. With respect to the last, a further investigation has shown that correcting the integrating nephelometer's governing equation to account for these real features of the source yields that for fog droplets the output of the instrument underestimates the expected value of the nephelometer scattering coefficient. This can be corrected by tilting of the lamp towards the photometer.

Prototypes have been built, consisting of four main components, (photometers, light source and light trap), see also fig. 2. Field tests have been carried out.

CROW meteo

Two forecasting systems have been developed, one for fog prediction and the other to forecast aquaplaning.

A description has been given of a new FOg FOrecasting System (FOFOS) for road sites. For the development of this system a knowledge based system (KBS) approach has been chosen. The resulting system offers a large variety of data and knowledge from which the system itself draws conclusions about the evolution of visibility on road sites during fog conditions.

The output of the system to the road user or road authority consists of probability values to expect fog (for planning purposes) and expected visibility values on a short time range for specific spots along the road.

Algorithms of extrapolation of weatherdata and the risk of aquaplaning have been developed. The output of the system consists of measured and forecasted rain areas for planning purposes and expected risk of aquaplaning values of specific spots along the road.

Both systems have been tested extensively. Some results are shown in fig. 5 (from [10]) where point forecasts (two hours ahead) of rainintensities are compared with observed values for 27 June 1991, near the town Eindhoven (The Netherlands).

CROW traffic

The work included the following special studies:

- Study on relationship cross-wind and traffic safety.
- Statistical studies of accidents during bad weather conditions, in order to detect parameters influencing occurrence and seriousness.
- Study of motorway specific situations during bad weather conditions.

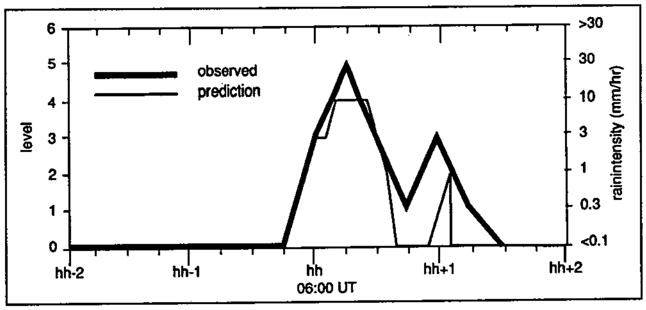


Figure 5. Rain Intensity Forecast Versus Observation

The study on the relationship crosswind-safety revealed that cross-wind is usually seriously underestimated. The reason for this is that cross-wind is not only a hazard on its own but it effects the vehicle-road contact reducing the total feasible lateral force during cornering. This means that for increasing crosswind the safe driving speed for cornering is reduced. Especially in combination with bad weather conditions in winter (snow, ice) when also the highest wind velocities occur, this may result in a considerable loss of traffic safety.

Furthermore, cross-wind sensitivity of cars is more than proportionally increased with vehicle velocity. It is reported that a large majority of all loss of control accidents occur for wind conditions being worse than average, with a relatively high accident rate for road section with exceptionally bad wind conditions.

Simulations were carried out for representative vehicles under cross-wind loading, in combination with wet road conditions. The results were used to derive critical driving speeds.

In the further study of safe driving limits, a detailed list has been given of all parameters and variables which must be considered in order to evaluate the safe driving limits according to road, weather and driving condition.

It is pointed out that the determination of safe driving limits is complicated by the fact that the driver is not able to evaluate correctly any modifications of road and driving conditions. This is illustrated in fig. 6 showing traffic speed versus distance during the day. The grey curve shows the speed of the vehicles on a motorway as function of visibility distance. The solid curve refers to the relation (on a dry road) between speed and emergency braking distance. It is shown that for visibility distance less than 120 meters, the driver is not able to come to a complete stand-still within its visibility range.

Important in the assessment of safe driving conditions are:

- traffic characteristics
- road surface status
- wind and visibility conditions

A general description of a meteo and road-condition monitoring unit has been given where the essential components such as sensors, algorithms, road and traffic databases and the general system architecture have been discussed. This description forms the basis for the CCC (CROW Control Centre).

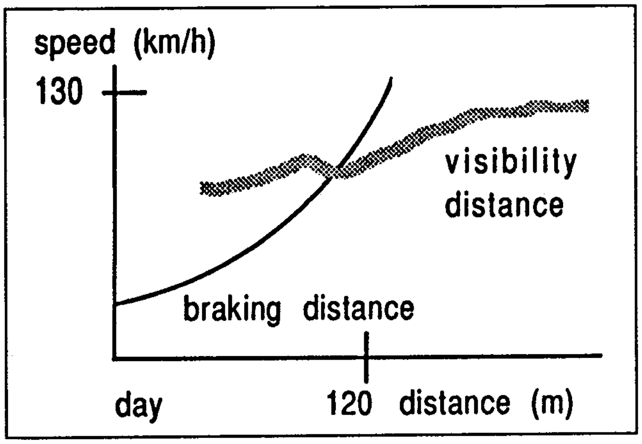


Figure 6. Visibility Distance Versus Vehicle Speed

Technical requirements are listed, with definition of desired resolution, update rate, accuracy, range, etc. Economical specifications were given as well, such as reliability, cost, size, etc.

An algorithm has been written, the Traffic Risk Algorithm for CROW Evaluation "TRACE", distinguishing between four different kinds of risk:

- cornering under low friction and/or cross-wind
- lateral deviation due to cross-wind and/or low friction
- poor visibility and/or low friction
- low friction for high traffic density

The algorithm calculates a safe traffic speed under various weather-, road- and traffic conditions, for different road configuration parameters.

In addition, an in-depth study has been started on driver-vehicle behaviour in car-following under bad weather. It includes the driver as human controller, and describes different car-following models.

CROW demo

This part of CROW played a crucial part in the last year of the project. Goal of a CROW Pilot Demo was to present the development results of CROW. This includes the Crow Control Centre (CCC) has been established, consisting of three parts:

- A processing unit, dealing with the TRACE algorithm, and the meteo algorithms. It also contains the (road-, and traffic) databases.
- An interface to the sensors (road condition-, meteo-, and traffic sensor)
- A simulator unit, to by-pass arbitrarily some of the sensors with a prescribed time history of "sensor" data (to enable scenarios).

The use of dedicated single-chip microprocessors in each input channel increases the flexibility of the interfacing between the sensor manufacturer and the roadside processor manufacturer. A simple but effective protocol has been proposed, to be used in the communication between the sensor and the road-side processor.

The input channels of the CCC must handle a large variety of input streams. This problem is solved by a pre-processor, dedicated to the specific sensor or sensorsystem. Each sensor can then have its own input channel. This preprocessor will sort and reduce the incoming data without losing vital information, and store the sensor data in a local database. The content of these databases will then be sent to the roadside processor (to calculate risk, etc.) under control of this processor. A design for this preprocessor has been established. Hardware (interface, simulator for the CROW Control Centre) has been built and tested.

The demo has been carried out in different ways. The sensors have been tested using weather- and road surface conditioners, and using data files from previous tests. On the other hand, a number of different scenario's have been run, within the CROW Miniworld as described earlier. The case of short-time predictions (15 minutes ahead) of dangerous circumstances have been addressed as well, to allow the road authority to foresee forthcoming dangerous traffic conditions.

Different display screens were designed, where distinction has been made between:

Warning Message Display
Indication of hazard (with symbols, see fig. 2), actual average speed and safe driving speed.

Present Hazard Display
Indication of local weather and road conditions such as cross-wind (speed, angle), visibility distance, friction level (100 % means dry), speed distribution and distance between vehicles. These values are input for the safety margin assessment processor.

Time History Display
Time histories of road condition and traffic data. It covers the period from 6 hours in the past up to a prediction of two hours ahead.

Conclusions and Follow-up Activities

CROW contributes especially to the traffic safety and mobility, with consequences to environmental improvements.

Better data acquisition on weather and road condition means that no time is wasted in taking necessary actions to avoid accidents or to reduce the consequences of that. CROW will yield a risk assessment under bad weather conditions, and this tool can be used to select appropriate actions, i.e. with a highest level of traffic safety. This will contribute to less injuries or people killed.

In the same time, traffic will not be disturbed unnecessary, leading to improved efficiency. Reliable information in advance about expected dangerous road conditions makes it possible to avoid them or direct the traffic along other routes, with the consequence of reduced resulting congestion.

Finally, more reliable information about expected weather conditions will lead to a more efficient salt spraying scheme, which is less damaging for the environment.

So far, the DRIVE project CROW, dealing with monitoring of road condition and weather, has yielded the following results:

CCC: Concept local road and weather station
Sensors: Ice, fog, aquaplaning, cross-wind
TRACE: Traffic safety algorithm
Forecasting: Road condition prediction (fog, aquaplaning).
Simulator: CROW demonstrator based on CCC.

It has been focused on road-side systems, and implementation within a road-side data network. These results will be marketed further individually by the partners. It is intended to extend and implement these results with a new consortium within DRIVE II. In fact, a proposal has been submitted. Some of the individual activities are listed below.

- The IR/MW sensors are further commercialised and modified for a more extended use. This means reduction in size and application for traffic monitoring.
- It is intended that the laser sensor is miniaturized further to make it suitable for in-vehicle use.
- The visibility sensor is in the status of an industrial prototype.
- The traffic safety algorithm will be further improved by taking into account the driver response to bad weather and information strategies.
- This will lead to driver control models within commercial software tools for closed loop vehicle dynamics simulation.
- Meteo systems are made available to meteorologists within national meteorological organisations.

The CROW results were achieved, based on the expertise within the consortium. Follow-up activities should benefit from developments within other DRIVE projects and other initiatives such as PROMETHEUS as well.

The next obvious step is the **implementation** of the CROW concept in a real environment, and to examine the practical value of CROW with respect to safety and efficiency, within a larger scope than in DRIVE I.

This concept of CROW is to combine data on present and forecasted road-condition, road configuration (road database) and traffic (traffic database) to a risk assessment at present and in the near future, which will enable a higher level of safety under bad weather conditions. The same information can be used to improve long-term predictions of icy conditions, thus enabling a higher level confidence in maintenance organisation. Furthermore, this concept may be used in a more general sense, not restricted to bad weather alone. Implementation involves four steps.

1. **Data acquisition.** Monitoring and prediction of present and future traffic, road-condition and local weather conditions. This can be done using road-side sensors or vehicle based sensors. The information may be derived from local and/or global weather data. The time-scale for predictions may be minutes (forthcoming risk) or hours (maintenance activities, rerouting). The information must be reliable and verifiable, which requires high demands with respect to failure. Available sensors should be used efficiently, i.e. integrated in one data-network. The assessment of road-condition usually requires information on traffic behaviour (occupancy, speed) and local road-configuration and texture (forecasts).
2. **Safety margin assessment/maintenance assessment.** As mentioned above, data of road-condition, traffic or vehicle behaviour, etc. is used to derive the relevant level of accident risk. In case of only road-side systems, this will be based on average or individual vehicle behaviour (for coarse or dense traffic monitoring network, respectively), average driver and vehicle performance, and fixed road locations (possibly generalized through "network risk maps").

   In case of autonomous in-vehicle systems, the safety margin is derived from the individual driver and vehicle capabilities and behaviour, vehicle dynamic behaviour, local atmospheric conditions, and tyre-road interface conditions. In addition, relative location with respect to other vehicles (Collision Avoidance System) or lane (lane keeping) may be taken into account. It is worthwhile to consider mixed situations as well, where in-vehicle systems use warnings of forthcoming weather hazards, road-side systems benefit from individual vehicle monitoring of road friction, etc. This requires some kind of communication between road-side and vehicle in two ways. Different concepts have been in progress in various DRIVE projects.

   Another point of concern is to decide whether forecasted bad road and weather conditions should be followed by maintenance activities. Winter maintenance is expensive. Costs refer to staff, materials, equipment and waiting time (stand-by staff). The CROW concept will be extended to an expert system to support these decisions, relying on human experience, questionnaires, correlation research, tests, etc. This will require an extended road database, taking into account time (of day, year,..), special critical points (ramps, intersections), road toplayer conditions, salt versus time, etc.
3. **Informing driver and road authorities.** Once a spot with high accident risk has been identified, this information has to be transferred to driver and road authorities to enable activities for risk reduction, such as speed reduction, trip replanning, hazard warning, control activities, maintenance activities, etc.

   This last item, maintenance, requires reliable information, and a sound judgement, based on experience. The assessment of critical spots relies on the road data base, introduced in CROW, which may need improvement.

   If data is acquired at the vehicle, this may require vehicle-beacon communication, vehicle-vehicle communication (cooperative driving), in-vehicle driver information, and semi-active or active intervention in vehicle behaviour (in emergency situations).

   On the other hand, if data is acquired at the road-side, this may require beacon to vehicle communication, application of variable message signs, a data link to winter maintenance stations and to traffic control centres.
4. **Intervention in vehicle and traffic behaviour.** In extreme traffic situations, requiring an immediate reaction by the driver and/or unusual manoeuvring or braking, accidents may be avoided by active intervention in vehicle behaviour. This may be done through lateral control (active rear wheel steering) or longitudinal control (Active Cruise Control). Concepts are under development within Prometheus. It requires individual safety margin assessment.

   Hazard warnings are intended to yield adapted traffic circumstances, leading to higher safety and reduced congestion. This might also, or in addition, be achieved by route guidance, flow modification (at ramps), or even closing part of the network temporarily. This requires an assessment of global (macro-) traffic behaviour, as a result of the micro-level modification of individual vehicle behaviour due to bad weather, and the selected warning/control strategy.

All of these steps are included in the follow-up project for CROW. National road authorities, meteorologists, human factor specialists, vehicle manufacturers and road furniture suppliers will work together to demonstrate the CROW concept in a real world, and to extend it further to yield a reduction of the number of traffic accidents, with special emphasis on those due to bad weather.

References

1. Blaauboer, D., Ellenberg, M., Pauwelussen, J.P., Terpstra, J.M.: New concepts in road and weather monitoring. DRIVE Conference, Brussels (1991).
2. Chen, Y.: Analyse d'images pour la detection du verglas. These Universite de Paris-Sud, Centre d'Orsay (1991)
3. Ellenberg, M., Seris, M.: CCC Algorithms. Report CETE de l'Est (1991).
4. Ellenberg, M., Seris, M.: Road database. Report CETE de l'Est (1991).
5. Gazzi, M. U., Georgiadis, T., Vicentini, V.: Prototype of road visibility meter. Part I: Operating principle. Report CNR (1991).

6. Gazzi, M., Bonafe, U., Georgiadis, T., Vicentini, V.: Prototype of road visibility meter. Part II: Laboratory experiment. Report CNR (1991).
7. Pauwelussen, J.P.: CROW, Executive Summary. (1991).
8. Pauwelussen, J.P., de Vos, A.P.: Traffic safety under bad weather. ISATA Conference, Firenze (1991).
9. Pauwelussen, J.P.(ed.): The effect of weather and road conditions on traffic safety. Workshop 14th DRIVE Concertation Meeting, Brussels (1991).
10. Terpstra, J.M.: Aquaplaning forecasting and weather-radar. Report KNMI (1991).
11. de Vos, A.P.: Driver behaviour and bad weather. TNO Report, in press (1991).

S2-O-09

Interactive Road Signalling—ISIS

L. De Vaulx
PSA Peugeot - Citroen

Introduction

Many accidents are caused by poor driver reaction confronted with an unforeseen situation or one of which account is taken too late.

This is one of the conclusions of the accidentology study carried out jointly by INRETS and PSA and which related to 30,000 accidents occurring in 1988 (outside built-up areas). Please refer to the paper "From accidentology analysis to the intelligent vehicle" (ref. 1).

From this study, an important factor that emerges is that 28% of serious accidents occur in bends and nearly 17% occur at junctions.

ISIS (Interactive Road Signalling), developed by PSA, is a simple information transmission system between the infrastructure and vehicles, the aim of which is to enhance the information passed to the driver before a difficult situation so that he has time to react correctly and decelerate sufficiently to avoid an accident.

Principle

As mentioned above, the aim is to enhance the information passed to the driver, both in terms of quality and quantity, so that his reaction is correctly adapted in time and in movement to the difficulty. If this does not happen, an automatic system can take over in the event of driver error.

By quality, we mean that the signal is repeated inside the vehicle, in case the driver has not seen it, to ensure that it is assimilated, and that the information is provided in an attractive form to avoid any additional fatigue.

By quantity, we mean that more detailed, precise information is given than in traditional signalling, for example on the topography of the hazard or on the environment.

For the following reasons, infra-red rays have been selected as the means of transmission:

- Well-developed and reliable technology, capable of being quickly manufactured.
- Technology enabling very localised transmission (no risk of receiving wrong or untimely information).
- Non-polluting technology in terms of radio frequency.

The implementation of this transmission system has been studied for the three situations which cover 45% of serious accidents:

- bend
- intersection with stop sign—blind intersection in urban area.

In the first two configurations, infrastructure/vehicle transmission has been used, and in the last configuration a vehicle/infrastructure link has been selected as simpler implementation which could be of interest for applications requiring reduced infrastructure.

Bend and Intersection with Stop Sign

For this configuration, a transmitting beacon set up on roadside continuously transmits.

A receiver on the vehicle transfers informations to an on-board calculator. The latter processes the datas and informs the driver of the type and seriousness of the difficulty. If the situation requires it, the vehicle brakes automatically.

Blind Intersection

For this second configuration, a "beacon" is placed in the centre of a four-way crossroad. This beacon is fitted with 4 receivers covering each one of the roads and a calculator which analyses the signals coming from them.

The signals received by the receivers come from transmitters mounted on the front of the vehicles which continuously emit informations relating to the vehicle~s chosen direction.

Depending on whether or not the presence of one or more vehicles is detected, and their announced trajectory, the calculator warns the drivers of a potential hazard by controlling an orange flashing light on the beacon.

Detailed Operation

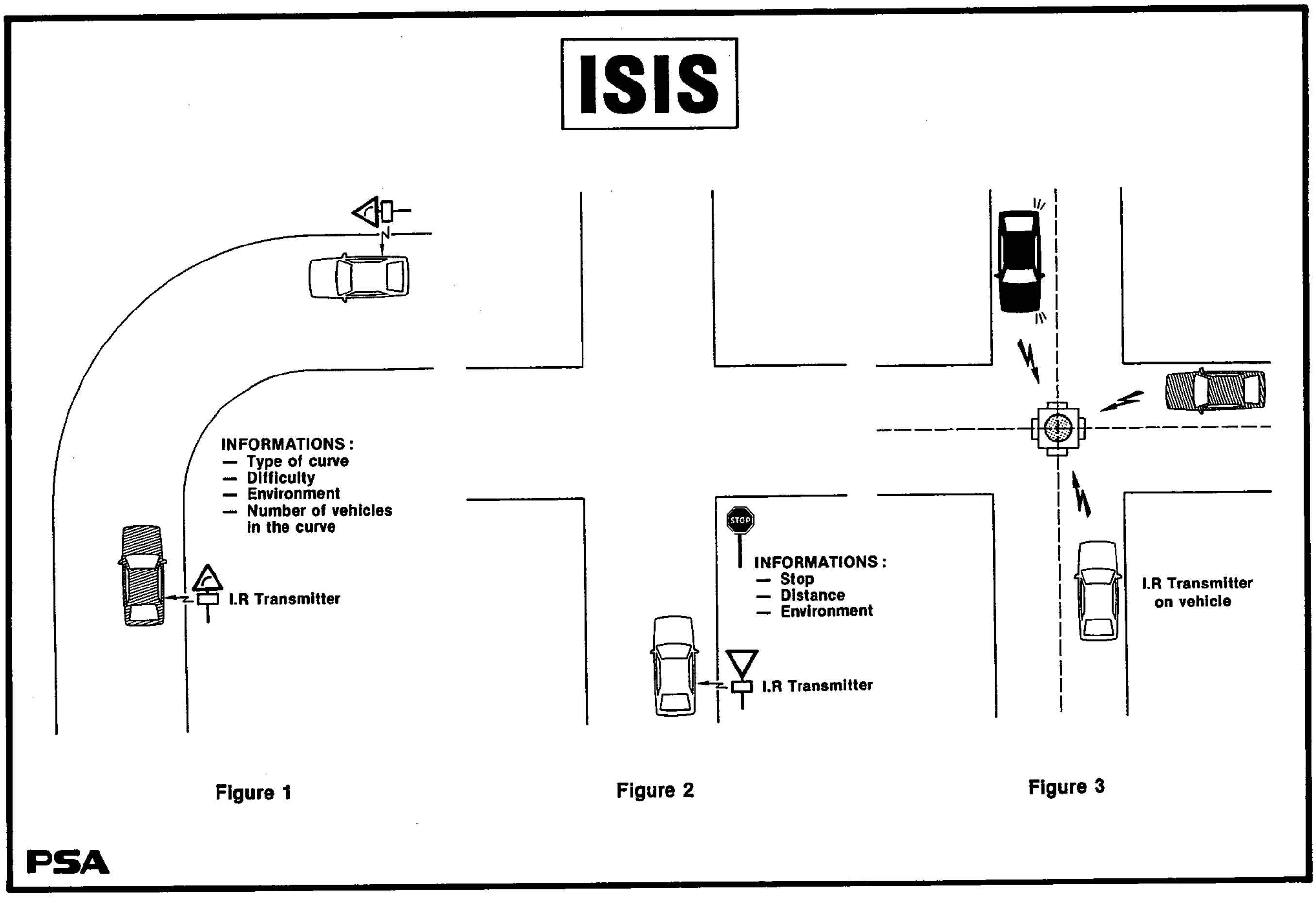
Bend (fig. 1) and Intersection with Stop Sign (Intelligent Stop Sign) (fig. 2)

- The infrastructure beacon is placed on the road sign and emits an infra-red beam directed perpendicularly to the road.

- The vehicle is fitted with an infra-red receiver mounted, for example, in the rear quarter-light, in such a way as to aim at the side of the road.
- The vehicle crosses the infra-red beam. It collects the data transmitted from the infrastructure and, depending on the direction of the beam, acquires a reference for the distance from the bend or from the stop sign. At the present time the data are transmitted on one byte, which enables the followinq factors to be defined:
  - 4 types of sign (bend, stop, etc.)
  - 16 degrees of difficulty for bends (4 amplitudes, 4 descriptions) or 16 stopping distances for the stop sign.
  - 4 types of adhesion, depending both on the road coating and climatic conditions.
- The data received are decoded and processed by the vehicle's on-board computer which reacts in two ways:
  - In the case of a bend, it computes a recommended speed depending on adhesion conditions and displays it on a screen in the dashboard, together with a reminder of the sign. In the case of a stop sign, it computes a deceleration law depending on the vehicle's present speed and on the stopping distance, and displays the sign on the screen. The information can be further reinforced by controlling a voice synthesiser.
  - It triggers emergency braking if, in the bend, the vehicle's measured speed is above the recommended speed, or, for the stop sign, if the vehicle's deceleration law is too low, i.e. if the measured speed is too high in relation to the distance to be covered. This assumes that the vehicle has an automatic gearbox and an anti-brake-lock system.

Blind Intersection (Intelligent Intersection Control) (fig. 3)

- Each transmitter mounted on the front of the vehicles transmits on one byte, the vehicle identification and two bits of information confirming whether the lett or right tum indicator is operating. The identification data are intended to warn against bounce-back interference which could lead to multiple signal reception.
- Each of the 4 receivers on the infrastructure beacon installed at the centre of the intersection transmits the received signals of vehicle identification and turn indicator operation to the calculator. When one direction receives a validated message, this engages the system for this direction operating a luminous



Figures 1-3. (1) Road Curve Management. (2) Crossing with a Stop, Intelligent Stop Sign. (3) Blind Crossing, Intelligent Intersection Control.

warning light (green in the present case) indicating that the transmitting-receiving equipment is operational.

If the calculator only receives a single signal, nothing happens (apart from the green warning light). If it receives two signals with different identification characteristics, nothing happens if the signals come from opposite directions and if the left-hand turn indicator signal is not present.

However, if two signals are detected from intersecting directions or from opposite directions, but with the left-hand turn indicator signal on one of the two signals, then the calculator activates the flashing orange light on the beacon to warn of potential danger.

Equipment Description (Figure 4)

Transmitter

The transmitter element comprises 16 diodes transmitting impulses at 930 nanometres.

Receiver

The receiver element comprises 3 diodes with a wide band, high gain amplifier.

Message

Comprising 2 bytes. This is being developed and will be increased to 8 bytes.

Transmission

Transmission is monitored and controlled by the VAN (Vehicle Area Network) protocol developed by PSA and Renault for vehicle multiplexing. It uses a Manchester code and a system for checking data transmitted (CRC). Transmission speed is 8 Kbits/sec, to be increased to 80 Kbits/sec.

Range

- Between 1 and 10 m without a lens.
- Over 50 m with a lens on the receiver (blind crossroads).

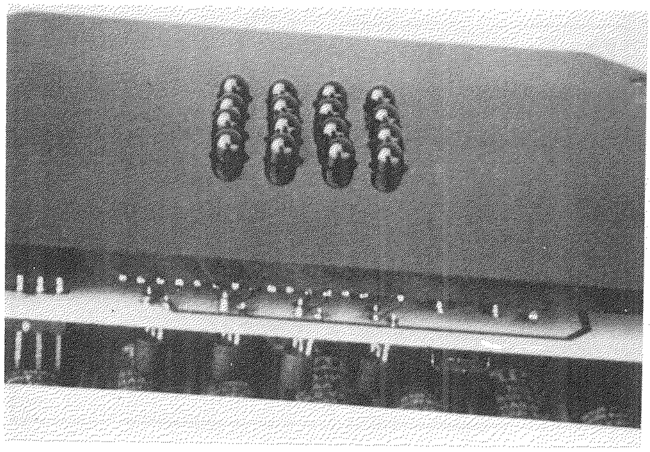


Figure 4. Upper Side of an Infra-Red Transmitter

Implementation (Figure 5)

This system is the fruit of the research and development being undertaken by PSA's Research and Scientific Affairs Direction and the Technical Direction for safety improvement as well as infra-red telecommunications within the framework of the European Prometheus programme.

Two CITROEN XM vehicles are fitted with the system to validate the ISIS concept applied in a bend and at an intersection with a stop sign.

Furthemmore, two PEUGEOT 605 vehicles are fitted with the system to validate the same concept applied at a blind crossroads.

The experiment has shown the advantages of the system:

- from the aspect of user benefits.
- from the aspect of confirming the conclusions of the paper "From accidentology analysis to the intelligent vehicle."
- from the aspect of the feasibility of widespread implementation.

On this last point, the fact that the well-known, reliable and inexpensive infra-red transmission technique is used means rapid implementation can be envisaged if necessary. However, this can only happen with the cooperation of the relevant authorities.

Naturally, not all problems have been resolved, in particular that of operating safety and maintenance, and multiple lane traffic operation. However, the field is sufficiently attractive for PSA to develop the system in three ways:

- increased transmission capacity to obtain multi-use beacons.
- data and information transmission between several beacons to form a network either by high frequency transmission or by cable.
- beacons which can both transmit and receive.

The aim of these developments, which will shortly be operational, is to increase the number of functions. One

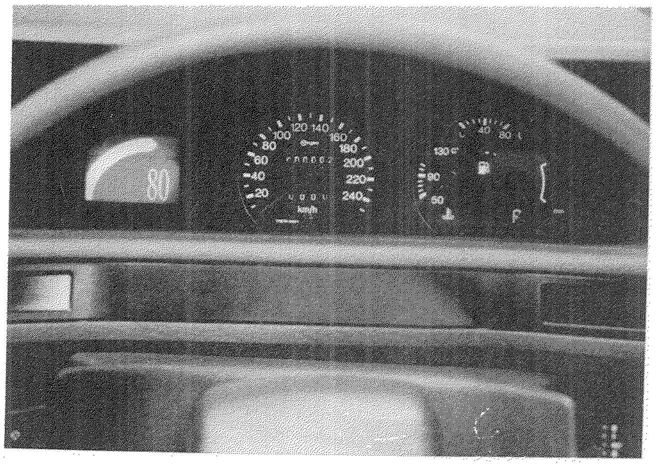


Figure 5. ISIS Indications in a Citroen XM Dashboard: "Curve to Negotiate at a Speed of 80 km/h"

of these is to warn the driver that a vehicle is coming in the other direction or is stationary in the bend, in order to avoid him of being surprised.

Conclusion

- A more detailed and safer knowledge of the environment should result in a large number of accidents being avoided, particularly in bends, junctions with stop signs and intersections.
- Information transmission between the infrastructure and vehicles would, to a great extent, fulfill this requirement.
- With the ISIS system, PSA has designed a simple, economical transmission system, which can be rapidly implemented if necessary, and which has shown the benefits of such transmission. But naturally this system can only be developed with close co-operation between manufacturers and the relevant authorities.

Reference

1. "From accidentology analysis to the intelligent vehicle," by MM. Colinot (PSA) and Lechner (INRETS)-France, document ref. ESV91-S4-W15.

S2-O-10

Detection and Control of the Degree of Vigilance of Drivers

Michel Vallet, Sina Fakhar,
Daniel Olivier, Daniel Baez
Institut National de Recherche
sur les Transports et Leur Sécurité
Laboratoire Energie Nuisances

Abstract

Maintenance of the vigilance of drivers is important for road safety. We consider the means that have been developed for detecting a decrease in this vigilance as well as the two important categories of indicators of the state of the driver:

- the psycho-physiological characteristics of the driver;
- the type of driving determined with reference to the characteristic parameters of the vehicle.

We review the different items of equipment that can be fitted to the drivers or their vehicles and then refer to the results of experimental work on the driver's posture and in particular the position of his head. Finally we refer to the importance of providing an appropriate alarm and the need for psycho-ergonomic work aimed at facilitating the acceptance and use of these driver aids.

Introduction

Maintenance of the vigilance of drivers is important for road safety. The relation between the more or less sustained attention of the drivers and safe driving was determined a long time ago, in particular on studying collision-free accidents. Tarrière (1960) observed that half of the accidents of this type occurred on straight sections of road. The road system has been the subject of a lot of development since this time and accident studies carried out by Lafont (1987) have revealed the effects of drowsiness and fatigue in the case of trips undertaken on the motorways during the period from 1982 to 1986. Thus for a yearly sample of about 300 killed, a loss of vigilance in the operational sense of this term was the prime cause (34%) of fatal accidents compared with (12%) due to burst tyres, (12%) due to a failure to make proper allowance for the weather conditions, (11%) due to a failure to keep a safe distance from the vehicle ahead and (9%) due to a loss of control of the vehicle because of excessive speed, these statistics being based on the assumption that there was a single cause for each of these accidents. It should be noted however that these statistics were derived from police reports of the accidents which were based either on statements made by the drivers or on certain assumptions neither of which can be regarded as completely objective accounts of what really happened.

Current Research

The many investigations of driver vigilance have resulted in a good understanding of this phenomenon and its variations. The neurologist Head (1923) defined vigilance as a "state of high efficiency of the central nervous system" which ensures that there are prompt adaptation responses. Macworth (1957) redefined it as a "state of readiness in detecting and responding to short-lived and randomly occurring changes in the environment." The expression "sustained attention" is more commonly used in current psychology studies (Warm 1984, Parasumaran 1984). Thus a distinction is made between the basal vigilance of the nervous system and an operational vigilance concerned with the behavioural readiness of the subject. In the second case we have the work of Lecret-Grillon (1976 and 1985) on driver fatigue. It appears to this author that the "best approach in dealing with road problems is to consider the vigilance of drivers with respect to the prevention of accidents" which calls for the conduct of research concerned with the use of electro-physiological techniques rather than monotonic performance tasks.

However Mackie (1987) considers that studies of vigilance under actual or simply realistic conditions are not yet sufficiently advanced for us to be able to propose effective means for ensuring the maintenance of driver vigilance.

In this paper we describe the state of research on this subject, outline the principles of operation employed in detecting the vigilance of drivers of motor vehicles and briefly review the questions that arise.

There have of course been attempts to modify the behaviour of drivers, for example on reducing the length of journeys that they undertake. Circadian variations in vigilance have also been taken into account and attention has been drawn to the importance of drivers making suitable arrangements for sleeping before embarking on a long journey.

In addition to this effort aimed at the drivers there have been constant improvements to the way in which we make use of the roads. There has also been some progress with the vehicles themselves. Thus the car has for some years been the subject of development in two respects. First of all there have been attempts to improve the "well-being" of the driver on paying attention to the different physical conditions within the vehicle that could interfere with driving and then there has been considerable interest in introducing electronic systems designed to provide the driver with information or assistance. In the first case ergonomic specialists employed by the vehicle manufacturers have improved the driver's work station, that is the interior of the vehicle, in every respect. Research institutes have also made a contribution concerning the methods that can be employed in investigating the behaviour of drivers (Delhomme and Malaterre 1990), the effects of noise and vibration within the vehicle (Pachiaudi et al 1987, Vallet 1987) and the carbon monoxide levels to which drivers can be exposed (Hickman and Huguers 1978). Sweden appears to be the only country to have introduced regulations concerned with the penetration of exhaust gases into the interior of the vehicle. The effects of ambient temperature have been determined by Wyon et al (1971). However the interior of the vehicle should not be the subject of too much protection (Poulton 1978) and according to Craig (1984) should even give rise to a slight degree of stress.

In the second case the tendency towards the use of on-board electronic systems for the provision of information is likely to become much more pronounced given the technical progress that has so far been made, the importance of the current research programmes and the predictions concerning the intelligent car to be available by 1995. This tendency should lead to changes in the relations between the motorist and the external environment. Some specialists even consider that this will be a matter of a new way of driving where more checking operations will be carried out by on-board aids and more decisions will be taken by the driver. This on-board equipment, following the necessary research and development, will need to be the subject of investigations aimed at determining the way in which it will be accepted and actually used by the drivers (Malaterre and Saad 1986). This acceptance and use is not always as envisaged by the designers of the equipment. For example fuel consumption indicators fitted to certain vehicles during the period from 1975 to 1985 were disconnected by some drivers after a certain period of driving.

The items of equipment at present being tested are of a very varied nature and are concerned with more or less all the current driving functions including means of communication for the guidance of the vehicle along the road and the driving aids themselves (Parey and Lauer 1987).

Some of these items of equipment are concerned with anything that can inform the driver about his immediate environment including himself. They consist of:

- warning devices for the maintenance of vigilance;
- tyre deflation indicators;
- fog and ice indicators; proximity (anti-collision) radar.

These items of equipment all operate in a similar way. Thus the operation includes a phase of identification of the driver-vehicle-road system (somnolent driver, fog at 500 metres) and a second phase concerned with the rapid supply of information to the driver, this latter in turn constituting a first step in monitoring the manual control of the vehicle.

Detection of a Decrease in Vigilance: Principles of Operation and Current Systems

Applied research centres have been producing prototype systems and equipments and putting forward rapidly tested solutions over the last 10 years. These efforts have been based on the following relations:

- a decrease in vigilance is associated with different states of the body that need to be identified before delivering an alarm (posture, muscular tonicity, various physiological signals);
- a low level of vigilance gives rise to particular types of driving that need to be identified in terms of specific actions (movements of the steering wheel, deviation from the normal trajectory along a traffic lane).

Currently known systems, some examples of which are described below, virtually all make use of these two relations in diagnosing the state of the driver. A complete description is given by Tarrière et al (1988).

Systems Based on the Diagnosis of the State of the Driver

Skin Resistance (Domalert, England 1985). The subject is fitted with two electrodes and variations in the electrical resistance of the skin measured while the subject is driving. The equipment gives an indication of increases in skin resistance which falls with a decrease in vigilance. It is doubtful if this system would prove to be sufficiently reliable given the difficulties that have been experienced in measuring electrodermal reactions.

Magneto-encephalography (Sweden 1987). Two electrodes attached but not cemented to the scalp provide indications comparable to those provided by an EEG. The magnetic flux densities concerned are of the order of 10-12 to 10-13 Tesla compared with that of the earth's magnetic field which amounts to about 10-4 Tesla. In spite of the slight attenuation of the earth's magnetic field due to the presence of the vehicle body it does not seem likely that it will be very easy to measure the variations in magnetic flux associated with vigilance except in the case of a high amplification of the signal emitted by the driver.

Artificial Skin (CNRS-LAAS[1]), France 1987). Pressure sensors are fitted to the steering wheel, the foot pedals and the seat of the vehicle. The principle of operation is a matter of detecting the variations in pressure and movements associated with a reduction in vigilance. For example we can monitor the pressure applied to the steering wheel which puts us in a similar situation to what applies in the case of the use of the "dead man's handle" on trains. Temperatures can also be taken into account in that the muscles of the hand relax as the degree of vigilance decreases which leads to a looser grip of the steering wheel and a consequent drop in the temperature of the hand-wheel contact. However this principle of operation does not appear to be very practical because of variations of this contact temperature according to the subject concerned.

Position of the Head. A decrease in the degree of vigilance is associated with a relaxation of the muscles in the back of the neck with a consequent inclination of the head. A detection system fitted to the ear (Slarner, France 1980) or to the head itself (Majima, Japan 1984) triggers an alarm when the angle of inclination of the head exceeds a predetermined value.

The ATMOSTAT system can be included under this heading. This system is not designed to detect a decrease in the degree of vigilance but rather to dispense negative ions in the vehicle which have the effect of reducing the fatigue of the driver.

Validation tests are now in progress but it is difficult to carry out such tests under realistic conditions because of restrictions associated with the use of the sensors.

Systems Based on the Use of Equipment Fitted to the Car

These systems analyse the behaviour of the driver in terms of his control of the car. Two criteria are involved. The first is concerned with the displacements of the steering wheel and then, by extension, with deviations from the vehicle trajectory according to the vehicle speed. Thus adjustments of the steering wheel are less frequent and of greater amplitude when the degree of vigilance is low than when the driver is wide awake. The second criterion is concerned with the trajectory of the vehicle with respect to an ideal and safe trajectory defined by lines painted on the road surface. The VIGILYNX system, which is at present under development, is an application of this principle of operation in that it is designed to detect the contrast between the road surface and white lines painted on the road. However it is thought that a basic disadvantage of the system is that it does not deliver a warning of inadequate control of the vehicle in sufficient time. If a vehicle travelling at a speed of 130 km/h on a motorway leaves the carriageway at a slight angle it is possible in principle to regain control following an alarm on making use of the emergency braking lane. However this would not apply when driving on an ordinary road.

The most advanced systems have been developed by the motor manufacturers themselves, that is by Renault, Nissan and Ford.

These systems analyse the way in which the steering wheel is displaced in adjusting the trajectory of the vehicle, such displacements being closely related to the degree of vigilance of the driver as determined with respect to electro-physiological criteria (Yabuta et al 1985).

The Japanese system has already been commercialised but the results of the evaluation that should have been made are not known despite the fact that some thousands of vehicles equipped with the system have been produced. Yabuta (1989) is continuing his work at Nissan but we are unable to comment on the progress that has been made. The most advanced system is that produced by Renault where the research workers are carrying out validation tests under actual driving conditions. At Mercedes however work is proceeding with the aid of a powerful simulator. The distinctive characteristics of the driver are analysed at the beginning of each trip and the results retained in defining the high degree of vigilance of the subject. The Renault system that is under development is designed to deliver alarms at a number of different levels but the designers (Tarrière et al 1988) consider that the vigilance should not be allowed to become too degraded before delivering an alarm if the driver is to be able to regain control of his vehicle.

Warning of the Driver and Subsequent Control of the Vehicle

The detection of a decrease in the degree of vigilance is only the first step in the control process. It is then necessary to deliver an appropriate alarm and to regain a suitable mode of control, manual or automatic, of the vehicle. The characteristic features of this situation are the short time of operation of the alarm of a few seconds and the regain of control of the vehicle by the driver. These two steps have conflicting demands: a prompt reaction following an indication of a malfunction is not always appropriate. We have seen how this can be the case in processes of longer duration, e.g. as in a nuclear power station. The detailed investigation of the Three Mile Island incident highlighted the problem associated

---

[1] Centre National de la Rescherche Scientifique—Laboratoire d'Automatique et d'Analyse des Systemes.

with the latent period between the delivery of an alarm and the instant of taking appropriate action.

These two steps leading to a regain of control of the vehicle arise in other situations where there is a certain degree of urgency: deflation of tyres or the sudden appearance of fog or ice on the roads. The introduction of anti-collision radar gives rise to the question of automatic control of the speed of the vehicle given the very urgent situations that can be involved.

The papers that have been published are rather cautious on this aspect of control of the driving process. This is understandable given the difficulties of carrying out any experimental work in studying this situation. Practical observations and analyses of accidents suggest that inexperienced drivers tend to oversteer in the event of accidents. This reaction can also be observed in the case of drivers who have had too much to drink and who are not able to synchronise their driving operations as well as before. This suggests that the correction of the trajectory of a vehicle could be the subject of instruction and could be taught to learner drivers although this latter possibility would be controversial.

Experimental studies of this difficult problem could be carried out on a high performance driving simulator. However this immediately gives rise to the question of the degree to which the experimental conditions would be realistic. Thus the way in which the simulation can be seen as a "game" where the subjects are aware that there is no real danger could affect the reliability of the results. The simulator, having been adjusted with respect to real operating conditions, would nevertheless be of use in carrying out comparative studies. Continuing this argument we need to consider whether drivers are likely to drive a specially equipped vehicle at a "constant risk" since they know that the "system" is monitoring the situation. It should be noted here that in studying the behaviour of transport drivers where the investigator travels as a passenger, the drivers continue to drive until they are about to fall asleep (Germain 1988). This can be seen as constant risk driving where the presence of an observer constitutes a system for monitoring the degree of vigilance of the driver. Thus there is a risk that the provision of electronic equipment designed to ensure continued vigilance could have adverse effects and research needs to be carried out with a view to evaluating this risk.

Experimental Research: Body Posture as an Indication of the Fatigue of the Driver

Introduction

The object of the research was to determine the combined effect of noise and infrasonic vibration on the vigilance of drivers of light vehicles under actual driving conditions. This research was coordinated with that of Dr. Tarrière (Renault company) who worked with a simulator. Some of the subjects were common to he two series of tests, one on the roads and the other using the simulator and this led to a good validation of the results.

Attempts were made to evaluate the variations in the degree of vigilance and attention at the end of a long journey as well as the fatigue resulting from the efforts of the drivers in trying to maintain their vigilance and level of perceptive-cognitive performance.

Observation of the decrease in vigilance due to the combined effects of noise and vibration should lead to recommendations concerning the arrangement of the interiors of the vehicles.

The results of the experiments will eventually allow us to put forward proposals for additions to the ISO 2631 and AFNOR 90401 standards for the measurement of vibration at the man-seat interface. In the case of the driving of cars we need to provide for complementary measurements in the region of the upper and lower limbs and to take account of the levels of the ambient noise considered as background or residual noise where a combination of noise and vibration is being experienced.

The experiments were carried out for the four different noise-vibration combinations of two levels of noise and two levels of infrasonic vibration.

The degree of vigilance while driving was determined with reference to behavioural and physiological indicators. The sensory-motory performances of the drivers were measured at the end of the journey on carrying out reaction time tests which have proved to be sensitive in the case of other investigations concerned with noise.

To begin with we describe the method employed to evaluate the posture of the drivers as developed in our laboratory. We then report on the preliminary results that have been obtained on referring to the relation between the electro-encephalographical recordings and the bodily posture while driving.

Determination of the Posture

The posture of the subject was determined on recording the displacement of a number of points on the side of the body. These points were positioned on taking account of the locations employed by ergonomic specialists in studying the relation between fatigue and the posture of an operator (Fourcade et al 1975). Light emitting diodes (LED's) were fitted to these points for recording purposes. The driver was filmed by means of two CCD cameras (Charge Coupled Devices) fitted in the car. These cameras were connected to a computer via an image digitising board (figure 1). The LED's were illuminated each time a photograph was taken simultaneously by the two cameras. Each image was then digitised in order to obtain the coordinates of the LED's.

Let R (O,I,J,K) be a reference system in space and M a point having coordinates X,Y,Z within this reference system.

Let R1 (O1,i1,j1) be a reference system in the image plane of camera 1 and x1 and y1 the coordinates of the image point M1 of M within the reference system R1.

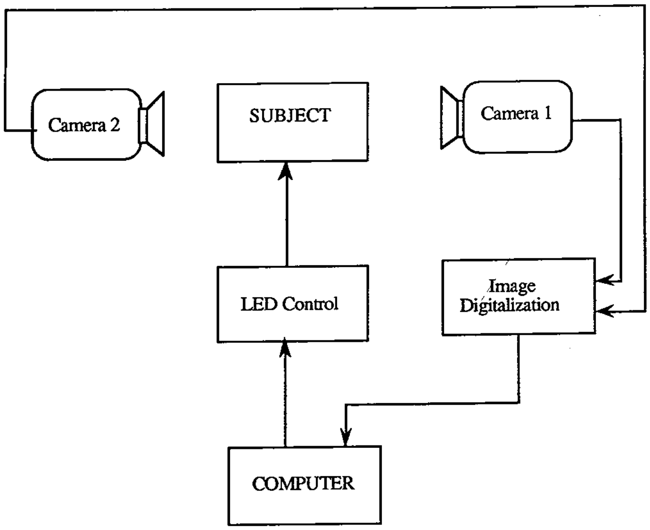


Figure 1. Block Diagram of the Posture Recording System

Let R2 (O1,i2,j2) be a reference system in the image plane of camera 2 and x2 and y2 the coordinates of the image point M2 of M within the reference system R2.

Given the colinear relations and the equations for a change of the reference system we can write (Abdel-Aziz and Karara 1971):

$$x1 = \frac{A1X+B1Y+C1Z+D1}{E1X+F1Y+G1Z+1} \qquad x2 = \frac{A2X+B2Y+C2Z+D2}{E2X+F2Y+G2Z+2} \qquad (1)$$

$$y1 = \frac{I1X+J1Y+K1Z+L1}{E1X+F1Y+G1Z+1} \qquad y2 = \frac{I2X+J2Y+K2Z+L2}{E2X+F2Y+G2Z+2} \qquad (2)$$

These are the basic equations for the digital photogrammetry of an ideal optical system. The values of the coefficients A1, B1 and C1 .... and A2, B2 and C2 .... are determined during a calibration phase using points of known coordinates within the reference system R. The system having been calibrated, the coordinates of a point M in space verify the sets of equations (1) and (2) having unknowns X, Y and Z. Thus we have 4 equations and 3 unknowns. The system can accordingly be resolved and the coordinates X, Y and Z of M determined. Photographs taken at regular intervals then allow us to follow changes in the posture of the subject in terms of the coordinates of each LED.

Procedure

The tests were carried out under actual driving conditions during a 4-hour trip on the motorway running between Lyon and Dijon. Each subject was fitted with LED's and electrodes, all connected to a portable computer installed in the car. Thus records of both the posture and certain physiological responses of the driver were obtained. The latter consisted of an electroencephalogram (EEG: derivation ..), an electrocardiogram (ECG) and an eye blinking (EBG) record. The posture was determined with reference to LED's placed on the temple, shoulder, hip and knee of the subject and on corresponding points on the seat (figure 2).

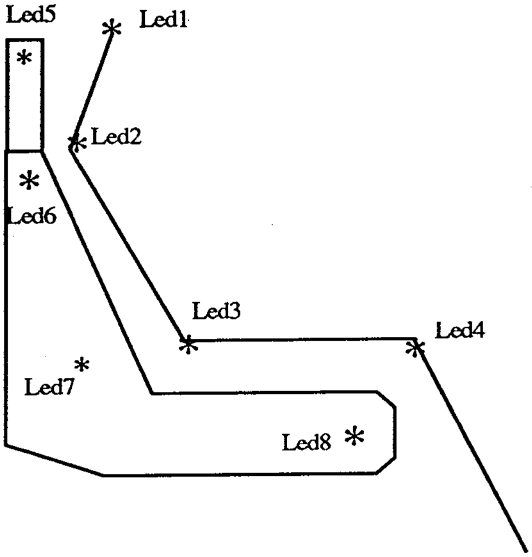


Figure 2. Location of the LED's on the Subject and the Seat

The subjects were asked to drive for an initial two-hour period in order to get used to the test conditions. They were then asked to drive normally on respecting the speed limits. They were each accompanied by a technician who was instructed not to talk to the subject and to closely observe his behaviour.

Preliminary Processing of the Postural and Physiological Data

We were interested in the angles O1 and O2 and distances d73 and d84 (figure 2) as a function of the usual physiological indicators over 15 second periods. O1 is the angle of inclination of the head to the "vertical" axis given by the head rest and O2 the angle between the line of the trunk and the line joining the hip to the knee. d73 is the distance between the hip and a reference point on the back of the seat and d84 that between the knee and a reference point on the front edge of the seat.

As previously mentioned the measuring system was concerned with the coordinates of each point in space. Points 5 and 6 were selected so that the vector V56 was practically vertical with O1 being the angle between vectors V12 and V56.

The EEG was analysed over 15 second periods as a function of the frequency concerned. We then determined the alpha and beta energy bands and the ratio of alpha to the beta energy band.. The value of this ratio is greater to the extent that the subject is more or less vigilant (Gale 1977).

The eye blinking record was analysed in order to determine the mean number of blinks per minute and the way in which this rate varied (Egelund 1982).

Statistical Analysis of the Data

In this paper we confine our attention and the analysis of the data to the inclination of the head which varies in a very particular way with the decrease in the degree of vigilance. An example of the recording of this parameter that was obtained is shown by figure 3.

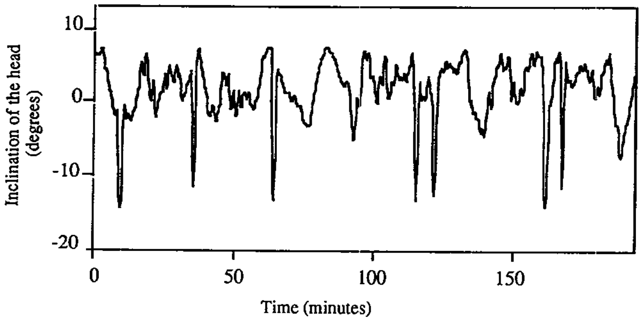


Figure 3. Variations in the Inclination of the Head During a Trip on the Motorway

The different variables concerned were as follows:

- Dependent variable: angle of inclination of the head to the vertical. Average values of this variable over 15 second periods were determined in order to limit the amount of data to be dealt with.
- Independent variables: the degree of vigilance (high, average and low); the level of vibration (2 different levels); the level of noise (2 different levels).

a) Degree of vigilance

The alpha/beta ratio was employed as an indicator of the degree of vigilance. In order to show up the relation between the degree of vigilance and the inclination of the head, a histogram of the average distribution of the observed alpha/beta ratios was determined for each subject for all the trips that were undertaken. We accordingly dealt with a quasi-normal distribution of the data.

Given this distribution we defined three different degrees of vigilance:

- high degree of vigilance (HV): alpha/beta < a - 1o
- average degree of vigilance (AV): a - 1o < alpha/beta < a + 1o
- low degree of vigilance (LV): alpha/beta > m + 1o

where a = average value, o = standard deviation.

The alpha/beta values were averaged over 15 second periods and divided into the HV, AV and LV categories defined above.

b) Level of vibration

Two levels of vibration were produced on using one car where the seat was fitted with degraded anti-vibration mountings and another car where the seat was fitted with normal anti-vibration mountings.

c) Noise level

Two noise levels were produced on amplifying the normal noise within the vehicle so as to obtain a difference of 3.5 dbA between the normal and amplified levels.

Results

a) Effects of the degree of vigilance

The degree of vigilance had a significant on the inclination of the head (under the conditions defined above) at $p = 0.001$ [$F(2.14) = 20.3$].

The average values were as follows:

Degree of vigilance	Average value of O1
Low	4.80
Average	3.60
High	3.50

A t Student test showed that the effect on the average angle of inclination of the head was more significant for the low degree of vigilance ($p < 0.05$) than for the average and high degrees of vigilance.

These results show how variations in the degree of vigilance have a significant effect on the inclination of the head.

b) Effect of the level of vibration

The level of vibration had a significant effect on the angle O1 at $p < 0.02$ [$F(1.7) = 8.2$].

The average values were as follows:

Level of vibration	Average value of O1
Normal	40
Accentuated	3.90

These results show how low levels of vibration had a limited but significant effect on the inclination of the head.

Having obtained these results we studied the inclination of the head on taking account of the sign of that inclination. It was then found how the degree of vigilance had a very significant effect ($p < 0.001$) on the backward inclination of the head (negative angle). This reaction could be due to the use of the head rest as a consequence of a decrease in the tonicity of the muscles in the back of the neck. However it would seem that this effect only comes into play beyond a certain threshold value of the alpha/beta ratio whose value has yet to be determined (variation in the threshold value according to the subject, driving conditions, etc.).

The study of changes in the posture under real driving conditions showed how there was a significant interaction between the position of the head and the degree of vigilance for our group of subjects.

There was a particularly noticeable effect on the position of the head, namely a backward inclination, for a low degree of vigilance. The results that have been described will allow us, in a second phase of our work, to develop more appropriate techniques based on more sophisticated signal processing with a view to detecting significant "patterns" in the way the position of the head changes. If the significant relation between the posture of the body and the degree of vigilance is confirmed then it would seem that determination of this posture could be of use in monitoring the degree of vigilance of the driver.

Conclusion

A system for maintaining the vigilance of the driver would have to be provided in parallel with the the provision of other electronic systems in the car and this will affect the predictions in the BIPE (1987) report concerning future requirements, the systems at present being offered by the manufacturers being concerned with map displays. However the annual inquiry on the behaviour and attitude of motorists conducted by INRETS (1991) showed that more than 50% of motorists considered that a system designed to maintain the vigilance of the driver would be very useful. The total amount of information to be supplied by the new systems could no doubt be assimilated by the driver but it is known, for example, that the provision of general traffic information can interfere with the degree of vigilance of the drivers. Thus the work of Crespy (1972) has shown that the use of an electronic navigating aid leads to a decrease in vigilance that shows up on an electroencephalogram.

The most likely possibilities for the future are concerned with the technical development of various driving aids. The most advanced systems for the detection of vigilance however rely solely on displacements of the steering wheel. Attempts to take account of the values of a number of different parameters would complicate the detection of any decrease in vigilance. In addition to the work on the detection of the degree of vigilance of drivers it is important that parallel psychoergonomic research be carried out concerned with the understanding, the acceptance and the actual use of these systems by the drivers.

While waiting for a successful outcome to the technical developments it would seem that we need to (a) ensure that the consumers of psychotropic medicaments (and the doctors who prescribe them) are aware of what is involved and (b) explore the field of research concerned with self activation of the driver by means of appropriate mental exercises whenever he himself is aware of a slight loss of attention.

References

Abdel-Aziz Y.I. and Karara H.M. Direct linear transformation from comparator coordinates into object space coordinates in close range photogrammetry. American Society of Photogrammetry, 1971.

BIPE (Bureau International de Prevision Economique). 1987 Quelles voitures pour l'an 2000? Paris.

Craig A. 1984. Human engineering: the control of vigilance. In: Sustained attention in human performance by Warm J.S., editor, pages 247-291, J. Wiley, New York.

Crespy J. 1972. Le guidage de La conduit, etude dun system de guidage electronique. Cahier d'etudes de l'ONSER NO 29.

Delhomme P. and Malaterre G. 1990. Methodes d'investigation du comportement du conducteur par observations embarquees. DRIVE programme report. Paris, INRETS, 50 pages.

Egelund N. Spectral analysis of heart rate variability as an indicator of driver fatigue. Ergonomics, 1982, volume 25, pages 21-29.

Fakhar S., Vallet M., Olivier D. and Baez D. La posture corporelle comme indicateur de fatigue du conducteur. In: Le maintien de La vigilance du conducteur. Paradigm ed. (to be published).

Fourcade J., Martin J.P., Jacq J.and Defayolle M. Attention visuelle posture. Contribution a l'etude du system. Variations de La posture de l'operateur humain en fonction du flux d'information et de La duree du travail dans une tache de controle. Le travail Humain, 1975, volume 38, NO 1, pages 119-132.

Gale A. Some EEG correlates of systained attention. In: Vigilance: theory, operational performance and physiological correlates by Mackie R. New York Plenum Press, 1977, pages 263-238.

Germain C. 1988. Le conducteur routier, gestionnaire de contraintes. Thesis. Conservatoire National Arts et Metiers, Paris.

Head H. 1923. The conception of nervous and mental energy. Vigilance: a physiological state of the nervous system. British Journal of Psychology, 14, pages 126-147.

Hickman A and Huguers M. 1978. Exposure of drivers to carbon monoxide. Transport and Road Research Laboratory, United Kingdom, 24 pages.

INRETS. 1991. Enquete annuelle sur les comportements et attitudes des automobilistes. SOFRES report.

Karube I. 1990. A driving ambition. Asia Technology, Tokio, CPE 1990, Bulletin NO 64/01/90, page 25.

Lafont R. 1987. Rapport d'activite ASSECAR. Paris.

Lecret F. 1976. La fatigue du conducteur. Cahier d'etudes de l'ONSER No 29.

Lecret-Grillon F. 1985. La vigilance et ses variations lors dune tache de longue duree: le cas de conduit automobile. Thesis, Paris, 198 pages.

Macworth N.H. Some factors affecting vigilance. The Advancement of Science, 1957, 53, pages 389-393.

Malaterre G., Saad F. 1986. Les aides a La conduit, definition et evaluation. Le travail humain, volume 49, NO 4, pages 333-346.

Mackie R. 1987. Vigilance research. Are we ready for countermeasures? Human Factors, 29 (6), pages 707-723.

Pachiaudi G., Vernet M., Foti A and Laurens J.F. 1987. Etude de La communication parlee a l'interieur des voitures. INRETS report NO 53.

Parasumaran R. 1984. The psychobiology of sustained attention. In: Sustained attention in human performance by Warm J.S., editor.

Parey C and Lauer A. 1987. La voiture intelligente. La Recherche NO 190, sup. pages 46-55.

Poulton E.C. 1978. Increased vigilance with vertical vibration at 5 Hz: an alerting mechanism. Ergonomics NO 9, 2, pages 73-76.

Tarrière C. 1960. Un moyen d'etude des accidents inexpliques. L'epreuve de vigilance. Medical doctor thesis. Faculte de Paris.

Tarrière C. Hartemann F., Sfez E., Chaput D. and Petit-Poilvert C. 1988. Some ergonomic features of the driver-vehicle interface. FISITA 88 Congress, Detroit.

Vallet M. 1987. Vibration and low frequency noise in motor vehicles and their effects on vigilance and road safety. A literature review. Journal of Low Frequency Noise and Vibration, volume 6, NO 3, 1987.

Warm J.S . editor. 1984. Sustained attention in human performance. J. Wiley, New York.

Wyon D. et al. 1971. Factors affecting the subjective tolerance of ambient temperature swing. Proceedings, 5th International Congress for HVAC, Copenhagen, pages 87-107.

Yabuta K. 1989. Etude sur mouvements du volant lies a l'etat de vigilance du conducteur. pages 282-288.

Yabuta K., Iizuka H., Yanagishima T., Kataoka Y. and Seno T. 1985. The development of drowsiness warning devices. 20th International Conference on Experimental Safety Vehicles. Oxford 18 pages.

S2-O-11

Technical and Medical Aspects Influencing a Motorist's Driving Ability

Andrea Costanzo, MD[1]
Rome University "La Sapienza"

Abstract

The present work researches into the most significant technical and medical aspects capable of affecting a motor vehicle driver's ability within the bounds of the highest safety possible and with an eye to the prevention of accidents. Therefore, this work focuses basically on aspects of passive safety. One technical aspect to be considered is that of the characteristics of the driver's seat which can afford a motorist the possibility to dampen the load an such parts of his body as the lumbar and cervical column. Based on this, same spinal column configurations have been identified which allow a correlation of the ensuing loads on function of several seat-dictated postures. Also some physical-kinematic patterns have been studied which are typical of how vertebral and lower limbs act with respect to trunk. A simplified geometrical scheme has been indicated including also the choice of a so called H point. This study has not dealt in any special way with other technical aspects, such as the construction of motor vehicles because, although intrinsically capable of improving driving conditions, they are primarily, or aught to be the concern of car manufacturers. Among the various medical and driver's physical characteristics the following have been studied:

- fatigue as pertaining to some regions of the human body;
- mental stress;
- insecurity;
- exhibitionism;
- aggressivity.

The conclusions arrived at this study are basically aimed at sensitizing all agencies and organizations. Concerned with road safety in order to identify both means and experts most suitable to research into the many problem areas.

Introduction

The study proposes the analysis, for road safety purposes, of the technical and medical aspects conditioning a motorist's driving abilities.

These abilities exert a direct influence on the possibilities of increasing active safety in the sense of preventing accidents when the driver enjoys optimal psychic conditions and conditions of comfort.

The study has been kept within the bounds of conceptual exposition and evinces the methodologies for laying the basis of the analytical calculations. Diagrams and figures have, accordingly, been prepared to enable the aspects of the problems to be analysed with ease, and the appropriate solutions be determined.

The factors influencing man's driving abilities have been divided, in this context, into two main areas, namely:

- Stress stemming from the inadequacy of the driver's seat;
- The motorist's psycho-physical characteristics.

Mechanical Stresses

Although the comfort of the driver's seat affects many regions of the human body, we have focused the analysis on some the most important areas, namely:

- the cervical column;
- the lumbar column;
- the lower limbs.

---

[1] Andrea Costanzo is Associated Professor of Traumatology at the School of Medicine and Surgery—Rome University "La Sapienza" and Medical Consultant for Automobile Club of Italy (ACI) Address: Via Monte delle Gioie 1/D-00199 Roma (Italy).

Cervical Column

The conditions of equilibrium of the single vertebrae, for simplicity's sake considered in the sagittal plane only, are assigned to the function of various elements which contribute, in a different but concomitant way, towards ensuring the stabilities and movements of the cervical column.

Figure 1 outlines, in the two main sections of the cervical column, the typical configuration of a vertebra and shows the essential connecting and binding elements for the movements between the vertebral bodies.

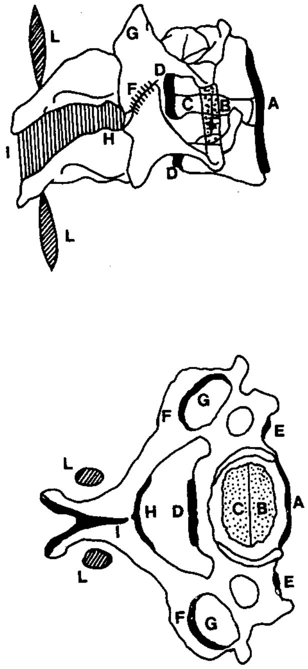


Figure 1. Typical Configuration of a Vertebra in the Two Main Sections

On limiting the analysis of the problem to the movements of flexion and extension of the column in the sagittal plane, and in the hypothesis of making only a comparative evaluation between the stresses to which the vertebrae are subjected in two zones of the cervical column (the central and lower zones respectively), the system can be outlined as follows:

- each vertebra behaves as a lever of the first type with the fulcrum materialised on the axis of rotation contained in the median plane of the intervertebral disc;
- the constraints can be represented, beside the fibrous structure of the disc (Fig. 2), by the front and back ligamentous and muscolar formations, which act both as movement-generating elements and compensation elements for the moments applied, to ensure the stability of the cervical column. (see Fig. 1).

An incorrect posture brings about abnormal stresses of the intervertebral muscles and ligaments. This causes fatigue to these structures, with resulting contracture and pain.

Fatigue will then give rise to a reduction of attention and concentration with resulting decrement of the driving ability.

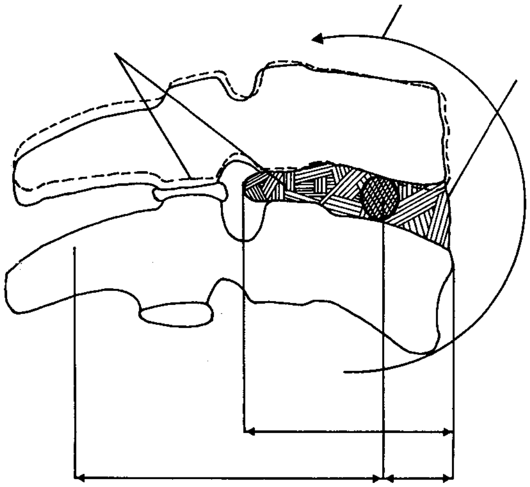


Figure 2. Structure of the Intervertebral Disc

The mechanical study to enable the effects of this fatigue to be quantized has been developed on the basis of a schematization of the cervical column represented by two segments only, as reported in Fig. 3, in which the three vertebrae that stabilise the ends of the two segments are the seventh cervical vertebra situated in point B, the fourth vertebra situated on point C, and the first vertebra situated in point A where the head mass is assumed, concentrated in a point.

For clarity's sake, the constraints have not been reported in this figure.

It has also been assumed that starting from the condition of rest, identified by the position BCA°, the column shifts rotating around C until it reaches, as second position, the total straightening of the column itself with the alignment of the two straight segments considered (position BCA).

Further movements of flexion are assumed with rotations around point B, but keeping the alignment of the two segments forming the column.

We have, with this scheme, and always with the purpose of simplifying the analysis procedure, considered the stresses acting on the two vertebrae only (the central one and the lower one) throughout the variability curve of the shifts from the starting position to the final one because of the vertical load applied on the upper end of the cervical column. It is considered helpful to note that in this outline, apart from considering the head mass applied in the upper end of the cervical column, it is possible to ignore the neck mass in order to avoid analytical complications that do not make substantial changes of the results.

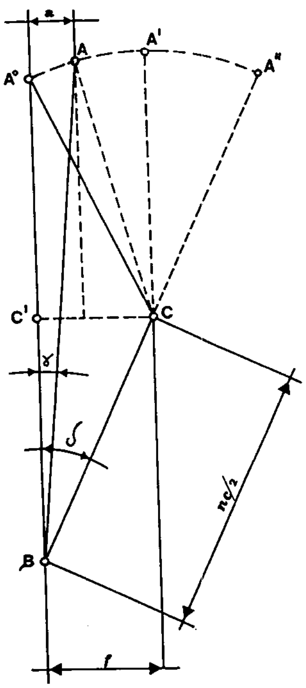


Figure 3. Schematic Representations of the Cervical Column as Two Segments Hinged in B (seventh cervical vertebra), A (first cervical vertebra), and C (fourth cervical vertebra)

Referring to the diagrams shown in Fig. 3, we have used the following symbols:

a = the unbalance of the weight force with reference to point B supporting the column base;
f = initial lordotic sagitta;
h_c = rectified length of the cervical column;
γ = inclination angle of segments A B from the vertical A° B;
δ = inclination angle of segment A" B from the vertical A° B;

equivalent to:

$$\delta = sen^{-1} \frac{2f}{h_c}$$

With these indications and having assumed:

s = f/h as a dimensional parameter for determining the initial lordosis;
r = a/d as a dimensional parameter for determining a segment;

the stresses falling on the disks of the vertebrae considered (σVII and σIV) of area A, because of the head mass P_t applied in A, can be obtained.

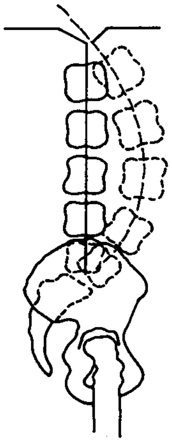
The possible configurations of the cervical column that lead, either because of excessive sagitta in the central zone or of excessive forward unbalance of the head, to abnormal increase of the compressive stresses, shear and moment in these zones, determine the fatigue of the whole cervical segment.

The optimal position, therefore, is that which leads to the motorist's posture in the driving seat being such as to keep the head the least unbalanced forwards as possible and a containing of the lordotic sagitta within the minima allowed by the physiological posture.

This last consideration leads also to differentiating the various subjects among themselves in relation to their natural characteristics.

Lumbar Column

Similarly to the approach set for the study of the cervical column, the examination of the lumbar part (see Fig. 4) has been developed by schematizing the column formed by only two segments as shown in Fig. 3 in which L5-S1 is situated in point B, L3 in point C, and Ll-T12 in point A.



H: Reference Point of the Cartesian Axes;
H1: Central Point of the Upper Face of S1 Vertebra;
HS: Central Point of the Upper Face of the L1;
LL: Rectified Length of the Hs-H1 Segment;
Fl: Lumbar Inflection;
αHs: Reference Angle of L1 Upper Face;
αHl: Reference Angle of L3 Lower Face;
αHi: Reference Angle of L5 Lower Face;
αHc: Reference Angle of S1 Upper Face

Figure 4. Geometric Parameters of the Lumbar Column

This makes it possible to establish the various postures of the lumbar column. Since, however, it is necessary to take account of the seat supports a scheme must be established for this also.

Therefore, the inclusion of the seat in the overall system and the consideration that the only reference point remaining fixed is precisely the cushion-seat-back joint has suggested the introduction of a new representation on two cartesian axes as shown in Fig. 5.

In this case the whole lumbar column-sacrum-coccyx complex must be considered mobile (including point H), with respect to this reference system.

We shall start, first of all, to define the geometry of the system as follows:

- the reference system is that of two cartesian axes with origin in the point which joints the cushion and the seat-back;
- the shifting of point H is exclusively represented by the rigid translation on the line parallel to the trace

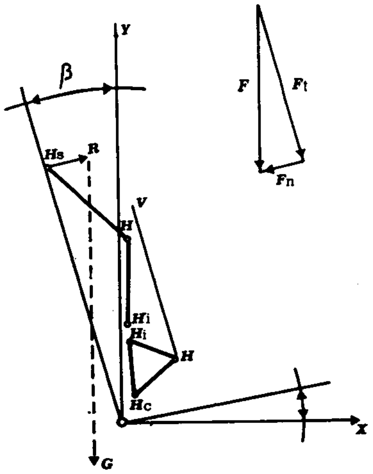


Figure 5. Semplified Scheme of the Lumbar-Sacral System Referred to the Seat Parameters

of the plane of the cushion inclined at an angle α to the axis X;

- the sacrum-coccyx complex is represented by a triangle having for vertexes point H, the middle point of the segment representing the trace of the upper face of S_1 (H_1) and the lower end of the coccyx (Hc). It is, therefore, assumed that all the representative points if the sacrum-coccyx undergo the translations of point H and revolve on a circular trajectory around it;
- the lumbar segment hinged at the bottom on point Hi consequently follows the allowed shifts;
- the shifting of point Hs (upper end of the lumbar column) is exclusively represented by the rigid translation on the line parallel to the trace of the plane of the seat-back included at an angle β with respect to the axis X.

With this schematisation it is possible to determine the coordinates of the characteristic points Hc, H1, H, Hi, HL, Hs and the inclinations of the relative segments joining them.

Once the representation, even if only in outline, of the lumbo-sacral-cox-femoral system has been obtained and the lines of action, the intensities of the vertical loads and of the constraining relations both on the seat-back and on the cushion, as reported in Fig. 5, known the stresses in the various points of the column can be calculated.

At this point, it is necessary to introduce the concept of binding forces and reactions so as to determine the loads.

In this case, also, simple schemes are assumed, but ones that do not take generality from the analysis, in order to respect the terms of the problem set.

The schematisations introduced can be described as follows:

- the vertical loads acting on the trunk of the body can be incorporated in a result of a force F with line of action as reported in Fig.5;
- This force F can be separated into two components, one parallel and the other at a right angle to the seat-back plane;
- The reaction of the load along the trunk as component parallel to the seat-back plane, determines a reaction V at the level of the cox-femoral joint (point H);
- The reaction of the load perpendicular to the trunk, as ortogonal component to the seat-back plane, determines a reaction R at dorsolumbar column level.

The component of force F at a right angle to the seat-back plane, as previously specified, determines a variety of reaction schemes of the seat-back itself in relation to the type of support of the column. Basically the problem can be determined in the two extremes cases:

- the column rests uniformly on the seat-back. The reaction, in this case, is represented by a distributed load (see Fig. 6) and the most favourable conditions are determined for compensating other bending moments;
- the column rests only on the upper end of the same (point Hs). In this case the reaction is represented by a force concentrated in the same point and the most unfavourable conditions, like bending stresses on the column, are determined.

Between these two extreme situations, a whole range of possibilities can exist, which approaching one another allow a glance to be obtained of the measures that can be introduced to mitigate the damage to the column. Fig. 6c shows one of these cases.

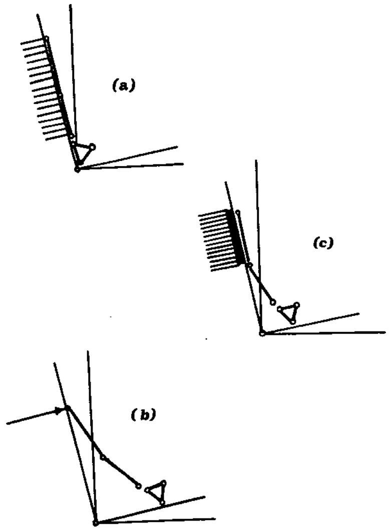


Figure 6. Most Significant Cases Showing the Support Scheme of the Lumbar Column on the Seat-back

The analysis of the loads, stresses and deformations of the lumbar segment has highlighted the following aspects:

- as the inclination of the seat-back increases, the axial load on the column is reduced, whereas the transversal component of the load itself increases.

From this viewpoint, with the condition that there is a perfect support of the column on the seat-back, it can be concluded that the stresses and the loads decreases with the increase of the seat-back inclination.

Lower Limbs

Although there are no significant loads on the lower limbs because of the various positions of the seat, account must be taken that the particular posture of the motorist in the driving seat involves an angular variation of the various joints. This will exert an influence according to the distance between the pedals and the seat and the latter's angulation on the posture of the pelvis with resulting variations of stress borne by lumbo-sacral limit and thus by the whole lumbar region.

Therefore the loads determined in the analysis of the previous paragraph lead to taking account of the posture of the lower limbs and, thus, of the limits of distance from the pedals, in terms of the inclination of the seat and the seat-back.

Mental Stress

This part has been dedicated to the analysis of those characteristics of the driver in the driving seat that can definitely condition the abilities to control the vehicle.

First and foremost it would be necessary to analyse the driver's personality to establish the various aspects determining his capacity.

This study has considered mental stress, insecurity, exhibitionism, and aggressivity as characteristic elements.

A classic example of this aspect is represented by the conditions that occur when the motorist is compelled to keep sustained attention in order to drive long distances and, above all, at high speed. These conditions determine a reduction of the driving ability through fatigue and consequent slowing down of the reflexes.

The consequences of the driver's state of agitation due to a state of anxiety characteristic of the subject or to a contingent situation of reaction (anger) cause a general imbalance of most of the organic functions.

The functions concerned by a state of anger, determine a discharge of adrenocorticotropic hormone by the adrenal glands.

The main consequences are: the escape of leukocytes and blood platelets because of constriction of the spleen (*ispissitio sanguinis*), brachycardia, gastroenteritic motility depression and endoabdominal vasoconstriction.

The examination made shows that the concomitance of the various causes of stress, i.e. physical, mental and emotive stress, acts in co-operation with one another determining a lowering of the vehicle driver's attention threshold. The relationship existing between the driver's physical state and his or her capacity to control the vehicle would remain to be demonstrated, but, since it is not possible to generalise in view of the lack of homogeneity of the subjects, it may, at least be said, that the problem is important and must be tackled case by case; the participation of the physician is, consequently, fundamental.

Although the examination of this aspect is beyond the scope of this analysis, we would like at the conclusion of this study to highlight that checking the physical state and knowing one's own limits, at the particular time, lay the grounds for driving in conditions of greater safety.

References

Bonaccorsi S., Costanzo A. La patologia vertebrale nel conducente abituale di autoveicoli (analisi biomeccanica e fisiopatologica) Pag. 379-410.

Atti I Congresso Naz. Medicina del Traffico. Fiuggi Terme 6-7-8 5iugno 1974.

Costanzo A. La colonna cervicale nel conducente di autoveicoli (postura, funzione e sollecitazicni). ATA Ingegneria Automotoristica n. 11-12 Vol. 36, 1983.

Costanzo A. Posto di guida (postura e patologia del rachide). Bollettino del Collegio Medici Italiani dei Trasporti, n. 4, 1983.

Costanzo A. La patologia cervicale del conducente di automezzi pesanti (importanza dell'altezza del posto di guida). Bollettino del Collegio Medici Italiani dei Trasporti, n. 2, 1984.

Costanzo A. La colonna lombare: funzioni, carichi, sollecitazioni. Bollettino del Collegio Medici Italiani dei Trasporti, n. 3, 1984.

Costanzo A. La colonna lombare del conducente al posto di guida (criteri di ottimizzazione del sedile). Bollettino del Collegio Medici Italiani dei Trasporti, n. 1, 1985.

Costanzo A. Analisi biomeccanica della patologia vertebrale per sovraccarichi funzionali derivanti da sollevamento e spostamento pesi. Ed. Roma Medica 1988.

Costanzo A. Human factor capabilities for avoiding traffic accidents. I2a International Thecnical Conference on E.S.V. May 29-June 1 1989-Gothenburg.

Fielding J.W. Cineroentgenography of the normal cervical spine. J. Bone Joint Surg. 39 A: 1280, 1957.

Johnson R.M., Crelin F.S., White A.A. and Paniabi M.M. Some new observation on the functional anatomy of the lower cervical spine. Clin. Ortop. 111:192; 1975 (Review of some important aspects of the surgical and biomechanical anatomy).

Leonardi A. Le protrusioni posteriori del disco intervertebrale. Atti 51° Congresso S.I.O.T. Catania 22-25 ottobre 1966.

Munro D. The factors that govern stability of the spine. Paraplegia 3:219, 1965.

Paniabi M.M., White A.A. and Johnson R.M. Cervical spine mechanics as a function of transection of components. J.Biomech. 8: 327, 1975.

Paniabi M.M., White A.A., Keller D., Southwick W.O. and Friedlaender G. Clinical Biomechanics of the cervical spine 75-WA BIO-7 Am Soch Mech. Eng.; New York, 1975 (Experimental basis for presumptions about the usefulness of the strecht test).

Wells E Luttgens. Kinesiologia, Verduci Editore 1978.

White AA. and Hirsch C. The significance of the vertebral posterior elements in the mechanics of the thoracic spine. Clin. Ortop. 81: 2, 1971.

White A.A., Johnson R.M., Paniabi M.M. and Southwick W.O. Biomechanical analysis of clinical stability in the cervical spine. Clin. Ortop. 109: 85, 1975.

White A.S., Paniabi M.M., Hausfeld J. and Southwick W.D. Clinical instability in the thoracic and thoracolumbar spine. Review of past and current concepts. Presented at the American Orthopaedic Association Meeting Boco Racan, Florida 1977.

White A.A., Southwick W.O., Paniabi M.M. and Johnson R.M. Practical biomechanics of the spine for orthopaedic surgeons (Chapter Instructional Course Lecture, American Academy of Orthopaedic Surgeons). St. Louis C.V. Mosby 1974.

White A.A. and Paniabi M.M. Clinical Biomechanics of the spine ed. J.B.Lippincott Company Philadelfia - Toronto 1978.

Technical Session 3
Specialized Road Users

Chairperson: Kenichi Goto, Japan Co-Chairperson: Kaneo Hiramatsu, Japan

S3-O-01

Factors that Influence the Involvement of Motorcycle Riders in Traffic Accidents

Hubert Koch
Industrie-Verband Motorrad Deutschland e. V.
Ulrich Schulz
Universität Bielefeld

Abstract

Recent studies have shown that age, driving experience, and risk exposure, measured in annual mileage, have a major influence on the involvement of motorbikers in accidents. Recent studies have shown that a further factor that is frequently discussed namely the performance of the motorbike, does not possess the importance that is attributed to it in the public discussion. Recent studies in Germany and other countries show that machine performance has no significant influence on accident involvement in the sense of a correlation between high performance and a high number of accidents. In the present study, a sample of more than 800 motorbikers were surveyed with a detailed questionnaire on accident involvement at the IFMA and the Motorshow in Essen in 1990. The detailed assessment of individual reports on motorbikes and accidents permitted a further study of the fundamental effects of the above mentioned factors in the most comprehensive sample yet to be studied in Germany. It also provided detailed information on involvement in accidents.

Introduction

Up to now two different methods have been used to study motorcycle accidents. The first is the statistical processing of data collected by the police at traffic accidents. These data generally refer to the type, location, and time of the accident as well as material damage and physical injury. Data that provide more detailed descriptions of the vehicle and the rider are hardly ever collected. The lack of depth in the assessment of accident related data is a weakness of the surveys performed by the police. A further deficit can be considered to be a large number of unreported accidents, for example, accidents not involving other road users.

The second possibility of collecting data is to carry out detailed surveys of road users. This method is used to obtain more detailed information on the location, type, and severity of accidents as well as specific information on the accident vehicle and the road users involved. In recent years, it has frequently been used to gain more detailed information on the involvement of motorbikers in accidents [see Koch and Hagstotz, 1990, (3); Schulz, 1990, (8), (9); Schulz and Hagstotz, 1990, (10); McKnight and Robinson, 1990, (7); Simard, 1990, (11); Taylor and Maycock, 1990, (12); Taylor and Lockwood, 1990, (13)]. The last studies were able to provide a more precise analysis of the impact on the vehicle and the driver. Effects of the driver have been shown for the variables, gender, age, driving experience, and the goal of biking. A further effect is shown by the type and the extent of risk exposure. The time of year, location, and the annual mileage are important variables. Finally, the motorbike's engine size and performance are discussed as variables of the vehicle.

A Discussion of the Variables

Effects of the Person

Statistical accident surveys have shown that age is an important variable in accidents [Kroj and Stöcker, 1986, (3); Koch, 1990, (2)]. In general, accident statistics show a decreasing trend in accidents with increasing age [Kroj and Stöcker, 1986, (3); McKnight and Robinson, 1990, (7); Taylor and Maycock, 1990 (12); Koch, 1990, (3); Schulz, 1990 a,b, (8,9). In the western part of Germany, accident involvement peaks among 18- and 19-year-olds [Koch, 1990, (2)]. A closer analysis of the influence of age on the risk of accidents shows that a moderator function is present here. The age variable assesses not only the riding experience in young motorbikers but also adolescent risky behavior. These two, potentially independent, variables can contribute to an increased involvement in accidents. One variable is the age specific tendency to search for new experiences and test own skills; the other variable is the learner riders' inexperience in riding a motorbike through the complex system of road traffic. Therefore, driving experience is generally assessed with age. If the former variable is additionally measured through the length of regular motorbiking, it is found to correlate very highly with the age variable. Only one American study, which also included very young motorcyclists without driver's licenses, has been able to achieve a high level of independence. With this exceptional data set, McKnight and Robinson (1990,7) have been able to show that the accident rate of motorcyclists clearly dropped with increasing riding experience (measured in years of riding practice). A corresponding impact of riding experience on the accident rate among British motorcyclists has also been confirmed by Taylor and Maycock (1990, 12) and

Taylor and Lockwood (1990, 13). A second type of riding experience is regular riding practice. Both Taylor and Maycock (1990, 12) and Taylor and Lockwood (1990, 13) have shown that low annual driving practice in an automobile leads to higher accident involvement with a motorbike. This is not the case in persons with intensive automobile driving practice. Schulz (1990 a,b, 8,9) was also able to show that motorbikers with a low annual riding practice tended to have a higher rate of accidents not involving other road users.

Effects of gender have only been reported by Taylor and Lockwood (1990, 13) and Taylor and Maycock (1990, 12). They found that young men were much more frequently involved in accidents than young women. Vice versa, the involvement in accidents of women who were over the age of 20 was somewhat higher than the rates found for men of the same age.

Type and extent of risk exposure

It is common practice to use the distance travelled by unit of time as a measure of risk exposure in traffic. Koch and Hagstotz (1990, 3), Schulz (1990 a,b, 8,9), Schulz and Hagstotz (1990, 10), Taylor and Maycock (1990, 12), and Taylor and Lockwood (1990, 13) have been able to demonstrate clearly that the accident rate increases with as a function of the extent of risk exposure in riders with intermediate to high annual mileage. A markedly higher involvement in falls and accidents involving no other road users was only found in very low annual mileages, which represent a measure of a lack of driving experience. According to Taylor and Maycock (1990, 12) and Taylor and Lockwood (1990, 13), further factors of risk exposure are the location, time of year, and purpose of road use. For example, riding motorcycles in inner city traffic, riding mostly during the winter months, and using a motorcycle purely as a means of transport (as opposed to riding as a leisure-time-activity) lead to higher accident rates. The latter should mostly be determined by the fact that the use of a motorbike for occupational purposes is strongly linked to road use in open areas, whereas the motorbike is mostly used as a leisure time vehicle in rural districts.

The Impact of the Motorbike

Accident statistics [e.g., Kroj and Stöcker, 1986, (4)] confirm that higher motor capacity or performance leads to an increased involvement in accidents. This circumstance has frequently been discussed by traffic experts and has had a marked impact on driving licensing for motorbikers in Germany. The literature reveals an intensive discussion on this phenomenon. Broughton's (1988, 1) analysis of British accident rates, which considered the mileage on motorcycles of various capacity, showed that mileage function is a moderator variable in relation between accident involvement and cubic capacity. In a recent analysis of accident data in Canada, Mayhew and Simpson (1989, 6) were unable to find any influence of motor capacity on the frequency of collisions. Taylor and Maycock (1990, 12) and Taylor and Lockwood (1990, 13) showed that a large number of motorbiking accidents occurred in open areas, and that high capacity motorbikes had a lower accident rate in rural areas than low capacity motorbikes. The German studies from Schulz (1990 a,b, 8,9), Schulz and Hagstotz (1990, 10) also do not support the hypothesis that high motor performance leads to an increase of accidents if the mileage was also taken into account. It is more the case that these studies show certain parallels to the results from Broughton (1988, 1), who indicated that intermediate motorperformance determined higher accident rates. As shown above, clear effects of the person and the extent of risk exposure can be determined in previous studies but no effects of the performance of the motorbike. A broader empirical basis for data is provided by the studies from Taylor and Lockwood (1990, 13) in Great Britain. Previous studies carried out in Germany on involvement of motorbikes in traffic accidents tended to be included as a side issue in other studies. For this reason the University of Bielefeld and the Institute for Motorcycle Safety prepared and carried out a separate survey that included all important aspects of accidents in autumn 1990. The findings of the survey will be presented below.

Questionnaire Survey of Accident Data

A Questionnaire

Data of accidents were collected by adopting and expanding parts of a previous survey of motorbikers that dealt with persons and involvement in accidents. Data were collected on gender, acquisition of various stages of a motorbike license (class 1b, 1a, 1), and information on the acquisition of an automobile driving license. The reports on motorbikes referred to the type, performance, and engine size of the motorbike. Reports on biking practice were assessed not only with the length of regular use of a motorbike with class I or class la driving licenses, but also the mileage driven per year over this period. Subjects were also asked the major purpose for using their motorbike and whether they also regularly drove an automobile. When yes, they were also asked to report their annual mileage with the automobile. Subjects had also to report their annual riding period, and whether they had previous driving experience on a low performance motorcycle (e.g., mopeds) before switching to a motorbike. This data collection was followed by the second part of the survey. This assessed the number of spills during the years of regular driving with the motorbike as well as the number of accidents during this period. If accidents were reported, the subjects had to answer more specific questions concerning those involved in the accidents, the amount of material and personal damage, and the causes of the accident.

Survey Procedure

The survey was carried out at three motorbike exhibitions. These were the IFMA 1990 held at Cologne in September, the Motorshow 1990 held at Essen in December, and a motorbike exhibition in the Bielefeld region in March 1991. Subjects were persons who had a motorbike driving license, and had regularly driven a motorbike in 1990. The survey was carried out with questionnaires. A total of 1 100 persons was surveyed. After the study, the questionnaire results were processed with a computer. As the data for 1990 were not based on the same periods because of the different survey dates, the analysis as restricted to those persons who had provided information on motorbiking for the entire year of 1989. After this and the removal of missing data, the final sample was reduced to 800 subjects.

Results

In the total of 800 subjects, 89.2% were male and 10.8% were female. Their average age was 27.7 years. 47.8% reported that they mainly used their motorbike for leisure time purposes. The rest of the subjects used their motorbikes half for leisure time and half for work. On average, the subjects had regularly driven motorbikes for six years. 37.5% had previously used a light machine. In 1989, the subjects had driven their motorbikes for an average of 8.5 months. They had driven an average distance of 11 100 km. The average cubic capacity of motorbikes they used was 63.2 PS.

The dependence of accident data on the person and motor performance variables was analyzed with a poisson regression analysis (see Maddala, 1983, 5). The basic equation $A = k T^a M^b \exp (C_i F_i)$ was used. In this equation T represents the length of time in the year the motorbike was driven, and M the annual mileage measured in units of 1 000 km. The variables F_i are additional independent variables. This took into account the youth of the driver. This variable was defined so that it took the value 1.0 at the age of 18, the value of 0.666 at the age of 19, the value 0.333 at the age of 20, and the value 0 for persons of 21 and older. The linear decline in these variables between 18 and 21 was preset. It agrees with the reduction in accidents given in the official accident statistics of the Federal Republic of Germany for motorbikers on the age of 18 to 21. Further variables that were applied were the number of years of regular biking, the number of years of regular automobile driving, previous experience on a small machine, annual mileage with an automobile, the capacity of the motorbike driven, gender, and whether motorbiking was predominantly a leisure-time-activity.

The dependent variables number of light falls in 1989, unaccompanied accidents in 1989, and accidents involving other road users in 1989, a stepwise regression procedure (using the stepwise addition of further, still explanatory independent variables) was followed by a separate estimation and testing of the coefficients of the above mentioned model. The 5% level of significance was applied to the coefficient tests.

The results of the coefficient estimations and the testing of the coefficients in the poisson regression model are presented in Table 1. The rows in this table present annual riding period, annual mileage, and the three additional variables youth, regular experience in motorbiking, and previous experience on a light machine. Only for these variables did we find a significant regression weight for at least one of the dependent variables. All other variables, namely annual mileage with an automobile, motor performance of the motorbike in PS, gender, and use of the motorbike showed no significant effects in any of the dependent variables observed.

Table 1. Results of Poisson Regression Analysis

	Dependent variable		
	spills	accidents not involving others	accidents involving others
riding period T (months) a	1.00	n.s.	n.s
annual mileage of riding (1000 km) b	n.s.	0,769	0.58
youth-variable C_1	2.14	n.s.	1.69
years of regular motorcycle experience C_2	-0.094	-0.14	n.sc
prior experience on low-capacity motorcycles C_3	0.433	-1.12	n.s.
constant k	0.0344	0.0135	0.0146
multiple regression coefficient	0.332	0.11	0.14

For all three dependent variables, the variables introduced with their weights in Table 1 showed various effects differing from 0. The corresponding multiple correlation coefficients [Maddala, 1983, (5)] are given in the bottom row of the table. The number of light falls did not depend on annual mileage but on the number of months driven per year. Number of falls increased with youth, decreased with the number of years of regular motorbiking, and was higher for persons with previous experience on a light machine.

The number of unaccompanied accidents increased with the mileage per year and sank with the number of years of regular motorbiking experience. Previous experience on a light machine also reduced the number of unaccompanied accidents.

The number of accidents involving other road users increased with yearly mileage, and additionally increased with youth.

The average number of falls and accidents predicted by the model are summarized graphically in Figures 1, 2, and 3. Figure 1 presents the mean number of light falls as a function of the number of months driven per year. Examples are given here of the model predictions for a motorbiker aged between 18 and 23. Previous experience and the number of years of regular driving practice were additionally varied. The figure shows a markedly higher mean number of falls for 18-year-olds, whereby the rate for bikers with previous experience on light machines was even markedly higher. For the 23 old road bikers, the fall rates are on a much lower level. They do not greatly differ from one another.

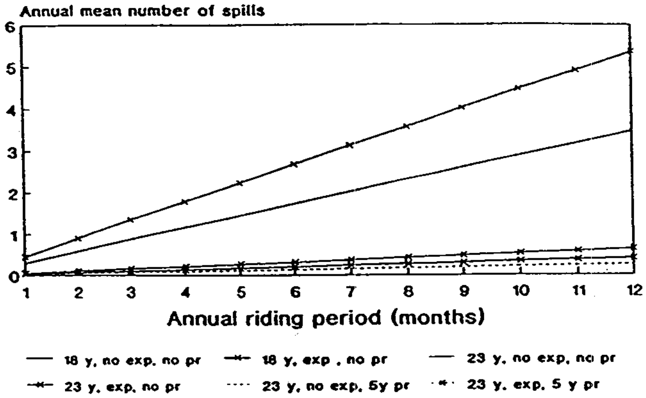


Figure 1. Spills

Figure 2 presents the dependence of the mean number of unaccompanied accidents on annual mileage, the presence of previous experience with a light machine, and the number of years of regular biking practice (0 to 5 years). The mean number of accidents increased with increasing annual mileage. It was higher for persons without previous experience with light machines, and those without driving practice. For persons without previous experience on light machines but with five years driving practice, the accident curve showed the second highest course, for persons with previous experience on a light machine and no biking practice, it was the second lowest. And for persons with five years driving experience and previous experience on a light machine it was the lowest.

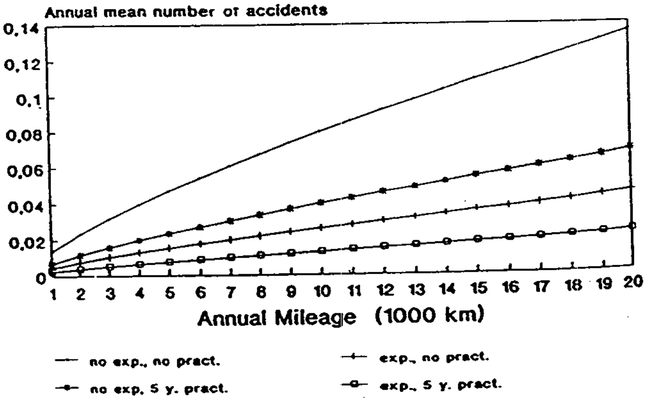


Figure 2. Accidents Not Involving Others

Figure 3 presents the dependence of the mean number of accidents involving other road users as a function of annual mileage. As here, only youth showed an additional effect, the effect of youth was completely varied from 18 years (1.0) across 19 years (0.66), and 20 years (0.33) down to 0 by the over twenties. The average number of accidents increased with annual mileage. It took the highest course for 18- year-olds and then dropped for 19- and 20-year-olds until at least the level of the over twenties. For this group of subjects, the accidents curve was relatively flat.

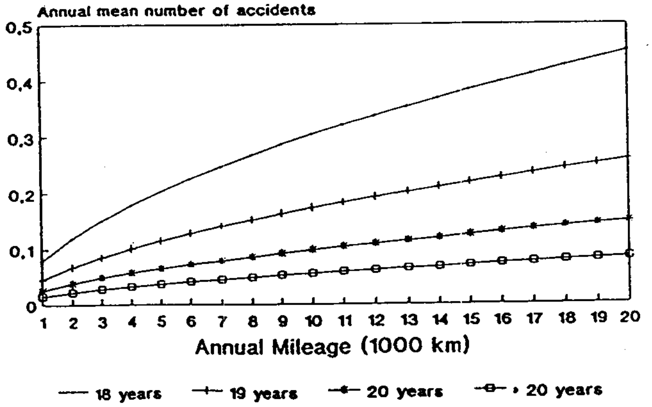


Figure 3. Accidents Involving Others

Discussion

The present questionnaire study represents the most comprehensive and detailed study to be carried out in Germany up to now that has used survey methods to address the accident involvement of motorbikers. In this study, the relevant variables were assessed with the comparable thoroughness to the study of Taylor and Maycock (1990, 12). None the less, the subjects belonged to a circle of interested, active motorbikers who could be found at motorbike exhibitions. Mean age and gender should be about the same as that in a representative sample of motorbikers. The same applies to the average mileage per year and the number of years of regular biking practice. However, the performance of the motorbikes was slightly higher than that in representative motorbike samples. The results of the analysis of the dependence of the single types of accident on the independent variables show that a separate consideration of the single types of accidents was appropriate. It is shown that it is not just the size of the single variables that has a varying effect on the dependent variables, but that other predictors are effective even by different kinds of accident. For example, it is notable that the number of falls does not depend on annual mileage, but on the number of months driven per year. On the one hand, the number of falls depends on whether the motorbike is driven across country or on streets. On the other hand, it depends on seasonable circumstances. In autumn and winter,light falls are more frequent than in summer. Such influences are recorded by the number of months driven per year. In the analysis of different influences on the involvement of motorbikers in accidents that are linked to age, the risks of youth are separated from the risks of lack of driving experience. This differentiation was introduced into the analysis by the youth variable and a separate measurement of driving experience in the form of the number of years of regular motorbiking practice. These two variables showed a different impact on the various types of accident. In light falls, both variables had a significant impact in the anticipated direction. In light, unaccompanied accidents, only riding experience in the form of regular driving practice had an effect, while in accidents involving other road users, only the youth variable had a significant effect.

A further variable of riding experience, which is frequently discussed in the literature, is previous experience on light machines. This was assessed for the first time in the present study, and proved to be an important predictor. In unaccompanied accidents, previous experience with light machines leads to a marked decrease in the accident rate. In light falls, in contrast, such previous experience leads to an increase. The reason for this could be that particular young motorbike learners with previous experience show a trend toward a somewhat more risky driving behavior of road and in unfavorable weather conditions. The anticipated dependence of unaccompanied accidents as well as accidents involving other road users on the annual mileage once more demonstrates the dependence of accident rates on the level of risk exposure.

In contrast to the British studies from Taylor and Maycock (1990, 12) and Taylor and Lockwood (1990, 13), we are unable to find any dependence of the three accident variables on gender, what the use of the motorbike, and the amount of driving experience with automobiles. The data analysis did not supply even the slightest hint that these independent variables influence the dependent variables. As in many previous studies, which are also discussed in detail above, the analysis of the three types of accidents once more reveals that motor performance has no influence on the frequencies of the three types of accident when risk exposure in the form of distance travelled per unit of time is also taken into account. In all, the findings of this study agree with the results on the variables effecting motorbike accidents in the western part of Germany that have previously been reported by Koch and Hagstotz (1990, 3), Schulz (1990, 8; (1990, 10). By differentiating various types of accidents and differentiating important variables such as youth and regular driving practice as well as including previous experiences, it was possible to greatly refine and specify these findings. Even compared with the much broader basis of the British studies from Taylor and Lockwood, we are able to obtain important new findings. On the other hand, the low sample size is certainly also responsible for the fact that we are unable to demonstrate the influence of less important factors, unlike the British studies.

References

1) Broughton, J.: The relation between motorcycle size and accident risk. - Crowthorne, 1988. - (TRRL Research Report; 169).
2) Koch, H.: Evaluation of the effectiveness of a graduated driving license model for beginner motorcycle riders In: The Human Element: 1990 International Motorcycle Safety Conference, Grosvenor Resort, Orlando, Oct. 31 - Nov. 3, 1990; proceedings / Motorcycle Safety Foundation. - Irvine, 1990. - S. 2.27-2.42.
3) Koch, H.; Hagstotz, W.: Einflußfaktoren auf die Unfälle von Motorradfahrern In: Motorradfahren: Faszination und Restriktion / H. Koch (Hrsg.). Institut für Zweiradsicherheit. - Bochum, 1990. - S. 139-164. - (Forschungshefte Zweiradsicherheit; 6).
4) Kroj, G.; Stöcker, U.: Statistische Analyse der Unfall- und Bestandsentwicklung motorisierter Zweiräder In: Der Motorradunfall: Beschreibung, Analyse, Prävention / H. Koch (Hrsg.). Institut für Zweiradsicherheit. - Bremerhaven, 1986. - S. 1-46. - (Forschungshefte Zweiradsicherheit; 3).
5) Maddala, G.S.: Limited-dependent and qualitative variables in econometrics. - Cambridge, 1983.
6) Mayhew, D.R.; Simpson, H.M.: Motorcycle Engine Size and Traffic Safety. - Ottawa, Ontario: Traffic Injury Research Foundation of Canada, 1989.
7) McKnight, A.; Robinson, A.R.: The involvement of age and experience in motorcycle accidents In: The Human Element: 1990 International Motorcycle Safety Conference, Grosvenor Resort, Orlando, Oct. 31 - Nov. 3, 1990; proceedings /Motorcycle Safety Foundation. - Irvine, 1990. - S. 1.1-1.13.
8) Schulz, U: Zur Unfallverwicklung von Motorradfahranfängern In: Motorradfahren: Faszination und Restriktion / H. Koch (Hrsg.). Institut für Zweiradsicherheit. - Bochum, 1990. - S. 165-186. - (Forschungshefte Zweiradsicherheit; 6).
9) Schulz, U.: Factors affecting different kinds of motorcycle accidents In: The Human Element: 1990 International Motorcycle Safety Conference, Grosvenor Resort, Orlando, Oct. 31 - Nov. 3, 1990; proceedings /Motorcycle Safety Foundation. - Irvine, 1990. - S. 1.14-1.33.
10) Schulz, U.; Hagstotz, W.: Zur Unfallverwicklung von Motorradfahranfängern: Analyse der Unfalldaten der Studie Motorradfahren in Deutschland: Basisstudie 1988 In: Motorradfahren: Faszination und Restriktion / H. Koch (Hrsg.). Institut für Zweiradsicherheit. - Bochum, 1990. - S. 187-208. - (Forschungshefte Zweiradsicherheit: 6).
11) Simard, R: Motorcycle accidents in the province of Quebec during the 1980s In: The Human Element: 1990 International Motorcycle Safety Conference, Grosvenor Resort, Orlando, Oct. 31 - Nov. 3, 1990;

proceedings /Motorcycle Safety Foundation. - Irvine, 1990. - S. 1.34-1.44.

12) Taylor, M.; Maycock, G.: Factors affecting the accident liability of British motorcyclists In: The Human Element: 1990 International Motorcycle Safety Conference, Grosvenor Resort, Orlando, Oct. 31 - Nov. 3, 1990; proceedings /Motorcycle Safety Foundation. - Irvine, 1990. - S. 1.45-1.70.

13) Taylor, M.C.; Lockwood, C.R.: Factors affecting the accident liability of motorcyclists: a multivariate analysis of survey data. - Crowthorne, 1990. - (TRRL Research Report; 270).

S3-O-02

Computer Simulation of Motorcycle Airbag Systems

J.J. Nieboer, A.P. Goudswaard,
J. Wismans, E.G. Janssen,
A.C.M. Versmissen
TNO Crash-Safety Research Centre

Abstract

Nowadays more and more effort is being spent on the research and development of motorcycle safety improvements. Among these improvements are motorcycle airbag systems. Although a few airbag-equipped motorcycles have been built, the technology is still in a research stage. Along with full scale testing, computer simulations can be a successful tool for studying and optimizing these systems. This paper gives a state of the art impression on research and development activities in the field of motorcycle airbag systems. Further the combined multibody-finite element approach offered by the Crash Victim Simulation program MADYMO is applied for modelling the motorcycle-airbag-rider interaction. Both a model of a motorcycle sled mock-up and a complete model of an airbag-equipped motorcycle were developed. The first model is the mathematical counterpart of an actual sled test, representing a 90° frontal impact between a motorcycle and a passenger car side structure, involving a pre-inflated airbag. Based on the correlation found between sled test and simulation results, it is expected that the full airbag-equipped motorcycle model can be used for performance evaluation of different motorcycle airbag restraint systems under different impact conditions.

Introduction

Motorcycles represent between 10 and 25% of motorized road vehicles in most European countries [6]. Motorcycling is a minor mode of travelling, accounting for less than 10% of all motorized kilometres travelled. It is a very dangerous mode, however. Despite the very high risk and the sizeable contribution to casualties, there seems to be relatively little activity in most countries to make motorcycles safer. What activities there are seem to focus on rider education.

Over the last 25 years, two basic strategies for protecting the motorcyclist in an accident have been developed. The first has been to put the protection system on the rider himself. The best example of this is the safety helmet. The second strategy has been to put the protection system on the motorcycle rather than on the rider, e.g. leg protectors and airbag systems. The latter strategy was plainly an adaptation of the approach that has been so successful in reducing injuries to automobile occupants.

The use of airbags to produce a tolerable deceleration in frontal crash conditions has been appreciated for some time. Airbags can be stored in a relatively small volume, they do not obstruct the rider during normal riding and are hence a possible acceptable restraint method for motorcyclists. Although a few airbag-equipped motorcycles have been built, the technology is still in a research stage.

The objective of this preliminary study is firstly to review current motorcycle airbag technology and secondly to develop and validate a motorcycle-airbag-rider mathematical model which can be applied for performance evaluation of different rider airbag restraint systems. The Crash Victim Simulation code MADYMO was applied for the modelling activities [5]. MADYMO is a well accepted multibody program for crash analysis; only recently this program was extended with a 3D finite element airbag model [4,8]. After an in-house test program and its use in some automotive consultancy studies [9], the MADYMO 3D FEM airbag model was judged to be suitable for airbag restraint simulation in a motorcycle crash environment.

Computer simulations of airbag-equipped motorcycles are not completely new [2]. Recently a study was conducted with the ATB model where 750 simulations were carried out [7]. The airbag in the ATB model, however, is a so-called empirical airbag model. In empirical airbag models, rather simple approximations for the contact interaction between human body and airbag are employed [1,4]. The airbag is represented by either a non-deformable elliptical shape or a deformable shape based on line segments and circular arcs. The FEM airbag used in our study deforms realistically when penetrated and generates bag inertia forces. Moreover, bag material properties can be directly incorporated.

Three steps can be distinguished in the work carried out, namely a literature review, crash tests and computer simulations. The literature review concentrated on the present accident situation, current airbag technology in general and various motorcycle airbag studies that have been conducted in the past. On the basis of the literature review, a sled test set-up was chosen representing a 90° frontal impact between motorcycle and passenger car side structure (see Figure 1). Pre-inflated airbags were mounted at instrument panel level. The simulation activities included the preparation of a mathematical model representing the sled test set-up and validation of this model on the basis of test results. After having validated the motorcycle-airbag-rider interaction, this sled model was extended to a full motorcycle model. A discussion on the major findings of this research program concludes this paper.

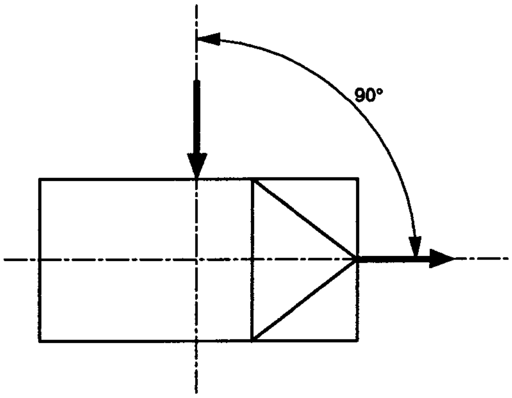


Figure 1. Frontal Impact Between Motorcycle and Passenger Car Under an Angle of 90o

Literature Review

Motorcycle Accidents

The number of people killed per 10.000 registered vehicles is higher for motorcyclists than for car occupants in all countries. For example in the Netherlands in 1988, the number of people killed per 10.000 vehicles was 3.7 times greater compared to car occupants [6]. In that year the death rate per 100 million km travelled was even 11 times greater in the Netherlands [3]. The complex nature of motorcycle accidents requires a full understanding of motion sequences and accident characteristics in the search for technological measures aiming at an increase in safety. One of the options to protect the motorcyclist during a frontal collision is the use of an airbag system.

The ways in which motorized two-wheelers are involved in accidents can be divided into four categories [6]:

- side collisions (the motorcycle is hit), 30%
- frontal collisions (the motorcycle hits another vehicle), 60%
- grazing collisions, 1.5%
- single accidents, 9-10%

In a frontal collision the motorcycle hits the opposing vehicle within ± 15° of the head on position; in 30% of the cases the motorcycle hits the front, 62% the side and 8% the rear of another car. Thus it can be concluded that the most frequent motorcycle accident is the frontal collision of a motorcycle against the side of a passenger car. In the case of frontal impacts of the motorcycle, no more than 13.5% of all accidents occur when the speed of the motorcycle is above 60 km/h. The main speeds range from 16 to 60 km/h; the essential speeds for passenger cars involved are even lower, namely between 16 and 45 km/h [6].

In the majority of accidents, the rider is still in a normal seated position just prior to the collision, so that airbag systems on the motorcycle could be effective during the crash phase. Injuries resulting from the frontal collision of a motorcycle against the side of a passenger car mostly occur to the lower extremities and the head. The risk of being injured can only be reduced if the direct impact of the rider against the other vehicle is avoided, in particular the direct impact of the head against the opposing vehicle e.g. by using an airbag. In general it was found that apart from safety devices, like leg protectors and airbags, the motorcycle design itself (e.g. fuel tank geometry and wheel construction) also affects the injuries occurring [6].

Airbags and Motorcycles

The aim of an airbag on a motorcycle during a frontal collision is to avoid direct contact of the rider with the opposing vehicle, or at least reduce his velocity before he hits the vehicle. The more conventional approach to the desired action of the airbag is to produce a controlled deceleration of the rider, as used in motorcar airbag systems. An alternative view is to promote ejection of the rider. Research has concentrated on these two philosophies (rider restraint versus rider trajectory). The HUK association discovered that, with a non-airbag equipped motorcycle, the severity of injuries sustained for a frontal accident in the case of a "fly-over" was less than the injury severity of the motorcyclist who impacted directly with the accident opponent in every speed range. This "fly-over" can be promoted by cast-wheels (intensification pitch motion), a touring handlebar and a fuel tank rising angle of about 45° [6]. However, for an airbag-equipped motorcycle, the philosophy that an ejected rider sustains less injury compared to a rider who is not ejected is not clear. Up to now no research has been published on this configuration. A combination of the rider restraint and rider trajectory approach could be considered as well; restraining if the collision speed is low and ejecting if the collision speed is high.

Although the benefits of airbag systems have been recognized by several authors and a few airbag-equipped motorcycles have been built, experimental and analytical work has been limited. Motorcycle impact test work has shown that an automotive airbag can reduce the rider kinetic energy by between 30 to 90% of his pre-impact energy, but the result very much depends on the detailed configuration of the airbag, motorcycle and impacted structure [6]. This variability demonstrates the need for a mathematical model to examine a wide range of airbag sizes, shapes, initial pressures and mounting locations so that optimal arrangements can be identified.

An additional problem to be solved concerns the sensing system. Much knowledge has already been acquired by the car-airbag industry. Research shows that for a motorcycle airbag system, the maximum delay for the inflator to be triggered should be set at 20 ms. Inflation has to start before the rider moves significantly forward relative to the bike. Thereafter 20 to 45 ms is available to inflate the bag before the rider hits it. A constant overpressure of 500-600 mbar should be sufficient to fully restrain the rider, provided the airbag can react against a substantial structure such as the fuel tank, the instrument panel or the rear of the windscreen of the motorcycle.

Test Description

Two sled tests were performed at the facility of the TNO Crash-Safety Research Centre representing a 90° impact between motorcycle and passenger car side structure. For this purpose both parts of the motorcycle and the car side structure were rigidly mounted on a sled. A 90° impact condition was chosen on the basis of the literature review findings, the sled test was preferred in order to create a relatively simple validation environment. To prevent contact between rider and car structure a cone-shaped pre-inflated airbag was mounted on the front of the motorcycle at instrument panel level. Figure 2 shows the test set-up. The impact velocities were 40 and 45 km/h, whereas the initial bag overpressures amounted to 50 and 25 mbar respectively. These pressures could be applied while the airbags were sealed by means of a plastic bag inside. The pressure inside the airbag was measured during a test by means of a pressure transducer, which was placed inside the bag near the bag attachment. The motorcycle windscreen was positioned in the car to act as a reaction surface for the airbag. The rider was represented by a 50th percentile Hybrid II dummy with a pedestrian pelvis, legs and neck bracket. The dummy was wearing a helmet. Forward movement of the dummy's lower extremities was limited by knee pads, placed just outside the car structure (see Figure 2). The sled was decelerated by means of crumple tubes having a configuration such that the longitudinal crash pulse obtained was representative of a 90° frontal impact between a motorcycle and a passenger car.

Model Description

The actual geometry of the sled mock-up was used in the MADYMO 3D model. Both fuel tank and buddy seat were modelled with two higher order ellipsoids. For the rider representation the MADYMO 50th percentile Hybrid II dummy database was modified. Different leg and pelvis properties were included, whereas the neck orientation relative to the upper torso was changed. A helmet, with a mass of 1.38 kg, was also included in this database. The helmet was rigidly connected to the head element. The cone-shaped airbag was modelled with the FEM module in MADYMO 3D on the basis of its design geometry, 2832 membrane elements were used for this purpose. Linear elastic isotropic material behaviour was specified for these elements, together with a Young's modulus of 6.E8 N/m^2. The airbag was inflated with air at room temperature during the first 10 ms of the simulation in order to accomplish an overpressure in accordance with the actual experiment. The bag volume amounted to 84 liters for an overpressure of 50 mbar. Figure 3 shows the mathematical model set-up. This figure shows that only the windscreen, foot rests and knee pads have been modelled as potential contact surfaces in addition to the motorcycle surfaces.

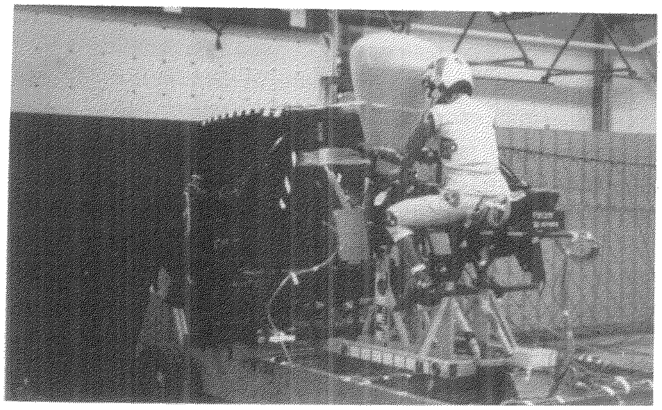


Figure 2. Sled Test Set-Up

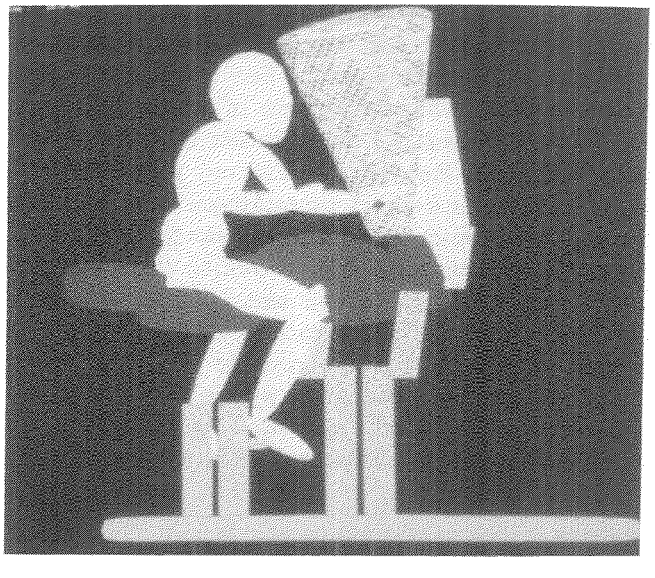


Figure 3. Sled Mathematical Model Set-Up

During the actual sled test, the motorcycle mock-up and sled have an initial velocity and are decelerated due to impact. This physical event is simulated in the MADYMO run by taking the sled stationary and by prescribing an acceleration field on the dummy. The prescribed acceleration fields in the forward and downward direction, for simulating the 40 km/h test, are shown in Figure 4. It can be learned from this figure that the vertical acceleration component is expected to play a significant role in the simulations, since the vertical peak acceleration approaches the horizontal peak value.

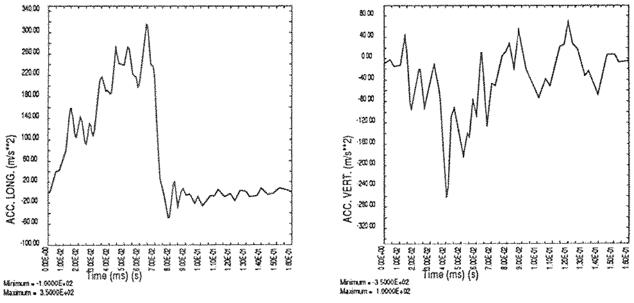


Figure 4. Longitudinal and Vertical Acceleration Components as Prescribed for Simulating the 40 km/h Test

Results

First of all, some details will be given about the sled test results. Thereafter the simulation results obtained will be compared with experimental results (a validation study). Since similar dummy kinematics were found during both sled tests, it was decided to concentrate on the 40 km/h test first for the validation effort.

Figure 5 shows approximately the maximum penetration in the cone-shaped airbag. This figure illustrates the typical dummy posture during impact. The pelvis is restrained by the fuel tank, while the helmet is restrained by the airbag. This results in extension of both neck and lumbar spine. Figure 6 shows a close-up of the tank deformations as found after the performance of the 40 km/h test. From the large fuel tank deformation it can be concluded that pelvis injuries are most likely to occur. Furthermore it is worth mentioning that the handlebar rotated forward during both tests and that both knee pads were not touched by the dummy in the 40 km/h test and only slightly touched in the 45 km/h test.

In Figure 7 a time sequence is presented of the rider motion and the interaction with the airbag resulting from a MADYMO simulation of the 40 km/h test (note that higher order ellipsoids are visualized as 2nd order ellipsoids in this figure). The dummy is positioned on the motorcycle by means of digitized marker positions at time zero. By comparing the simulated and experimental dummy kinematics, one can conclude that in the last part of the simulation both head and upper torso come down too far. The helmet slides through the airbag and the pelvis stays slightly too low. The possibility of forward handlebar rotation was not included in the model.

Figure 8 shows a comparison between measured and simulated acceleration signal components for the lower torso, upper torso and head. The lower torso components are directly influenced by the stiffness characteristic specified for the fuel tank. The latter acceleration components can be definitively improved by specifying a stiffness which describes the fuel tank collapse behaviour in more detail. Care should be taken with the interpretation of the upper torso accelerations, since the simulated orientation of the upper torso differs from the orientation observed during the actual sled test. The prediction for the head orientation is almost correct. The simulated head acceleration components show a fairly good correlation; the same holds for the simulated pressure inside the airbag (see Figure 9).

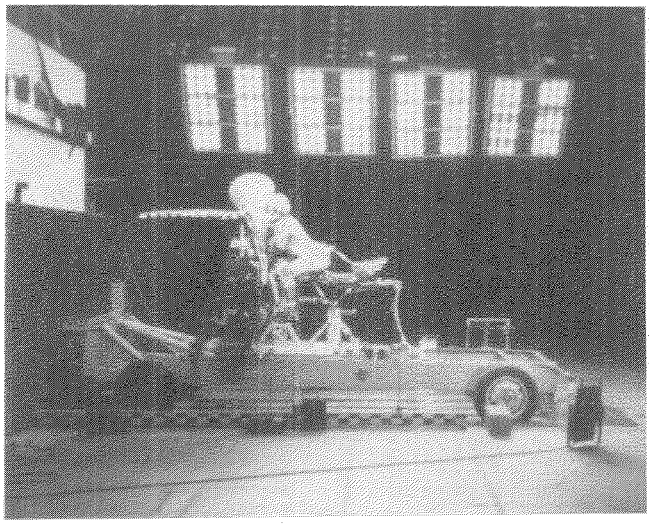


Figure 5. Dummy Posture During Impact

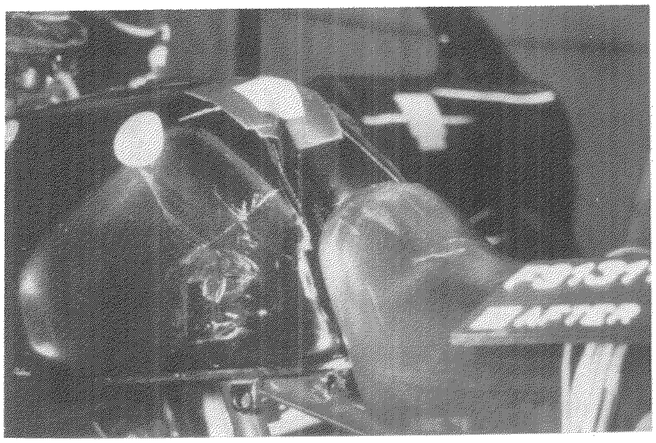


Figure 6. Fuel Tank Deformations Resulting From the 40 km/h Test

Model Extension

During the preliminary study, the sled model was extended to a full model of the motorcycle (touring type with a weight of 263 kg). Figure 10 shows the full motorcycle model set-up. This motorcycle model consists of two MADYMO systems with a total of six elements and features realistic wheel rotations, steering behaviour and suspension properties. This modelling approach allows the actual driving behaviour to be taken into account. The pitch motion of the motorcycle, for instance, can be simply represented. A simplified fairing

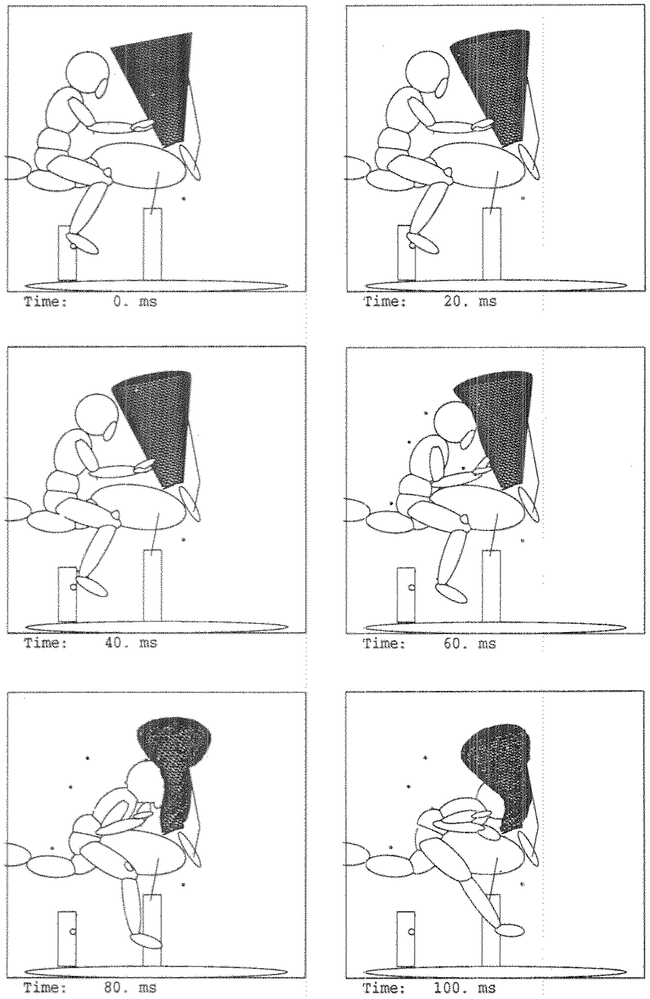


Figure 7. Simulated Kinematics During the 40 km/h Impact

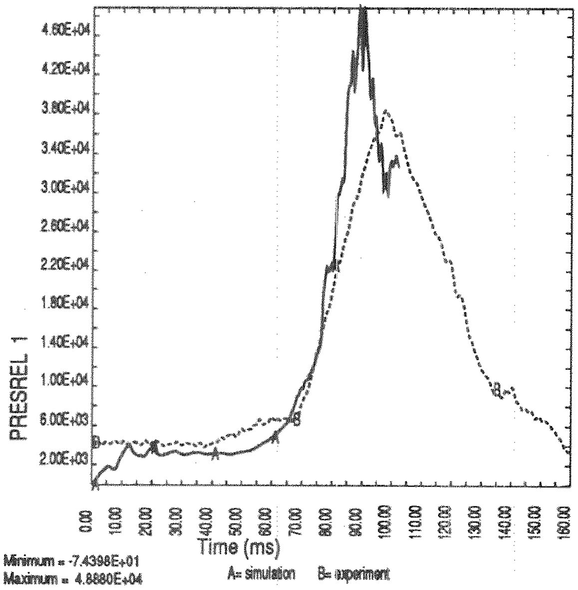


Figure 9. Comparison Between Measured and Simulated Pressure Inside he Airbag

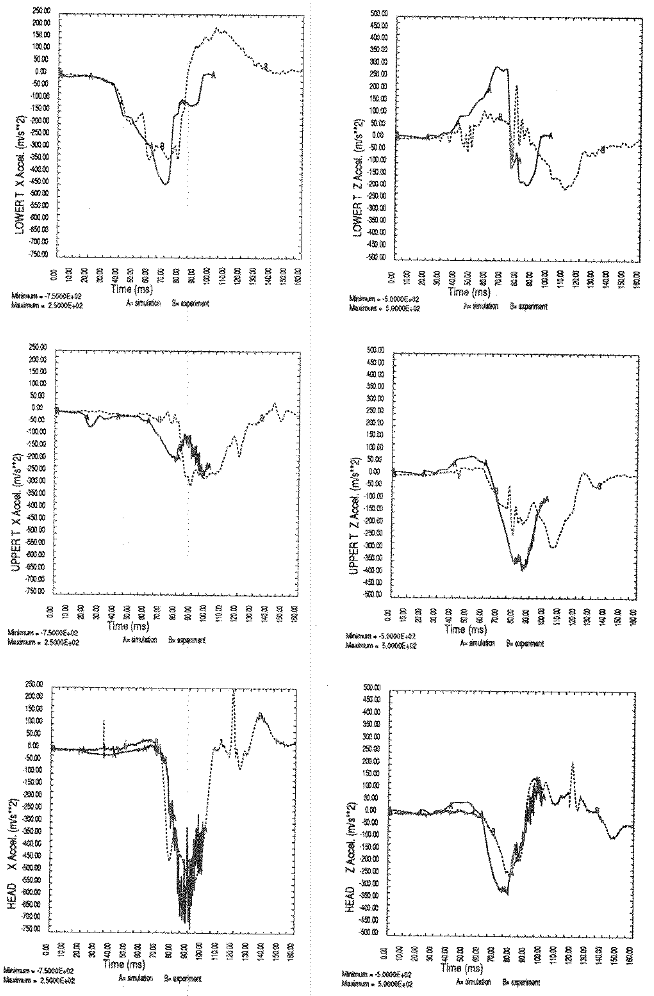


Figure 8. Comparison Between Measured and Simulated Acceleration Signals

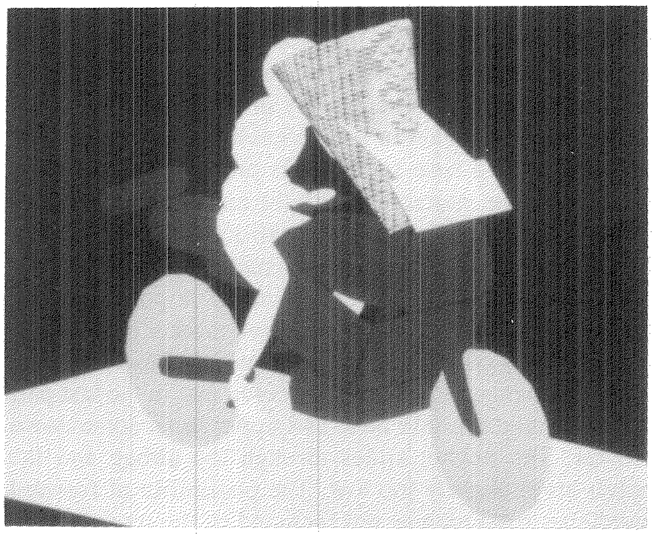


Figure 10. Full Motorcycle Mathematical Model Set-Up

is modelled by a number of planes. Moreover, front fork bending can be taken into account.

The rider seating position relative to the motorcycle is the same as applied in the sled model. The airbag shown in Figure 10 is not pressurized. To allow for realistic airbag behaviour, the bag should first be folded. The sensor feature in the MADYMO 3D FEM airbag model can then be used to initiate unfolding of the airbag when colliding into a vehicle structure.

Discussion and Conclusions

A literature review on the present accident situation, current airbag technology in general and various motorcycle airbag system studies was carried out. Both sled and full motorcycle models were also developed. In this paper an initial validation effort is described for the motorcycle-airbag-rider interaction, applying the sled model. Until now the potentials of the full motorcycle model for performance evaluation of different motorcycle airbag systems, under different impact conditions, have not been explored. These different impact conditions should have similar motorcycle-airbag-rider behaviour, e.g. different impact speed or bag volume compared to the validated case.

Based on the experience acquired in the research program we can conclude that there is a possible risk of spinal injuries with the airbag configuration tested. In reality the motorcycle will pitch to a greater or lesser extent when hitting the side structure of a passenger car, but this phenomenon was not taken into account with our sled test set-up. Pitch motion will probably influence the spinal injury risk, due to the more "rider trajectory" behaviour of the airbag. Moreover, it was found that the simulated pelvis movement is directly affected by the stiffness properties and the geometry of the fuel tank and that airbag material friction seems to play an important role in the experiments and consequently in the simulations. The deviations found between model and experimental results can be explained to a large extent by the impossibility of taking friction into account with the current version of the MADYMO 3D FEM airbag model. Airbag material friction is planned to be included in the next release of MADYMO.

In general it can be concluded that the simulation results obtained so far with the sled model are very promising. The selected multibody-finite element approach is judged to be very suitable for this type of motorcycle airbag analysis. It is expected that computer simulations will play an important role in the future in studying measures to improve or even optimize the protection of the rider in motorcycle accidents.

Acknowledgements

The authors wish to acknowledge the motorcycle division of BMW AG for generously allowing us to borrow their motorcycle sled test mock-up.

References

1. J.J. Nieboer, J. Wismans and E. Fraterman - Status of the MADYMO 2D Airbag Model; SAE paper 881729, 32nd Stapp Car Crash Conference, Atlanta, 1988.
2. J. Happian-Smith and B.P. Chinn - Simulation of Airbag Restraint Systems in Forward Impacts of Motorcycles; SAE paper 900752, International Congress and Exposition, Detroit, 1990.
3. Statistiek van de verkeersongevallen op de openbare weg 1990; Centraal bureau voor de statistiek, Staatsuitgeverij, Den Haag, 1990.
4. J.J. Nieboer, J. Wismans and P.J.A. de Coo - Airbag Modelling Techniques; SAE paper 902322, 34th Stapp Car Crash Conference, Orlando, 1990.
5. H.A. Lupker, P.J.A. de Coo, J.J. Nieboer and J. Wismans - Advances in MADYMO Crash Simulations; SAE paper 910879, International Congress and Exposition, Detroit, 1991.
6. A.P. Goudswaard - Airbags and Motorcycles, A literature review; TNO-report 751180002/1, TNO Road-Vehicles Research Institute, Delft, 1991.
7. N.M. Rogers - A Preliminary Study into the feasibility of Motorcycle Airbags; International Motorcycle Conference: Safety-Environment-Future, Bochum, 1991.
8. H.A. Lupker, H.B. Helleman, E. Fraterman and J. Wismans - The MADYMO Finite Element Airbag Model; paper 91-S9-O-23, 13th International Technical Conference on Experimental Safety Vehicles, Paris, 1991.
9. W.E.M. Bruijs, P.J.A. de Coo, R. Ashmore and A. Giles - Simulations with the MADYMO FEM Airbag Module; paper to be presented at the International Congress and Exposition, Detroit, 1992.

S3-O-03

The Effect of Dummy Leg Design on Motorcycle Crash Test Results

M.A. Macaulay
Brunel University
H. Karimi, B.P. Chinn
Transport and Road Research Laboratory
Department of Transport

Abstract

There have been several attempts over a period of 20 years to simulate bone fracture by incorporating breakable components in crash test dummies. None has come into regular use. This report considers attempts to develop dummy motorcyclists with breakable legs.

Material characteristics are discussed and the variation in the scatter fracture load of different materials is compared using the Weibull modulus. The materials used in the different dummy legs have been calibrated statically and uni-axially, whereas in crash tests multi-axial dynamic loads are sustained. The Independent Action criterion is used to show that compressive and torsion loads have only a small effect on bending and that differences in results from different laboratories is the result of scatter in the material characteristics.

The effect that leg fracture has on dummy trajectory is described using previously published experimental pedestrian impacts, motorcycle crash tests and pedestrian and car occupant computer simulation studies. Head trajectory is shown to be largely unaffected by leg fracture.

Introduction

Over the past twenty years there have been several attempts to simulate bone fracture by incorporating breakable components in crash test dummies (1) (2). None of these has come into regular use. At present there are interesting attempts to develop dummy motorcyclists with breakable legs (3) (4) (5), and it is important to assess what advantages these might have. There is now sufficient information published on the use of breakable legs for an assessment to be made. This is done in two main parts—the usefulness of those legs in assessing the probability of motorcyclist leg injury and the effect of leg fracture on the rider's trajectory. There is also relevant published information on the behaviour, in tests and computer simulations, of pedestrians struck by cars and unrestrained car occupants striking knee bolsters. Such information is included in the assessment.

Brittle Fracture

Static Uni-Axial

The legs considered all use the fracture of brittle plastic components to simulate the fracture of leg bones. Three different designs of breakable leg have been used. The first was produced by JARI and incorporated solid bakelite cylinders in modified Hybrid II dummy legs (3). The second was produced by Dynamics Inc and incorporated Kevlar reinforced plastic tubes in modified Hybrid III dummy legs (4). The third was produced by TRRL and incorporated solid bakelite cylinders in modified Hybrid II dummy legs (5). This latter was intended as a reproduction of the JARI leg.

An inherent characteristic of brittle materials is that the scatter in fracture loads is high. Because of this the mean fracture load by itself is of little use and it is necessary to specify the scatter as well. This is done by fitting a mathematical distribution to a sufficiently large number of test results. The two distributions must commonly used are the normal distribution, and the Weibull distribution, both of which usually fit the test results fairly well. The normal distribution is simpler, but although the Weibull distribution is more complicated it is more easily related to theoretical and analytical studies of brittle fracture and is widely used. In its simplest form the Weibull distribution uses two parameters, one of which specifies the amplitudes of the fracture loads and the other of which specifies the scatter (this is specified by the Weibull Modulus, which increases as the scatter decreases). Published information on the strength of brittle materials concentrates on the lower end of the statistical distribution because a designer using brittle materials for load carrying components aims for a low probability of failure and is interested in the lower fracture loads rather than the mean value. Usually the distributions are approximately symmetrical, so that although the higher values of the fracture loads are not always given they can be deduced from the lower ones. In figure 1 the one percentile fracture load is plotted against the Weibull Modulus. The one percentile fracture load is roughly equivalent to the Class A Allowable used in aircraft design (6) and means that one test specimen in every hundred will fail at this load or less. Because the strength of brittle materials varies greatly one percentile fracture load has been normalised by dividing it by the mean fracture load. Results for a wide range of materials can then be plotted on one graph. The Weibull Modulus is for the two parameter Weibull distribution which is widely used in studying brittle fracture loads (7). Some typical materials are shown in fig 1 together with results for the TRRL breakable dummy leg components. It should be noted that in fig 1 the closer the result is to the normalised mean of one then the lower the scatter.

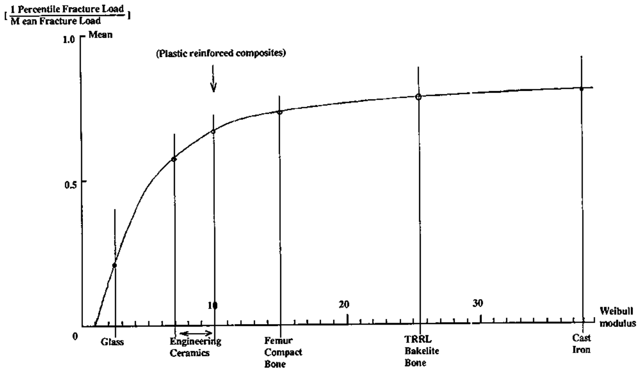


Figure 1. One Percentile Fracture Load vs Weibull Modulus (Static Uniaxail Tests)

It can be seen that the scatter in the fracture loads for glass is very high with one specimen in a hundred failing at about 20% of the mean load or less. Glass is not in regular use as a load carrying material but engineering ceramics are. There are wide variations in these and attempts are constantly being made to make them less brittle but roughly one specimen in a hundred is likely to break at about 60% of the mean fracture load or less.

An interesting point is that the scatter is high for high technology fibre reinforced plastics including Kevlar reinforced plastics in which, although the overall strength and fracture resistance have been increased, the variation in fracture loads has not been reduced [8] and the scatter is much the same as for engineering ceramics. The result shown for TRRL bakelite leg bones is based on a very small sample, but the relatively low scatter may well be genuine because the specimens were selected from a single batch after X Ray examination for flaws. When the one percentile fracture load is 60% of the mean fracture load 90% of specimens fracture within about ±25% of the mean fracture load. This is not very accurate for a measuring device but is probably tolerable if there are other outstanding advantages. It should be noted, though, that the results of fig 1 refer to testing to failure under very controlled conditions, and it is possible that the much less controllable conditions of crash testing may produce greater levels of variability, as the next section discusses.

Dynamic Multi-Axial

The results shown in fig 1 are for uni-axial static tests but the legs of the dummy motorcyclists in crash tests are subjected to multi-axial impact loads. To date fracturing legs for crash test dummies have to be calibrated statically using uniaxial loads so it is necessary to consider the correlation between the two types of loading. The relationship between static and impact loads in brittle materials is complex. In general the mean fracture load and the scatter both increase, leaving the one percentile fracture load largely unaltered; but there are wide variations in behaviour. For example, a fairly small increase in static stiffness can sometimes lead to a large decrease in impact strength [9]. The relationship between uni-axial and multi-axial loads is not yet fully understood.

With ductile materials it is possible, by making reasonable assumptions, to calculate theoretical interactions, amongst the torsion, tension, compression and bending stresses, which usually work fairly well in practice [10]. Brittle materials fail in a different way and there is much less interaction among the different stresses. Fracture is by the propagation of cracks and to a large extent each stress component propagates a different crack, so that they are working more or less independently. This leads to use of the Independent Action Criterion as a basis for semi-empirical relations [7]. In these the different principal stresses are assumed to act completely separately but empirical corrections can be made if necessary for observed variations in behaviour. To date there do not seem to have been any successful and generally accepted relationships which give better results than the Independent Action Criteria.

In a few cases breakable dummy legs have been strain gauged in full-scale motorcycle impact tests so that it is possible to compare dynamic fracture loads with static calibration loads.[11][12] Different measurements were made in the different tests so that there is not a single comprehensive body of results but the loading conditions are very similar throughout. Fracture was by bending and bending loads are available for all the tests. These are shown in figure 2. The Independent Action Criterion suggests that compression and torsion loads would have a relatively small effect on the bending fracture load. Bending stresses caused by two bending moments at right angles to each other are assumed to act independently and the values are plotted separately. There are only six tests in all but these cover two different dummies and three different research laboratories. At TRRL bakelite bones were used in an OPAT dummy. At FAA and JARI tubular fibre-reinforced plastic bones were used in an MATD dummy.

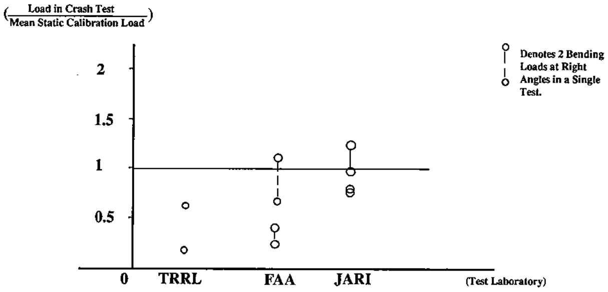


Figure 2. Fracture Loads in Crash Tests at Three Different Laboratories

It is not possible to draw statistical conclusions from so few tests, but there appear to be large differences between TRRL and JARI. The FAA results overlap both the TRRL and JARI results. This difference is probably caused by random variation but raises doubts about the reliability of breakable plastic bones as load measuring devices. High technology reinforced plastics need to be handled with extreme care. If they get wet or are accidentally dropped their fracture strength can be reduced drastically [12] and there is always the possibility that this may occur without being observed or reported. In static tests, the TRRL bones were of similar strength to the others, but about 20% stiffer which could be sufficient to lead to a 40% reduction in relative impact strength [9]. If these two factors were present they could explain most of the difference in results but this highlights the enormous problems of quality control in using brittle materials to measure loads if unambiguous results are to be obtained.

Comparison of Human and Dummy Leg-Bones

The long bones of the legs act mainly as struts and beams and the shafts of these bones are made of compact bone which is a complex, fibre-reinforced brittle material [13]. Towards the ends, where the bones swell outwards to give adequate bearing areas for the joints, they change to cancellous or trabecula bone, which is a honeycomb material enclosed in a shell of compact bone. The properties are very different from those of compact bone.

Loading conditions in a crash vary greatly and, as an example, we shall consider the effects of transverse loads on the tibia. If a simply supported beam is loaded statically by a single transverse point load, the amplitude to cause a constant bending moment varies as shown in figure 3 (14). In the middle half of the span the load remains fairly constant, but in the outer quarters the load increases rapidly to reach infinity as the load coincides with the end support. This suggests that when the leg is struck transversely fracture of the femur or tibia will be by bending of the compact bone if the contact point is in the middle half of the length but by crushing of the honeycomb bone if the contact point is in either of the outer quarters. This is borne out by results on cadaver tibias reported by Kramer(15) and shown in figure 4.

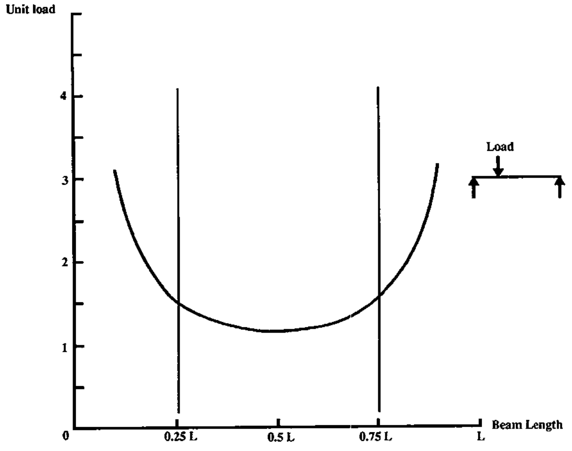


Figure 3. Variation in Static Load to Produce a Constant Bending Moment in a Simply Supported Beam

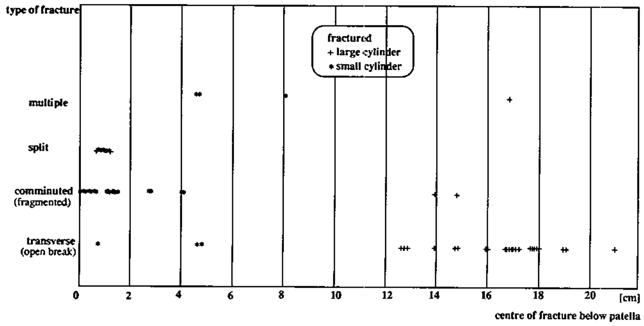


Figure 4. Type of Fracture versus Location of Impact in Transversely Loaded Tibias of Complete Cadavers (taken from Kramer)

Figure 5 shows real leg bones compared with those of the JARI and TRRL crash test dummies. The Dynamics Inc leg is fundamentally similar although there are differences in details because a Hybrid III leg was used instead of a Hybrid II leg and the Dynamics Inc "bone" is not of constant section. There are considerable differences between the legs of people and those of crash test dummies. When breakable plastic bones are fitted in dummy legs short lengths of breakable plastic are interspersed with heavy steel components which are virtually indestructible. Only a limited number of the possible types of fracture are reproduced so that regardless of load conditions a pre-determined type of fracture will occur in a predetermined location. Such a mechanism cannot replicate the variety of fractures found in real life. The knee joint in the Dynamics Inc leg is more complex than in the Hybrid II dummies, in an attempt to provide more realistic articulation, but even so it can make no allowance for dislocation by transverse loads which is a common source of injury (16) (17).

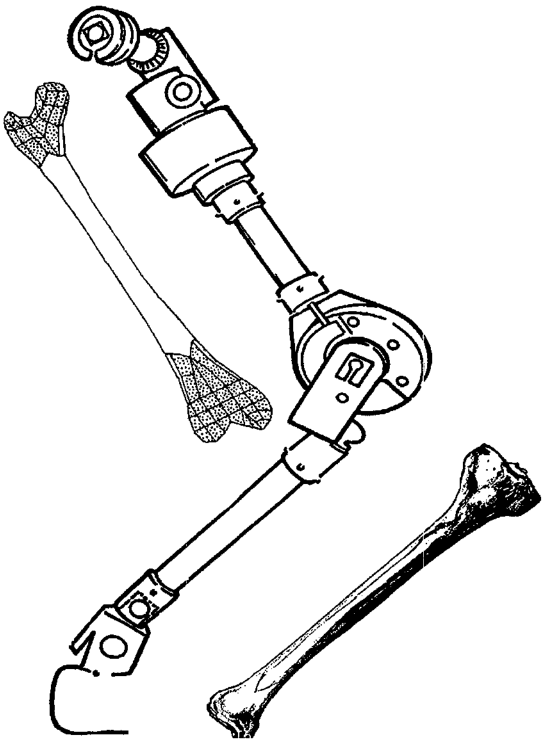


Figure 5. Comparison of Frangible Dummy with Real Leg

In the three existing dummies breakable bones are chosen to give approximately the same mean static breaking loads as real leg bones. How closely does a dummy reproduce the loads experienced by people? It is well known that with non-breakable metal bones there is poor correlation between the loads in the legs of dummies and cadavers. Depending on the circumstances, the axial loads in dummy femurs can range from about 3.5 times as great to slightly less than those in cadavers (18)(19), and it is important to establish whether plastic bones can offer any better correlation.

Two different analyses are possible. The first assumes that the stiffness of the bone is dominant so that the natural frequency of the leg has a large effect on the load in the bone. On this basis, as the plastic bone is about 0.1 times as stiff as the metal bone, the load in it is only $\sqrt{0.1}$ or about one third of that in the metal bone (20). The axial loads in the femur would then range from about the same as those in cadaver femurs to about a third of this. On this basis dummy legs would tend to break at loads higher than those which cause fracture in cadavers.

The second hypothesis is that the concentrated metal masses in the dummy leg are so large that the load in the bone is mass dominated (18). The axial loads in metal and plastic femurs would then be the same. There is only one recorded instance in which the axial load in a metal femur has been compared directly with the load in a plastic one (5). Tests are described in which a motorcycle was impacted into a car, using a dummy which in two instances was fitted with a non frangible metal leg and in two instances was fitted with a frangible bakelite leg. The load in the metal and plastic femurs were approximately equal, supporting the second hypothesis. On this basis dummy legs would tend to break at loads lower than those which cause fracture in cadavers.

This suggests, therefore, that there are considerable practical difficulties in designing breakable dummy legs to replicate the fracture behaviour of the real thing. There is high scatter in fracture loads, with little correlation between results from static, uni-axial calibrations and the multi-axial impact loads found in crash tests; no provision for the behaviour of honeycomb bone or dislocation of the knee under transverse loads; and poor correlation between the loads in dummy bones and those in cadavers. In addition, fairly minor mishaps during handling can cause hidden damage which greatly reduces the fracture load. This raises serious problems of quality control, and even with rigorous control doubts and ambiguities are likely to remain. While it is clear that non-fracturing metal bones cannot replicate the behaviour of the human leg, they at least provide consistent load measurement and the difficulty becomes one of interpreting the measured loads in terms of likelihood and severity of injury. The non-fracturing legs used by TRRL in motorcycle impact tests, using aluminum honeycomb and discussed in (21), whatever their shortcomings, at least give an indication of the location and intensity of transverse loads all along the length of the leg. However, it has also been claimed that the fracture of a leg bone has a considerable effect on the trajectory of a motor-cyclist in a crash (22) and if this were the case steel legs may give different results in some cases. This is considered in the next section.

Trajectory and Fracture

Impact Tests

There is one group of test results for which direct comparison can be made between the trajectories of dummy riders in crash tests, because the rider travels for some distance after impact before hitting anything. This is offset head-on impact between a motorcycle travelling at 30 mil/h and the front corner of a car. The configuration of the vehicles is shown diagrammatically in fig 6. There are two test conditions, with and without leg protecting fairings. There are two results from JARI (11), each with breakable legs, and four from TRRL, two with breakable legs and two with non breakable metal ones (5). Head trajectories are shown in figure 6.

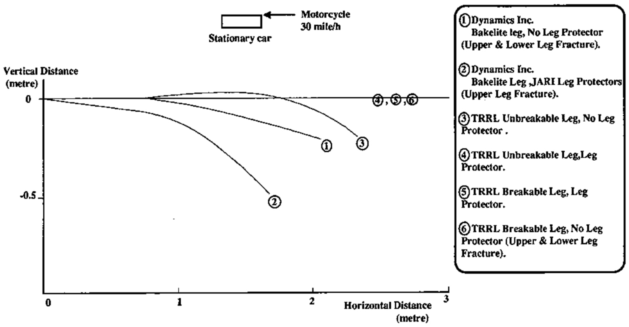


Figure 6. Effect of Leg Fracture on Dummy Head Trajectory

In the TRRL test with breakable legs and no leg protector (trajectory 6) the dummy's knee became detached and no load was applied from the leg to the torso. This is caused by the heavy metal knee joint snapping the relatively much weaker leg bones and bears no resemblance to any known injury reported from accident investigations. Such an occurrence appears to be unpredictable and did not occur with the very similar Dynamics Inc leg under nominally the same conditions. This might be because the latter leg had transition curves between a thicker tube at the knee socket and thinner tube in the measuring section. This has the disadvantage of reducing the length of the measuring section still further. In the TRRL test the dummy's head continued on approximately its original path. In the comparable JARI test without a leg protector (trajectory 1) both upper and lower legs broke but the knee did not pursue an independent path although it was free to do so, and head trajectory was very similar to that of the TRRL dummy with a metal leg which did not break (trajectory 3). At a horizontal displacement of 2 metres the difference in vertical head displacement is only 15 centimetres. This is comfortably within the scatter between two similar tests performed at two different laboratories.

In both TRRL tests with a leg protector (trajectories 4 and 5) there was no violent interaction between the motorcycle and the car and the rider's head continued substantially on its original course. In the JARI test with a leg protector (trajectory 2) there was substantial interaction between the motorcycle and the car, the rider's head stopped fairly rapidly and moved down as the torso swung forward about the hip joint. A very simple geometrical analysis, replacing the rider's torso by an inverted pendulum, shows that this change in trajectory can be reproduced almost exactly by increasing the retarding force by 50% above that for the standard motorcycle. This illustrates the difference between the TRRL and JARI approach to the design of leg protectors:

an overengineered and heavy leg protector can be more aggressive than a bare motorcycle, and it is important to design the leg protector so as to produce less interaction with the opposing vehicle than a bare motorcycle or one with a flimsy fairing.

Thus it seems that differences in trajectory found by JARI and TRRL are due to differences in the structure of the leg protector used rather than to using frangible and non-frangible legs. It is clear from figure 5 that the distribution of mass in a dummy leg is very different from that in a human leg. If the leg remains unbroken this should not lead to differences in gross body motion as long as the overall mass, location of the centre of gravity and moments of inertia of the dummy and human leg segments are similar. If the leg breaks, however, it seems unlikely that the mass location of the centre of gravity and moments of inertia of the broken portions will remain the same in dummies and people and this could lead to differences in gross body motion. With the similar dummies used in trajectories 1 and 6 of figure 6 the broken portions of the legs should be similar, so that there must be a different explanation for the difference in gross body motion between the two dummies in which both upper and lower plastic bones broke. It may be, of course, that it is due to the variability inherent in brittle plastic materials but it seems more likely that the difference is due to the behaviour of the dummy heavy knee moving as a loosely attached projectile in a highly erratic and unpredictable manner.

A considerable amount of research has been done on car impacts with a pedestrians' legs, and the results are pertinent here. Although loading patterns are different in detail there are common factors in the behaviour of legs struck transversely whether the crash victim is initially sitting or standing. Figure 7 shows head trajectories for dummy and cadaver pedestrians struck by a car (23). The original reference contains more results but, to avoid clutter, a small number of typical trajectories have been selected. These can easily be checked for relevance against the results in the source paper. The dummy had unbreakable metal legs and the tests were all identical apart from the vehicle speed. The dummy behaved in a consistent way: as impact velocity increased the head struck slightly further back on the car. Cadavers behaved like the dummy for impacts at 23 k/h but, at higher impact speeds, behaviour changed, with the cadaver's head striking appreciably further back on the car. Leg fracture occurred with at least one cadaver at each impact speed but it appears from the paper that this had no noticeable effect on head trajectory. The change in cadaver behaviour coincided with the onset of injury to the lumbar spine caused by excessive bending. Figure 8 (21) shows head trajectories for two dummy riders on stationary motorcycles struck on the side by a car. These are from tests performed and analysed at JARI. One had breakable legs and one did not. There is very little difference in trajectory caused by leg fracture but the dummy with unbreakable legs bent more at the lumber spine which would indicate the tendency to overextensions in bending observed with the pedestrian cadavers.

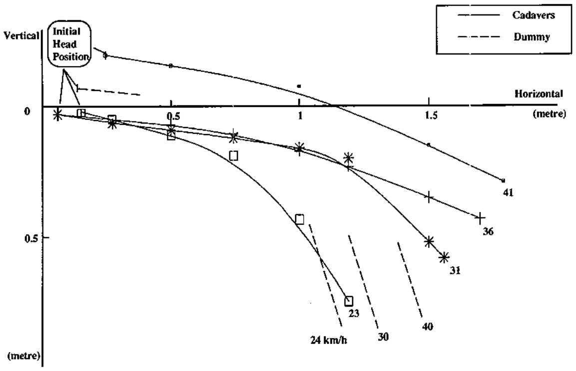


Figure 7. Head Trajectory of Pedestrians Struck at Different Speeds

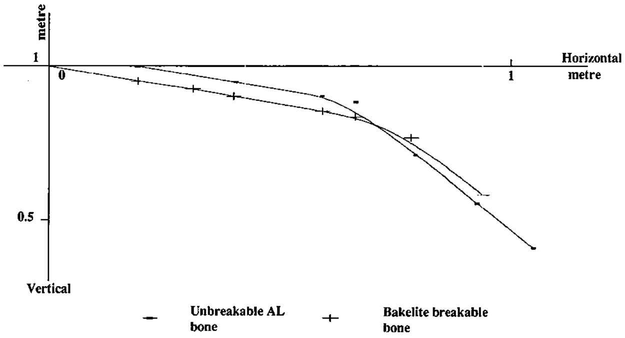


Figure 8. Head Trajectories of Dummy Motorcyclists Struck from Side (Based on Tadokoro)

Simulation

The fracture of a long leg bone has the effect of adding an extra joint and increases the number of segments in the body. In a computer study Wismans and Van-Wijk investigated the effect of the number of segments on the behaviour of standing pedestrians struck by motor cars. This was done with two-dimensional simulations having 2, 5 or 7 segments (24) ranging from a simple representation of 2 segments jointed at the knee, through a torso with head, waist and single leg jointed at the hip and knee (5 segments), to the seven segment model similarly jointed but with two legs.

Differences in behaviour were small. The 2 segment model gave the best validation against experimental tests, using a dummy, of the velocity with which the head struck the bonnet. The 2 segment and 5 segment models gave the best validation of head trajectory. These were almost identical as can be seen from Figure 9. The 7 segment model gave the best estimate of transverse loads on the legs again when compared with experimental tests using a dummy. Overall it appears that the number of segments in a simulation has a minor effect on the trajectories of pedestrians. This reinforces the test results on cadaver pedestrians showing that the occurrence of leg fracture had little effect on head trajectory.

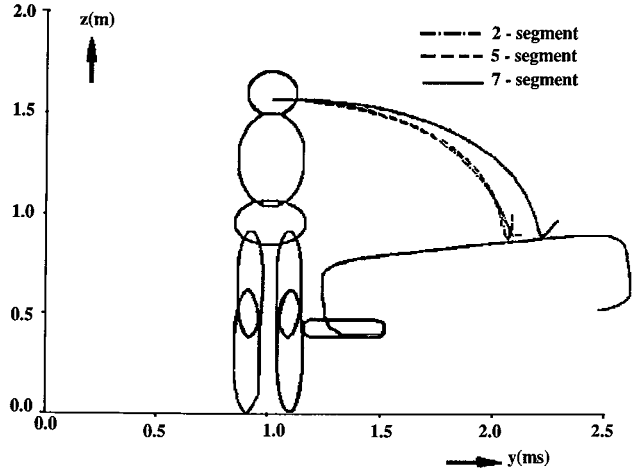


Figure 9. Effect of Number of Segments in Pedestrian Model on Head Trajectory of Simulated Pedestrian Accident, v=30 km\h (7 Segment Model Illustrated)

Behaviour of the dummy riders of stationary motorcycles struck on the side by motorcars also indicated that leg fracture had little effect on head trajectory. The offset head-on motorcycle crash tests described in Section 4.1 in which dummy legs broke gave two different results. In one case leg fracture had little effect on head trajectory. In the other case there was a significant effect (trajectory 6 of figure 6) but the dummy was obviously behaving quite differently from a person. Overall it appears that leg fracture has an effect on head trajectory only when there is serious malfunctioning of the crash test dummy's leg.

Other variables have a much greater effect on the trajectory. This is highlighted by computer simulations which can be surprisingly sensitive to very small changes in conditions. It does not appear to be feasible, in the present state of knowledge, to predict where such sensitive behaviour will occur and it is necessary to keep a look out for it at all times. Figure 10 shows results from a two-dimensional computer simulation of an unrestrained car occupant striking a knee bolster (25). This has been selected to illustrate a case of extreme sensitivity. For the three runs shown the differences in initial conditions appear trivial—a change of 2 cm in bolster height and 5° in the angle of the seat cushion. The changes in trajectory are very large and it is interesting to note the relationship between head trajectory and the behaviour of other parts of the body. The differences in head trajectory for runs B and C in Figure 10 are small although the positions of the body are very different.

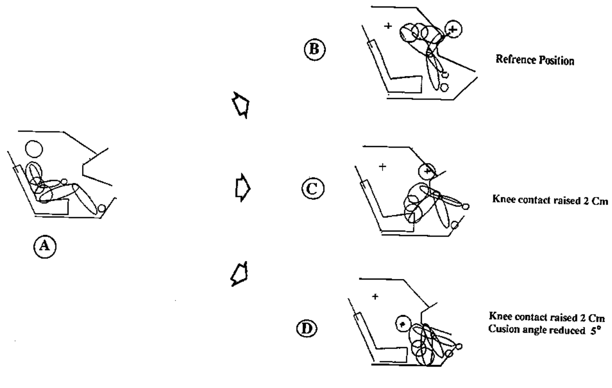


Figure 10. Sensitivity of Unrestrained Occupant's Trajectory to Very Small Changes in Initial Conditions

Head trajectory is obviously important in motorcycle accidents but the head is at the end of a complicated kinematic chain. Head trajectories can occur in a number of different ways and it is important that the behaviour of the rest of the body is understood as well. Figure 11 shows how the change in impact angle affects the rotational velocities for a simple 3-dimensional computer simulation of a motorcycle striking a rigid barrier (26). Behaviour is not so sensitive to tiny variations, but the differences are still large enough to cause wide variations in behaviour for differences of 10 or 20 degrees in impact angle.

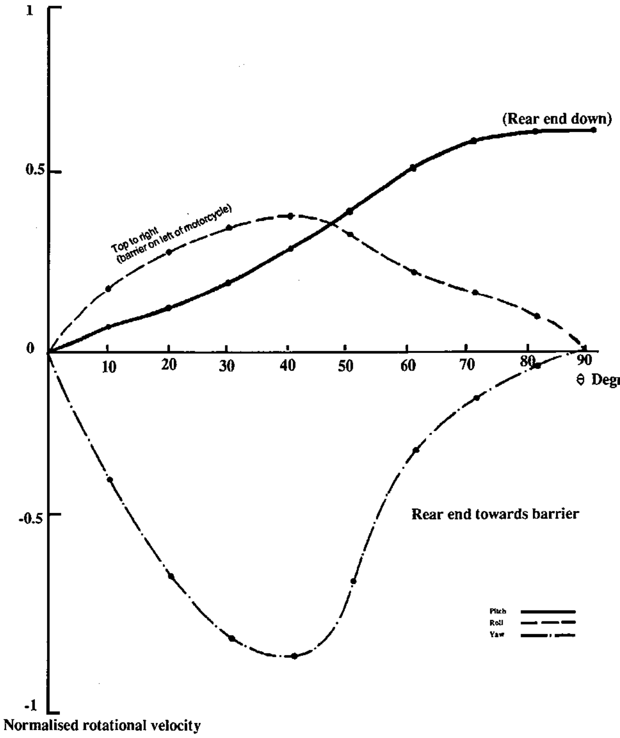


Figure 11. Effect of Impact Angle on Rotational Velocities at End of Impact

An advantage of computer simulations is that the repeatability is such that they can discern the effects of more minor variations than dummies, cadavers and motorcycles, so that areas of potential sensitivity can be highlighted. A disadvantage is that it is often difficult to find realistic values for key parameters such as joint torques or frictional forces. And, as with all modelling (and indeed dummies), the model is necessarily a grossly-simplified representation of real life, and the finer detail of model predictions has to be treated with great caution.

On occasion it is necessary to perform complex, 3-dimensional simulations of the kind shown in Figure 12 (27). These involve so many variables that it is possible to arrive at a plausible answer by many different routes unless accurate values are available for all the variables. Knowledge gained from simpler simulations and common sense analysis of test results is essential if such simulations are to be better than highly photogenic fairy tales.

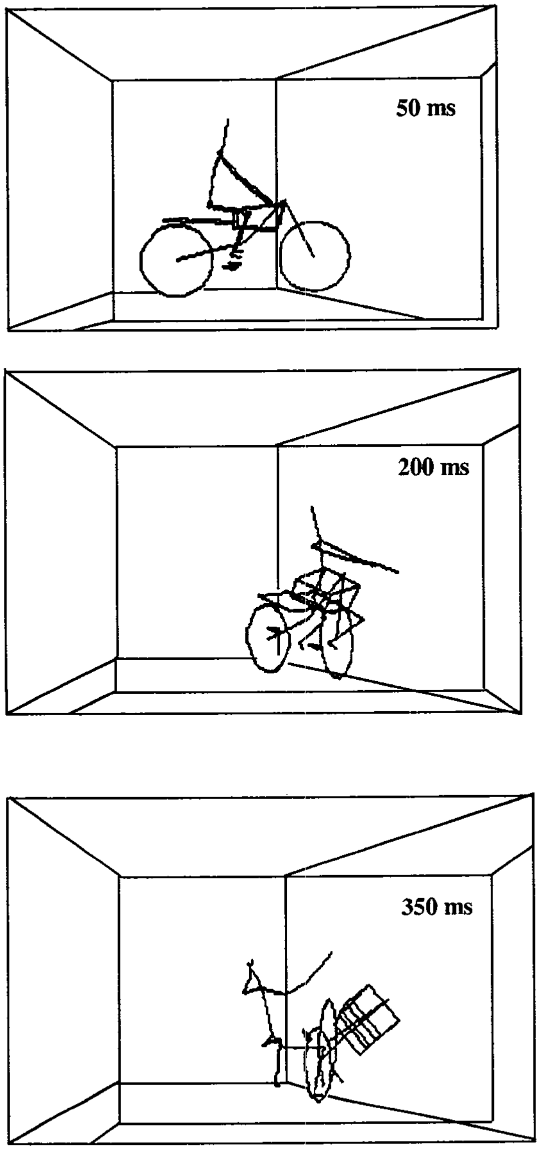


Figure 12. 3-Dimensional Representation of Motorcycle Rider

Conclusions

1. There is considerable scatter in the fracture loads of brittle materials. The behaviour of such materials is very complex and is imperfectly understood.
2. Fibre reinforced plastics are high technology, very versatile and stronger than unreinforced brittle materials, but the scatter in fracture loads is just as great. As a result the fracture of brittle materials provides an inefficient and unreliable way of measuring loads.
3. The effect of fracture of the long leg bones on the trajectory of surrogate or simulated motor cycle riders in crash tests is small except in cases where dummy malfunction is obvious.
4. The presence of a heavy knee joint held in place by two breakable bones can lead to unpredictable aberrations in the trajectories of dummy motorcycle riders in crash tests.
5. In computer simulations, trajectories are much more sensitive to minor changes in geometry than to the addition of extra articulations to the simulated crash victim, which is the effect of fracturing bones.
6. Overall it appears that dummies with frangible leg components offer few advantages and some serious disadvantages compared with dummies with unbreakable metal legs.

Acknowledgements

The work described in this paper forms part of the programme of the Transport and Road Research Laboratory and the paper is published by permission of the Director.

References

1. Melving J N, Shee T R. Facial Injury Assessment Techniques. 12th International Technical Conference on Experimental Safety Vehicles.Gothenburg 1989.
2. Stcherbatcheff G, Fayon A and Tarriere C. Simulation Biomechaneque des Membres Inferreure. 1st IRCOBI Conference Amsterdam 1973.
3. Tadokoro H, Fukuda S and Miyazaki K. A Study of Motorcycle leg Protection. 10th International Technical Conference on Experimental Safety Vehicles. Oxford 1985.
4. St-Laurent A, Szabo T, Shewchenko N and Newman J A. Design of a Motorcyclist Anthropometric Test Device. 12th International Technical Conference on Experimental Safety Vehicles. Gothenburg 1989.
5. Chinn B P and Karimi H. Leg Protection for a Sports Motorcycle. SAE International Congress and Exposition. Detroit 1990.
6. Rich M J and Maass D P. Developing Design Allowable for Composite Helicopter Structures, in Test Methods and Design Allowable for Fibrous Composites Ed. Chamis C C ASTM Special Technical Publication 734 (1981).

7. Jayatilaka A de S. Fracture of Engineering Brittle Materials. Applied Science Publishers (1979).
8. Tenn L F. Statistical Analysis of Fibrous Composite Strength Data in Test Methods and Design Allowable for Fibrous Composites. Ed. Chamis CC ASTM Special Technical Publication 734 (1981).
9. ASME. Mechanical Properties of Bone AMD - Vol 45 (1981).
10. Campbell J D. Dynamic Plasticity of Metals Springer Verlay (1970).
11. Sakamoto S. Research History of Motorcycle Leg Protection SAE International Congress Detroit (1990).
12. Mousley R F. In Place Compression of Darraycl Laminates in Structural Impact and Crashworthiness Ed. Morton J Elsevier Applied Science Publishers (1989).
13. Viano D C. Biomechanics of Bone and Tissue: A review of Material Properties and Failure Characteristics in Biochemics and Material Aspects of Lower Limb Injuries. SAE P.186 (1986).
14. Macaulay M A. Introduction to Impact Engineering. Chapman and Hall (1987).
15. Kramer M, Burrow K and Heger A. Fracture Mechanism of Lower Legs Under Impact Load. 17th Stapp Conference (1973).
16. Nyquist G W. Injury Tolerance Characteristics of the Adult Human Lower Extremities Under Static and Dynamic Loading in Biometrics and Medical Aspects of Lower Limb Injuries SAE P.168 (1986).
17. Viano D C et al. Bolster Impacts to the Knee and Tibia of Human Cadavers of an Anthropomorphic Dummy in Passenger Car Inflatable Restraint Systems SAE PT.31 (1986).
18. Horsch J D and Patrick L M. Cadaver and Dummy Knee Impact Response of Part 572 Dummy and Cadaver Subjects. 20th Stapp Conference (1976).
19. Hering W E and Patrick L M. Response Comparisons of the Human Cadaver Knee and a Part 572 Dummy Knee to Impacts by Crushable Materials 21st Stapp Conference (1977).
20. Tadokoro K. Load Measuring Method of Occupant's Leg on Motorcycle Collision 11th ESV Conference (1987).
21. Chinn B P and Macaulay M A. Leg Protection for Motorcycles IRCOBI Conference Delft (1984).
22. Miyazaki K, Kubota M and Sakamoto S. Load Measuring Method of Motorcyclist's Leg During Motorcycle Collision 12th ESV Conference (1989).
23. Kallieris D and Schmidt G. New Aspects of Pedestrian Protection Loading and Injury Pattern in Simulated Pedestrian Accidents in Accident Reconstruction Technologies SAE PT-35 (1989). 32nd Stapp 1988 P.881725.
24. Wismans J and Van Wijk J. Mathematical Models for the Assessment of Pedestrian Protection Provided by a Car Contour. 9th ESV (1982)
25. Niederer P and Walz F. Stability Considerations in the Mathematical Reconstruction of Traffic Accidents In SAE SP-412 (1976).
26. Happian-Smith J, Macaulay M A and Chinn B P. Compact Simulation of a Simple Motorcycle in Glancing Impacts with a Rigid Barrier. SAE International Congress Detroit (1990).
27. Mo L.S.M. Three Dimensional Computer Simulation of a Motorcycle and Rider Striking an Angled Barrier. Internal Report, Department of Mechanical Engineering. Brunel University (1991) (Unpublished).

S3-O-05

Current Situation of Pedestrian Accidents and Research into Pedestrian Protection in Japan

Hirotoshi Ishikawa, Kunio Yamazaki, Koshiro Ono
Japan Automobile Research Institute, Inc.
Akira Sasaki
Japan Automobile Manufacturers Association

Abstract

According to statistics on traffic accidents in Japan, approximately 60% of four-wheel vehicles involved in pedestrian accidents are passenger cars, 70% of the pedestrians involved are struck by the front of the vehicle, and 50% of the fatalities are persons 65 or more years of age. The proportion of elderly persons to the total number of pedestrian fatalities is expected to continue to increase, due to the rapid increase of the population in this age group, and further the total number of pedestrian fatalities is increasing. The findings from in-depth case studies of 113 pedestrian casualties show that the severity and location of the impact on the pedestrian depend upon the body size of the pedestrian and the shape of the front of the car, and important areas of a car from the view point of pedestrian protection are the bumper, the hood edge and the hood top. In order to understand the pedestrian kinematics involved in a collision between a car and pedestrian, and to obtain primary data for considering sub-system test methods for pedestrian protection, parametric studies were conducted with the use of full-scale sled tests and computer simulations, by varying the shape and stiffness of the front of the car and the body size of the pedestrian on the basis of accident analyses. The results show that the shape of the front of the car, particularly the hood edge height, greatly influences the pedestrian kinematics after the impact. The influence of the force-deformation characteristics of the front of the car upon the pedestrian kinematics appears to be small, compared to the dependence on the shape of the front of the car. The pedestrian kinematics varies according to the body size of the pedestrian, and is strongly influenced by the offset of the center of gravity of the pedestrian relative to the hood edge. The variations in head impact velocity and the angle thereof at the hood top,in impact angle at the hood edge, and in effective mass at the primary impact points are discussed with respect to the requirement for sub-system test conditions.

Introduction

Since the beginning of the seventies, the number of pedestrian casualties has dropped in most of the more motorized countries, marked by a reduction of around 50% in the number of fatalities in Europe (1). The greatest reason for this change is said to lie in the adoption of primary safety measures such as an isolation of pedestrians from motor vehicles, and traffic education, etc.

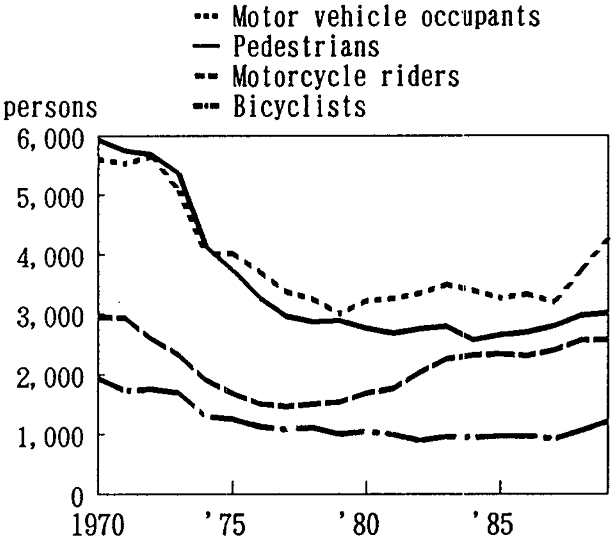
Nevertheless, pedestrian fatalities still account for approximately 15 - 30% of all road accident fatalities in Europe and America, as well as in Japan (2). In this context, in addition to primary safety measures, secondary measures (i.e., pedestrian protection features of motor vehicles) have become a major topic for consideration; currently, standardization of test methods for evaluating pedestrian protection requirements for motor vehicles is being promoted by the EEVC (3), the NHTSA (4)(5) and the ISO (TC22/SC10/WG2).

In the present report, first the current situation of pedestrian accidents in Japan is described, followed by a description of parametric studies concerning the influence of vehicle and pedestrian factors upon the pedestrian kinematics after impact, with a view to a consideration of test methods directed toward an improvement of pedestrian protection of motor vehicles.

Pedestrian Accident in Japan

Results of Statistical Analysis

Figure 1 shows modern trends in traffic accident fatalities in Japan for the respective types of accident situations. In Japan, a reduction of around 50% of pedestrian fatalities was recorded during the seventies (from 5939 in 1970 to 2888 in 1979), but this decreasing trend was subsequently reversed, and since 1984 the number of pedestrian fatalities has increased. Over the past decade, pedestrians have accounted for approximately 30% of road accident deaths.



Note:"Fatalities" are those who died within 24 hours after an accident.

Figure 1. Trends in the Number of Fatalities in Traffic Accident Type in Japan

Figure 2 indicates the trends in pedestrian fatalities and injuries for the respective age groups. In the group aged up to 15, both the number of fatalities and injuries are decreasing, and their numbers per population are also dropping. In the group aged between 16 and 64, both the number of fatalities and injuries have recently shown a slight increase, but their numbers per population have remained unchanged for the past decade. In the group aged 65 or older, both the number of fatalities and

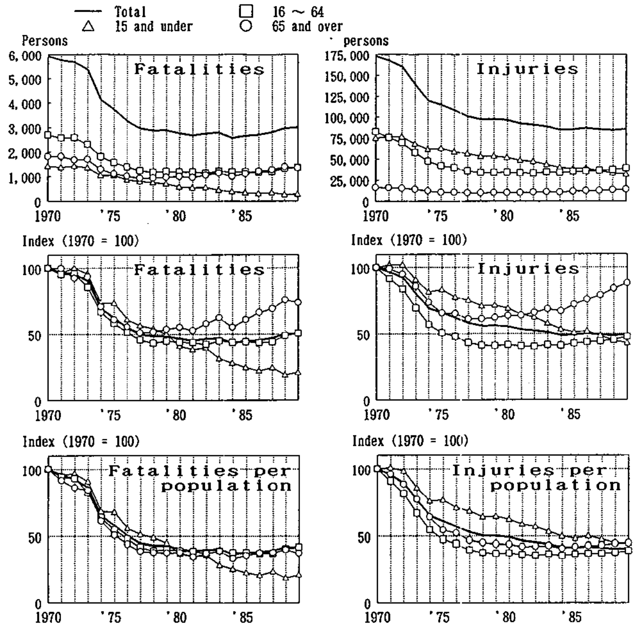


Figure 2. Trends in Pedestrian Fatalities and Injuries by Age Group in Japan

injuries have recently shown a marked increase, although their numbers per population have remained unchanged for the past decade. This marked increase of pedestrian casualties comes from the rapid increase of the population in this age group. It should be noted that, over the past decade, the number of Japanese people aged 65 or older has increased from 10.3 million in 1979 to 14.3 million in 1989 while the number of pedestrian fatalities in this age group has also increased by the same ratio of 1 to 1.4 (974 in 1979 to 1345 in 1989). The total number of pedestrian fatalities is increasing with the steady increase in the number of elderly people in Japan.

Figure 3 shows the number of pedestrian fatalities and injuries in each age group. The number of fatalities shows two peaks in the vicinities of 5-year olds and 80-year olds. The number of pedestrian injuries is highest for the ages of 4 to 7 and is several times higher than those of the other ages. Except for those 10-year old or younger, the rates of fatalities and injuries to the population increase in proportion to the age, but the rates for 10-year old or younger become greatest at the ages of around 5. Similar to the report by Godwin (6), the fatality rate per population shows a remarkable increase for the age group of 65 or older.

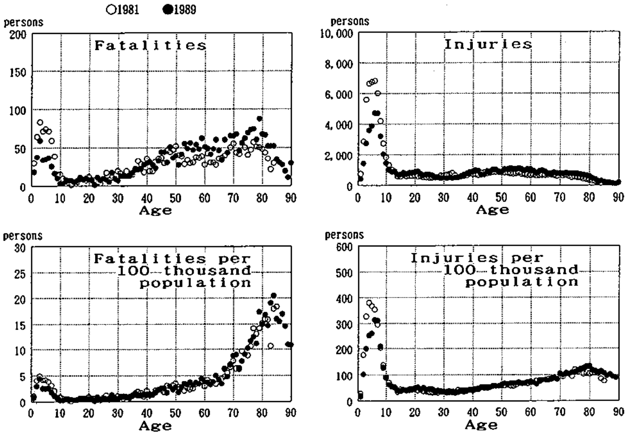
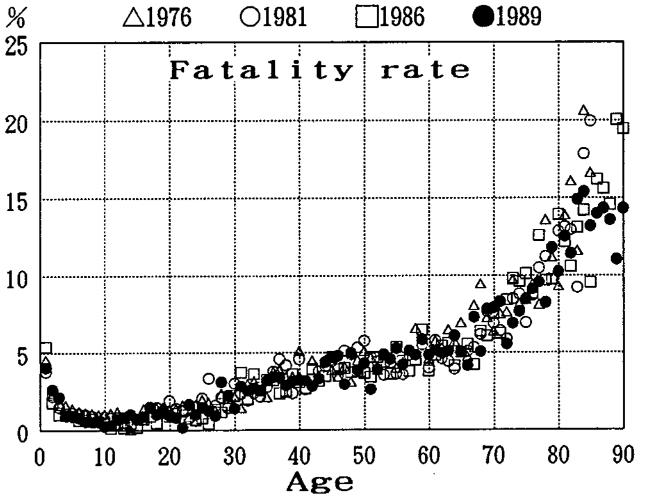


Figure 3. Pedestrian Fatalities and Injuries in Each Age in Japan

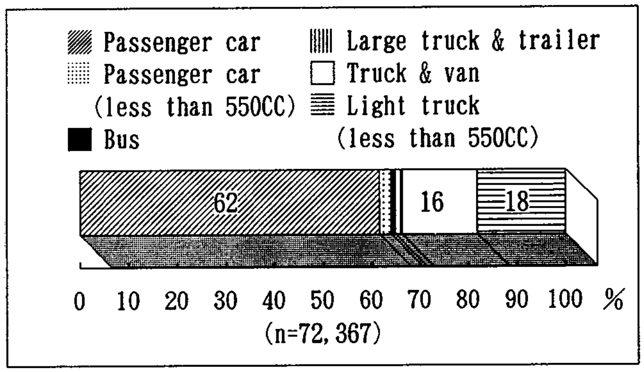
As shown in Figure 4, the pedestrian fatality rate per number of casualties is minimal for those around 10-years old, and thereafter, progressively increases with an increase in age, the rate of this increase being especially pronounced for those around 65-years old; this trend has not changed for the past 15 years.

Figure 5 shows the type of motor vehicles and the action of pedestrians in accidents. Approximately 60% of the four-wheel vehicles involved in pedestrian accidents are passenger cars, and about 70% of the pedestrian casualties are hit while crossing the road. Therefore, it may be assumed that approximately 70% of the pedestrians are hit by the front of the motor vehicle, and that such impacts are almost always squarely on the pedestrian's side.

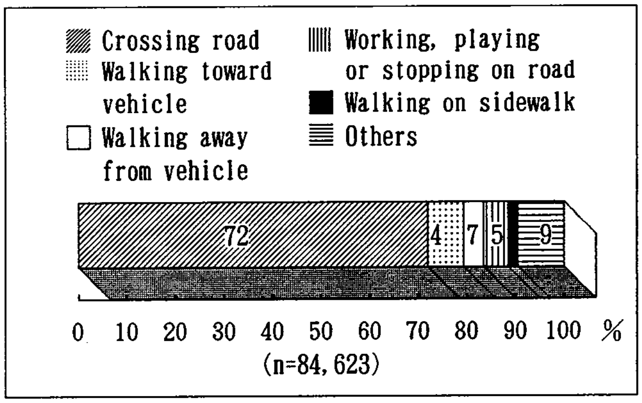


$$\text{Fatality rate} = \frac{\text{number of fatalities}}{\text{number of casualties}} \times 100\ (\%)$$

Figure 4. Fatality Rate Per Number of Casualties in Each Age in Japan



(1) Vehicle type in pedestrian accidents.



(2) Pedestrian action prior to impact.

Figure 5. Vehicle Type and Pedestrian Action (Japan 1989)

Findings of In-Depth Case Studies

In-depth case studies (7) have been carried out on pedestrian accidents that involved 113 casualties hit by the front portion of bonnet (cub-behind engine) type passenger cars or vans, in order to allow specific technical studies on severity and location of the impact on the pedestrian.

Table 1 shows the number of pedestrian injuries related to contact locations and body regions. More injuries to pedestrians are caused by vehicles than are caused by road surfaces. Many of the injuries are to the leg and caused by an impact with the bumper, in the head by an impact with the hood top, and in the pelvis or leg by an impact with the hood edge. Therefore, it is obvious that the most important areas of a car are the bumper, the hood edge and the hood top, from the view point of pedestrian protection.

Table 1. Number of Pedestrian Injuries by Body Regions and Contact Locations

Contact location \ Body region		Head/ Face	Neck	Chest	Abdomen	Pelvis	Arms	Legs						Total
								Over-all	Femur	Knee	Lower leg	Foot	Sub-total	
Car body	Bumper				2 (2)	1 (1)		1(0)	18(13)	29(13)	30(5)	1(1)	76(32)	82 (35)
	Hood top, Fender	43 (24)	1 (1)	9 (4)			22 (8)							75 (37)
	Hood edge		1 (1)	2 (2)	7 (4)	20 (9)	6 (4)		18(3)				18(3)	54 (23)
	Windshield	15 (0)	1 (0)				1 (0)					1(0)	1(0)	18 (0)
	W. frame, Pillar	11 (0)					2 (0)							13 (0)
	Others	4 (2)				1 (1)	6 (3)	1(1)	2(2)	2(2)	3(1)	6(1)	14(7)	25 (13)
	Sub-total	73 (26)	3 (2)	11 (6)	9 (6)	22 (11)	37 (15)	2(1)	38(18)	31(15)	33(6)	8(2)	112(42)	267 (108)
Indirect injury			12 (2)			2 (0)	3 (1)		2(0)			4(2)	6(2)	23 (5)
Ground		42 (23)		10 (4)	3 (1)	4 (2)	34 (18)	3(1)	3(2)	20(11)	1(1)	10(6)	37(21)	130 (69)
Unknown							2 (0)				1(0)	2(0)	3(0)	5 (0)
Total		115 (49)	15 (4)	21 (10)	12 (7)	28 (13)	76 (34)	5(2)	43(20)	51(26)	35(7)	24(10)	158(65)	425 (182)

The value in the parenthesis is the number of injuries for children.

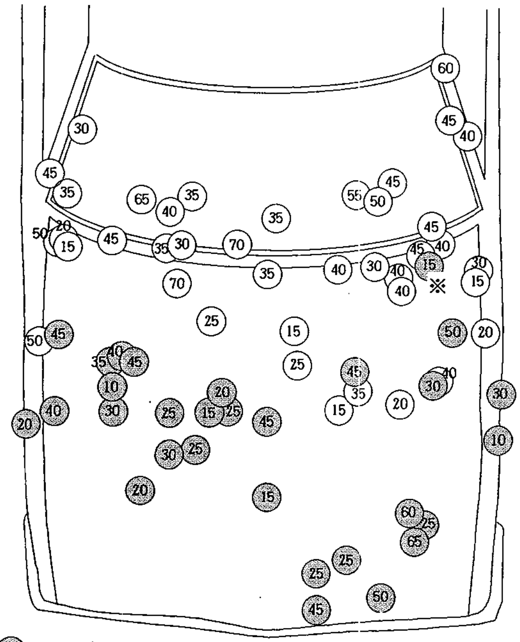
Figure 6 shows the head impact points; these are distributed over the entire surface of the hood top. The head impact points of children aged 15 or younger are located in the area covering two-thirds of the hood top, from the hood edge. For adults, about half of the head impact points are concentrated at relatively solid portions such as the cowl top, the windshield frame and the windshield itself.

Table 2 shows the relationship between femur bone fractures and the front shape of the car. Femur bone fractures of children are found when the bumper lead exceeds about 80 mm. For adult femur bone fractures, the bumper is the cause when the bumper lead angle is 65 degrees or less, and the hood edge is the cause when the bumper lead angle exceeds 65 degrees. That is, the severity and location of the impact on the pedestrian obviously depend upon the body size of the pedestrian and the front shape of the car.

Figure 7 shows the cumulative frequency of the vehicle impact speed by maximum AIS. The impact speed of the 50th percentile is about 15 to 20 km/h for AIS 1 or 2, about 25 to 30 km/h for AIS 3 or 4, and about 45 km/h for AIS 5 or 6. These results are about 5 to 10 km/h lower than those of Ashton's report (8).

Pedestrian Protection

On the basis of these accidents analyses, full-scale tests, component tests and computer simulations were conducted in order to determine the pedestrian kinematics involved in a collision between a car and pedestrian, and to obtain primary data for considering



● Child(15-year old or younger)
○ Adult(16-year old or older)

One child(*) is 13-year old and other children are 10-year old or younger.
Encircled numbers refer to vehicle impact speed (km/h).

Figure 6. Distribution of Head Impact Points

Table 2. Relationship Between Femur Bone Fractures and the Front Shape of the Car

(1) Children: up to 131cm

80mm

bumper lead	femur (n=23)	
	right	left
0mm		
20mm		
40mm		
50mm		
60mm		
60mm		
75mm		
80mm	▤ 3	▤ 3
80mm		
80mm		
80mm		
80mm		1
85mm		
85mm	▤ 3	
90mm		▤ 3
90mm		▤ 3
100mm		
105mm		
115mm		
130mm		
150mm		
150mm	▤ 3	▤ 3
150mm		

(2) Adults: 150cm or taller

65°

lead angle	femur (n=33)	
	right	left
40°		1
40°		
55°		
55°		
55°		1
60°	1	
61°	▤ 3	▤ 3
61°	▤ 3	▤ 3
61°		
62°		▤ 3
62°		
64°	1	
65°		
65°		1
65°	3	
65°		
67°	░ 3	
67°		
68°	1	
72°	1	
73°		
74°		
75°		
75°		
75°	1	
75°		
80°		
80°		
83°		
88°		░ 3
88°		
88°		
89°	░ 3	

▤ 3	femur bone fracture by bumper (AIS 3)
░ 3	Femur bone fracture by hood edge (AIS 3)
3	No femur bone fracture (AIS 3)
1	No femur bone fracture (AIS 1)

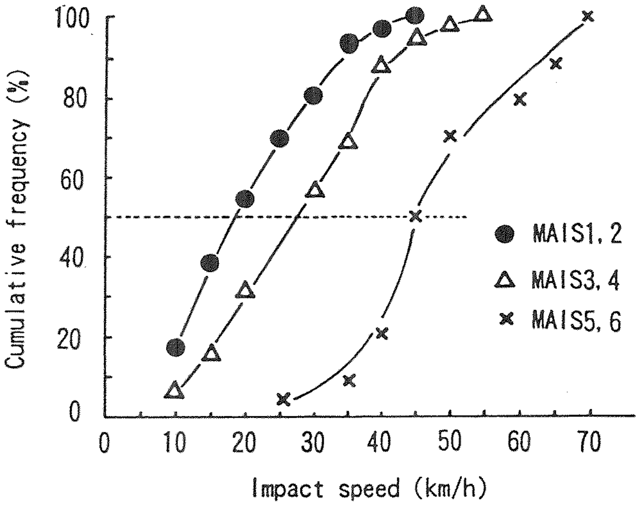


Figure 7. Cumulative Frequency of Vehicle Impact Speed by Maximum AIS

sub-system test methods for pedestrian protection, by varying the shape and stiffness of the front of the car and the body size of the pedestrian.

Full-Scale Tests

Mass production cars and a sled with simulated car shapes were used to strike a standing adult pedestrian dummy (HYBRID-II 50th percentile male). The pedestrian dummy was positioned to face 20 degrees towards the vehicle, from a directly sideways position and was hit on the right side. Then each leg was spread by 10 degrees with the left leg forwards and the right leg backwards, and the wrists of both hands were constrained by rope at the posterior side of the pedestrian.

Full-scale tests with mass production cars were conducted, in order to obtain data for validating the computer simulation model and for defining the component test conditions. Sled tests were conducted principally for validating the results of computer simulations. The sled simulated the shape of the front of the car with variations in bumper height, bumper lead and hood edge height, and installed impact force measuring transducers on the bumper, hood edge and hood top. The sled surfaces were covered with hard foam (polyethylene or urethane plastics) to reproduce the force-deformation characteristics of mass production cars. Figure 8 shows a typical sled test. The pedestrian kinematics determined by using mass production cars were successfully reconstructed by sled tests.

Component Tests

In order to obtain data on the force-deformation characteristics of mass production cars, component tests were conducted with respect to the bumper, the hood edge and the hood top, which constitute the most important areas for pedestrian safety. The impact points and directions were selected on the basis of the pedestrian kinematics involved in full-scale tests, and of the results obtained from accident analyses. The parameters used in the component tests are indicated in Table 3.

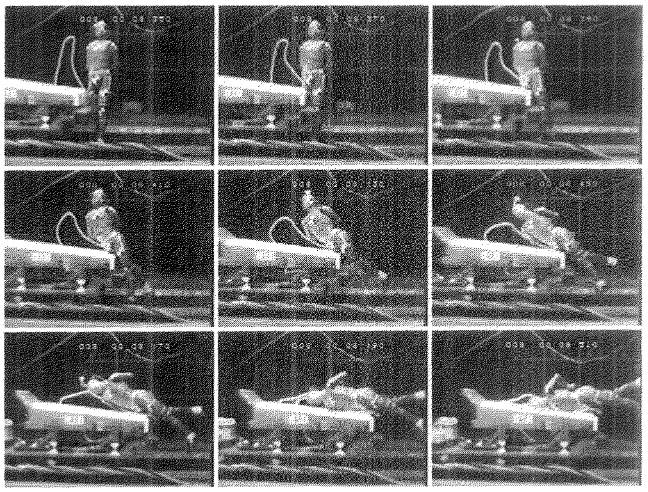
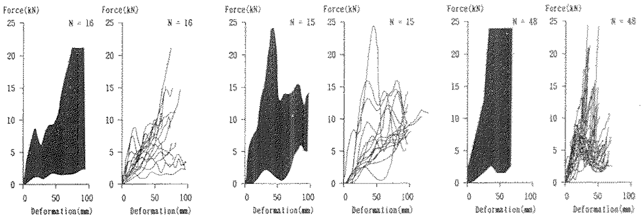


Figure 8. A Typical Sled Test

Table 3. Parameters for Component Tests

	Impact speed	Impactor	Impact point	Impact angle
Bumper	30 ~40km/h	Leg form 10 kg	Central part & bumper stay area	0° to horizontal
Hood edge	30 ~40km/h	Hip form 16 kg	Central part	30~45° to horizontal
Hood top	37km/h	Head form 4.5, 6.8kg	Entire surface	Normal to hood top

Figure 9 shows the force-deformation characteristics at the primary impact points. The stiffness of the bumper was varied by approximately 20 - 250 kN/m (for a deformation of less than 100 mm), and the stiffness of the hood edge was 50 - 500 kN/m (for a deformation of less than 50 mm), and thus both impact areas showed a wide range of stiffness. With regard to the hood top, the impact points were selected over the entire surface of the hood on the basis of the results obtained from accident analyses (See Figure 6). The stiffness of the hood top varied greatly at different impact points, with high stiffness values being obtained for areas directly above the strut tower and at the hood-fender boundary.



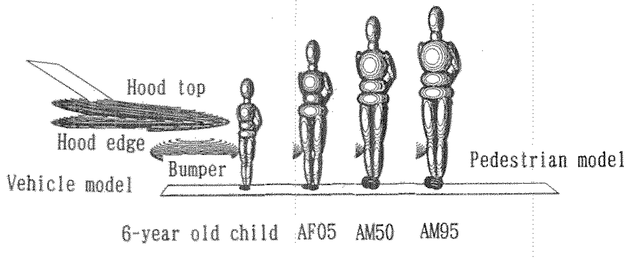
(1) Bumper (2) Hood edge (3) Hood top

Figure 9. Force-deformation Characteristics at Primary Impact Points

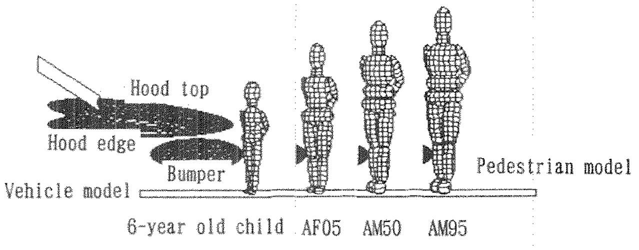
Computer Simulation

Pedestrian Model and Vehicle Model. CAL-3D and MADYMO were used for the computer simulations. Figure 10 shows the pedestrian and vehicle model used.

The pedestrian was made by using GEBOD (9) and was modified with reference to the data set for the part 572 dummy provided in the CAL-3D and MADYMO. The vehicle model represents the bumper, hood edge, and hood top as ellipsoids, and the windshield as a plane; these dimensions are defined in Figure 11.



(1) CAL-3D



(2) MADYMO

Figure 10. Pedestrian and Vehicle Model

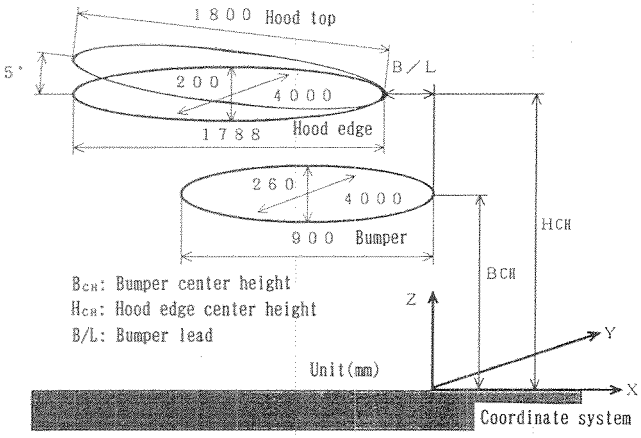


Figure 11. Dimensions of Vehicle Model

Input Data. The force-deformation characteristics at various pedestrian-vehicle impact points were determined by combining the component test results and the results obtained by static compression tests at the specified portions of the dummy. Figure 12 shows the force-deformation characteristics, which are assumed to remain unchanged even when the impact conditions (impact velocity, impact angle, pedestrian body size, etc.) are varied.

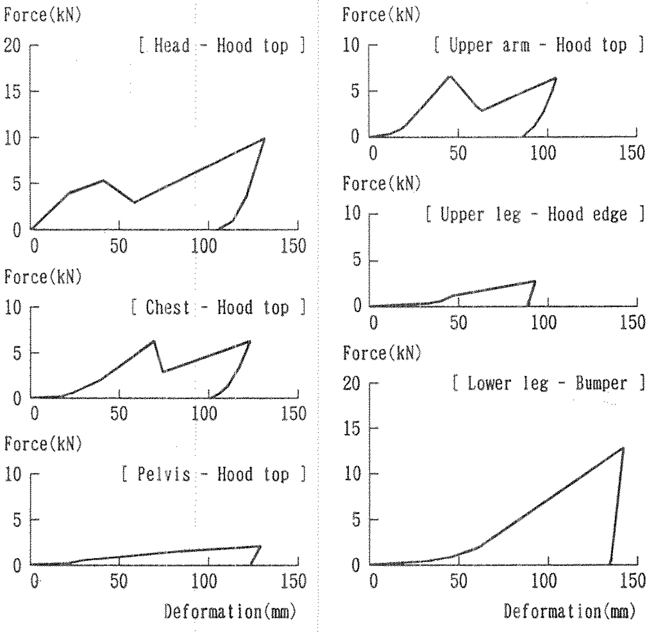


Figure 12. Force-Deformation Characteristics for Pedestrian-Vehicle Impacts

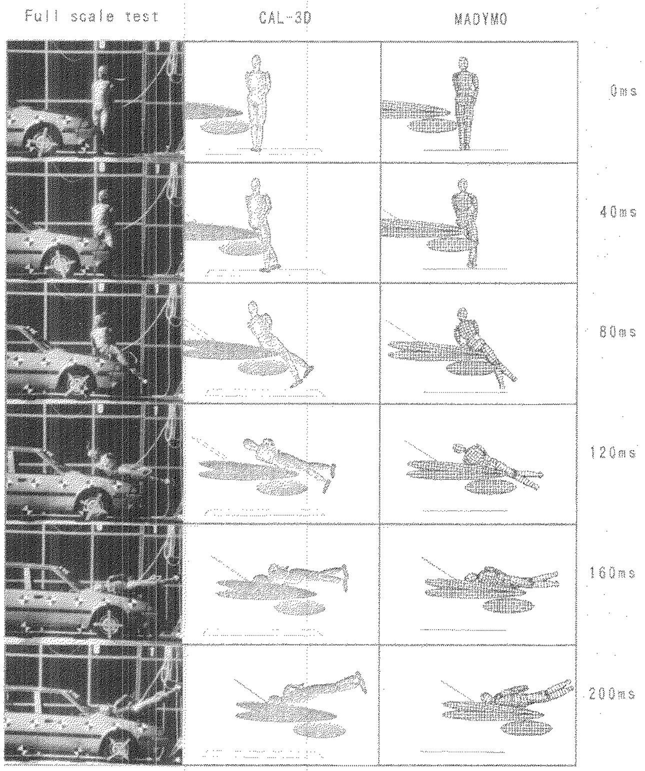


Figure 13. Comparison of Pedestrian Behavior Between Full-Scale Test and Computer Simulations (V_0 = 30.8 km/h)

Validation of Models. Figure 13 shows a comparison between the results of a full-scale test and computer simulations concerning overall pedestrian behavior. Figure 14 shows the head resultant velocity. The results obtained by CAL-3D and MADYMO agree well with the full-scale test results. These two models also successfully reconstructed the impact severity of the pedestrian dummy at various impact points. The models

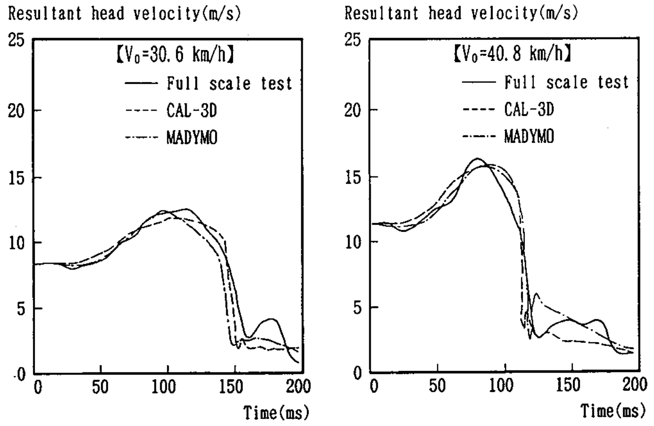


Figure 14. Comparison of Head Resultant Velocity Between Full-Scale Test and Computer Simulations

based on CAL-3D and MADYMO produced virtually the same results and were able to reliably simulate a collision between a car and the pedestrian dummy.

Parametric Studies

The parameters used were the shape and stiffness of the front of the car and the body size of the pedestrian, and were determined on the basis of accident analyses and component test results. The standing stance of the pedestrian coincided with that of the validation studies. The hood top sloped downward toward the front by 5 degrees to the horizontal in all cases.

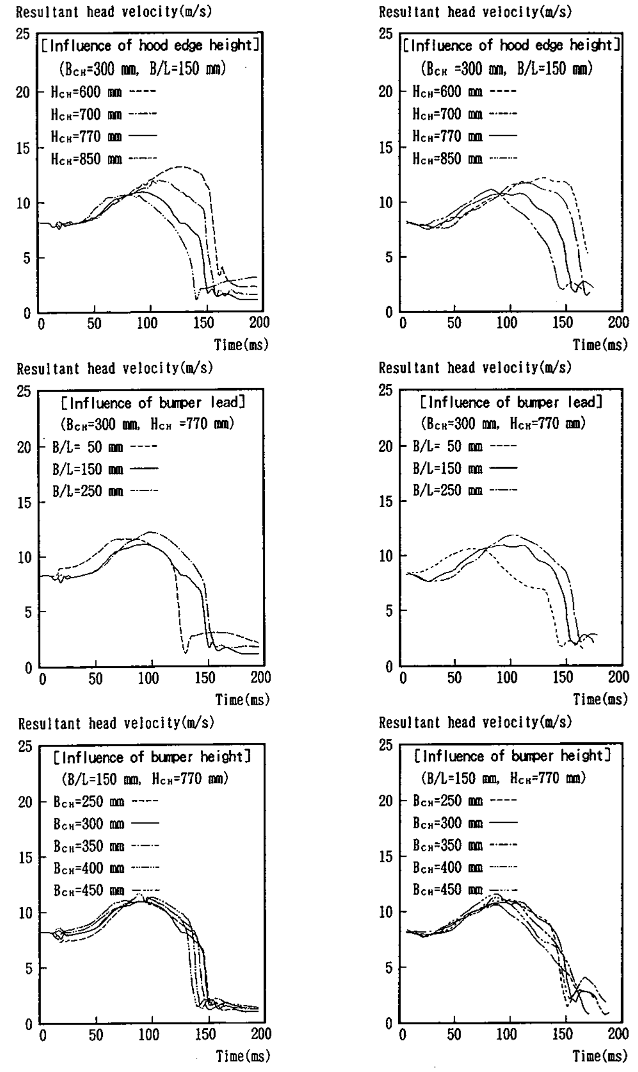
Influence of Vehicle Shape. The vehicle shapes were varied by using combinations of bumper height, hood edge height and bumper lead as shown in Table 4. The pedestrian was the part 572 dummy made by GEBOD. The force-deformation characteristics shown in Figure 12 were used in computer simulations, and in the sled tests, these characteristics were approximated to those of Figure 12. The impact velocity was 30 km/h.

Table 4. Parameters for Vehicle Shapes

Hood edge height H_{CH}		600 mm			700 mm			770 mm			850 mm		
Bumper lead B/L(mm)		50	150	250	50	150	250	50	150	250	50	150	250
Bumper height B_{CH} (mm)	250								*				
	300	*	*	*	*	*	*	*	*	*	*	*	*
	350								*				
	400								*				
	450								*				

Parameters selected are shown as *.

Figure 15 shows the head velocity. The maximum head velocity is increased as the hood edge height is lowered. With regard to the effects of the bumper lead, the time when the head velocity becomes maximum delays as the bumper lead is increased, but this maximum value in itself shows little variation in accordance with the bumper lead. The dependence of the head velocity upon the bumper height is slight.



(1) Computer simulation (CAL-3D)

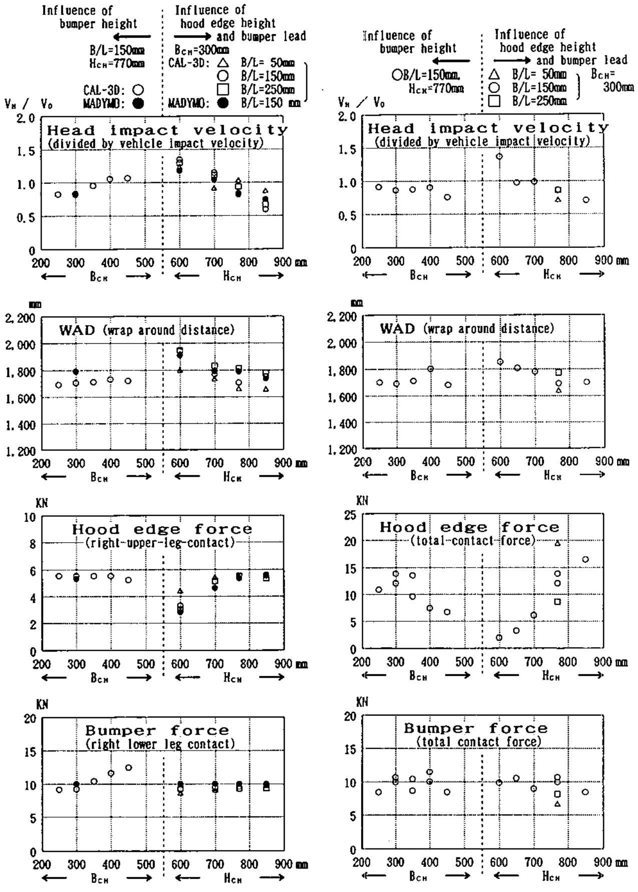
(2) Sled test

Figure 15. Resultant Head Velocity, Influence of Vehicle Shape

Figure 16 shows the head impact velocity, the WAD (Wrap Around Distance), the hood edge force, and the bumper force.

The head impact velocity tends to increase with a lowering of the hood edge height, although the influence of the bumper lead on the head impact velocity is dependent upon the hood edge height. The head impact velocity tends to increase with an increase of the bumper height, from computer simulations, but from sled tests the influence of bumper height is slight. This difference appears to be coming from the large knee deflection occurring in sled tests, which are not closely reconstructed in computer simulations.

The WAD tends to increase with a lowering of the hood edge height and an increase of the bumper lead, but has little to do with the bumper height.



(1) Computer simulation (2) Sled test

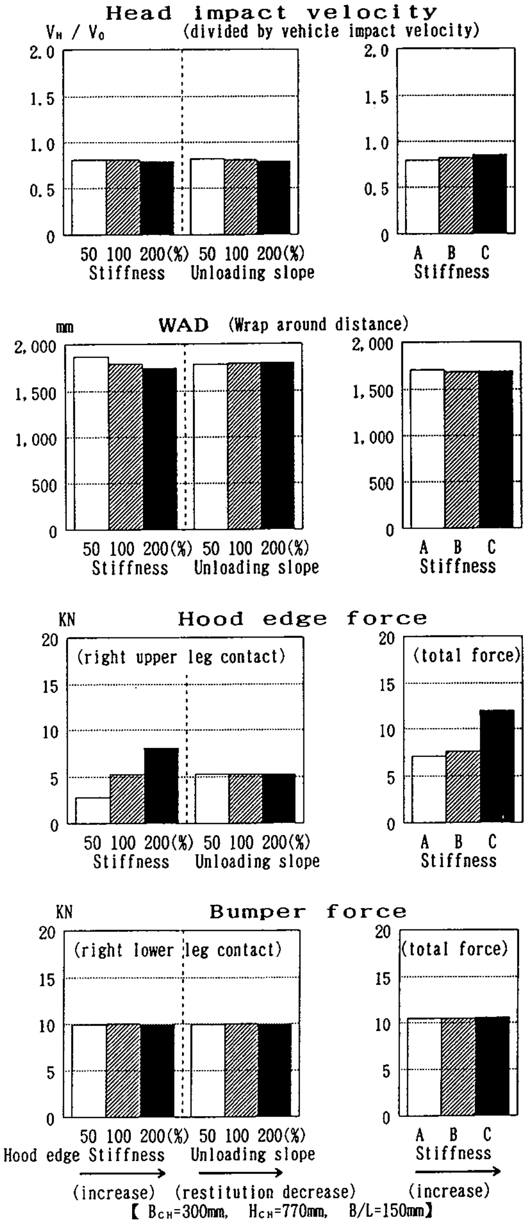
Figure 16. Head Impact Velocity, WAD, Hood Edge Force and Bumper Force: Influence of Vehicle Shape, V_0 = 30 km/h

The hood edge force tends to increase with an increase of the hood edge height and a decrease of the bumper lead. The differences between sled tests and computer simulations are due to the differences in measuring each item. The total contact force at the hood edge increases with a lowering of the bumper height.

The bumper force tends to increase with an increase of the bumper height, and compared with the variation of the hood edge force, the dependence of the bumper force upon the vehicle shape is slight.

Influence of Vehicle Deformation Characteristic. The force-deformation characteristics of the hood edge and of the bumper were varied in accordance with the stiffness and unloading slope thereof, as seen from the basic characteristics shown in Figure 12; 50% and 200% modifications were made in both of these values in computer simulations, and in the sled tests, these characteristics were approximated to those of the computer simulations. The vehicle impact velocity was 30 km/h and the following vehicle shape was selected: bumper center height, 300 mm; hood edge center height, 770 m; bumper lead, 150 mm.

Figures 17 and 18 show the head impact velocity, the WAD, the hood edge force, and the bumper force.



(1) Computer simulation (MADYMO) (2) Sled test

Figure 17. Influence of Hood Edge Stiffness and Unloading Slope, V_0 = 30 km/h

The head impact velocity tends to increase with an increase of the bumper stiffness and with an increasing restitution. Within the scope of the present analysis, the dependence of the head impact velocity upon the force-deformation characteristics of the hood edge is less pronounced than that of the bumper characteristics.

The WAD is almost unchanged by variations in the force-deformation characteristics of the bumper, but tends to increase with a decrease in the hood edge stiffness. That is, decreasing the stiffness of the hood edge appears to have the same effect on a pedestrian as an increase of the bumper lead, with respect to the WAD.

The impact force on the hood edge and on the bumper tends to increase roughly in proportion to the square root

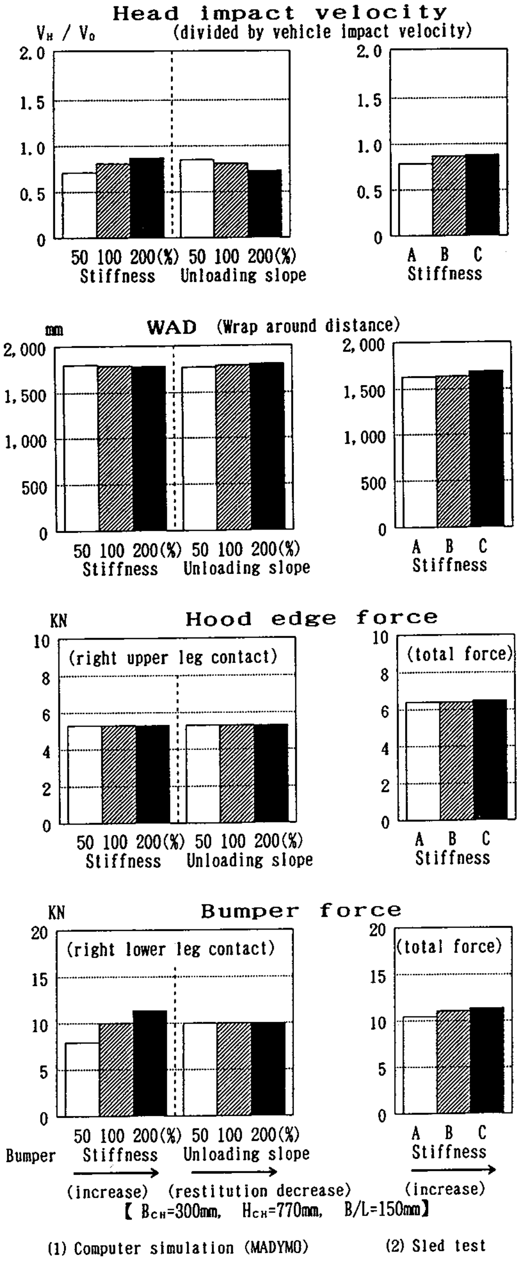


Figure 18. Influence of Bumper Stiffness and Unloading Slope, V_0 = 30 km/h

of the stiffness at impact points. Thus, considering the impact forces separately, the influence of the vehicle force-deformation characteristics upon the pedestrian kinematics appears to be slight, compared with the influence of the vehicle shape.

Influence of Pedestrian Body Size. The vehicle impact speeds were 30 km/h and 40 km/h, the pedestrian body size was that of a 6-year old child, the AF05, the AM50 and AM95, having the stature and weight as shown in Table 5.

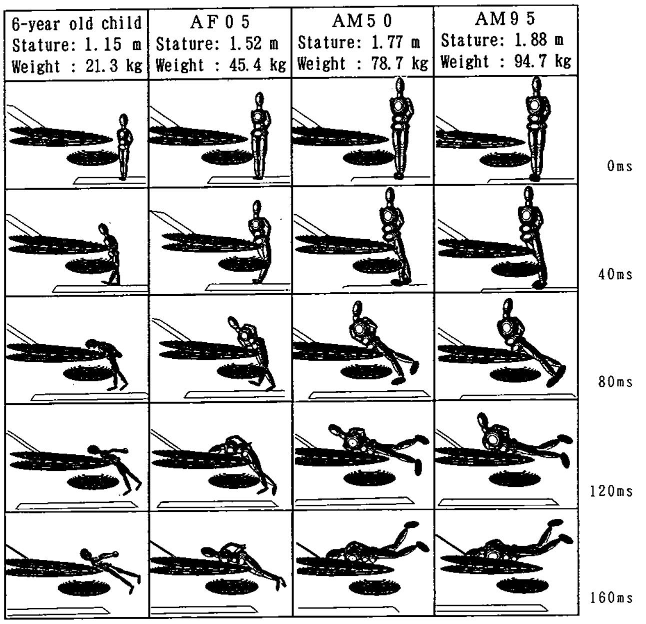
The average vehicle shape derived from accident analyses was as follows: bumper top height, 514 ± 28mm; hood edge height, 732 ± 52mm; bumper lead, 115 ± 37mm.

Table 5. Pedestrian Body Dimensions

	Stature	Weight	C.G. height
6 -year	1.15 m	21.3 kg	0.67 m
AF05	1.52 m	45.4 kg	0.85 m
AM50	1.77 m	78.7 kg	1.00 m
AM95	1.88 m	94.7 kg	1.08 m

The following vehicle shape was employed, since an approximate vehicle dimension is necessary in computer simulations: bumper center height (B_{CH}), 400 mm; hood edge center height (H_{CH}), 700, 800 mm; bumper lead (B/L), 100 mm. In view of the large effect of the hood edge height on pedestrian behavior, a value HCH = 800 mm was also included.

Figure 19 shows the overall pedestrian kinematics, which vary greatly according to the body size of the pedestrian. The severity and location of the impact on the pedestrian depend greatly upon the body size of the pedestrian, and therefore, the pedestrian body size must be taken into account when considering pedestrian protection measures.



B_{CH}=400 mm, B/L=100 mm, H_{CH}= 700 mm

Figure 19. Overall Pedestrian Behavior by Body Size (V_0 = 30 km/h, CAL-3D)

Figure 20 shows the resultant velocity of the head, wherein the circles in the diagrams indicate the time of the head impact on the hood top. In the case of adult pedestrians, the resultant velocity of the head progressively increased after the impact, and reached a maximum velocity greater than the vehicle impact velocity. Conversely, in the case of a 6-year old pedestrian, the resultant velocity of the head progressively decreased, and the head impact velocity was considerably lower than that of an adult pedestrian. If the center of gravity of the pedestrian is higher than the hood edge, the impact of the hood edge on the pedestrian causes a rotation of the body in a direction in which the head velocity is increased. If the center of gravity of the pedestrian is lower than the hood edge, the impact of the hood edge on the pedestrian reduces the head velocity. Furthermore, in the case of adult pedestrians, the greater the pedestrian body size, the greater the maximum head velocity. This is attributed to the fact that the larger the pedestrian body size, the greater the head displacement, which consequently increases the head velocity due to gravitational acceleration.

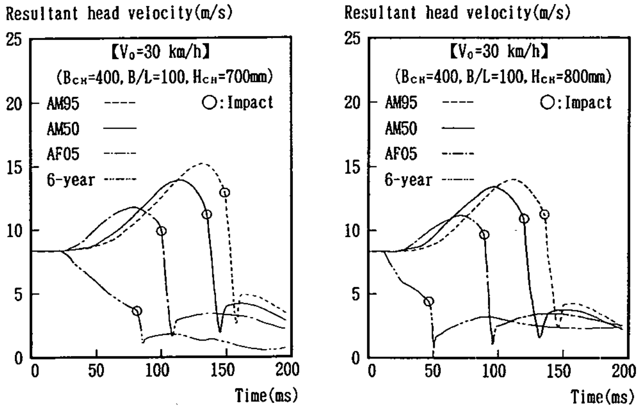


Figure 20. Resultant Head Velocity by Body Size (CAL-3D)

Some results for sub-system test conditions

The present section is devoted to a description of analytical results required for the study of sub-system test conditions.

Head Impact Velocity, Head Impact angle and WAD. Figure 21 shows the head impact velocity, the head impact angle and the WAD, obtained from the results of computer simulations. The abscissa in these graphs represents the offset (L) of the pedestrian's center of gravity from the hood edge center height.

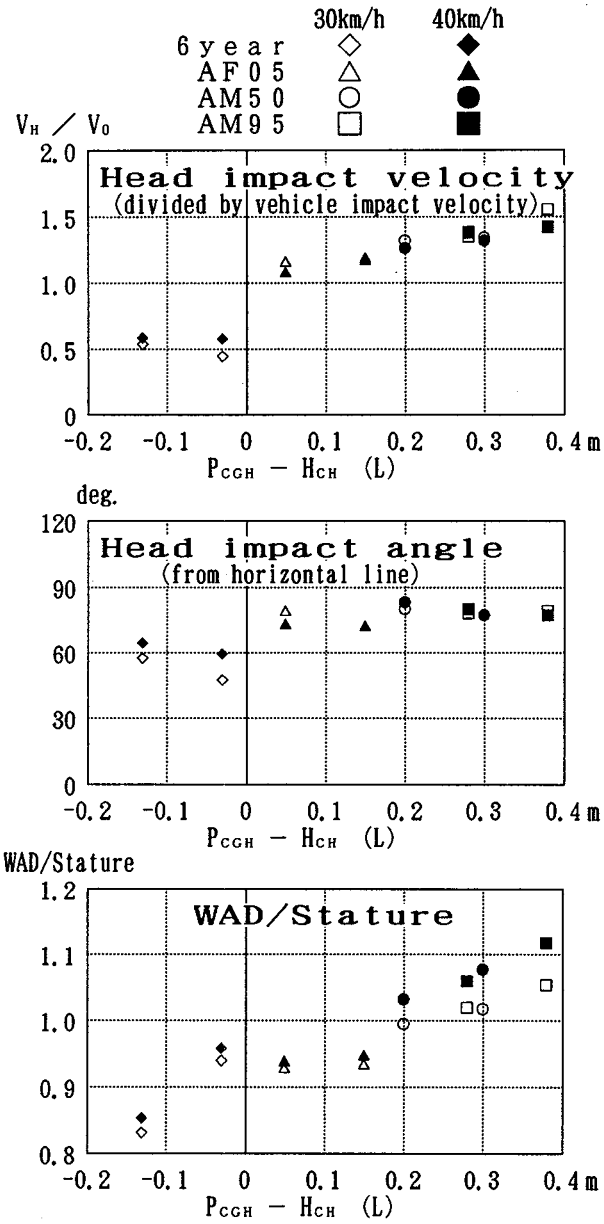
The head impact velocity ratio is approximately 0.5 for a 6-year old child, and 1 or more for adults. The head impact velocity tends to be reduced with a lowering of the value L.

The head impact angle θ is determined from the head impact velocity VH and the vertical velocity component V_{HV} thereof, in accordance with the following formula.

$$\theta = \sin^{-1} (V_{HV}/V_H)$$

For a 6-year old child, the head impact angle is approximately 50 - 60 degrees. For the adults, it is about 70 - 80 degrees, and the dependence thereof on the value L and on the vehicle impact velocity is slight.

The WAD/stature ratio is nearly proportional to L, and is approximately 0.85 - 0.95 for the 6-year old child and 0.95 for the AF05, whereas it is greater than 1 for the AM50 and AM95. The WAD tends to increase rapidly if L exceeds a certain value (about 0.2 m in the present analysis) and to become greater in proportion to the vehicle impact velocity.



[B/L=100mm, Bᴄʜ=400mm, Hᴄʜ=700mm & 800mm]
Pᴄɢʜ : Pedestrian C.G. height
Hᴄʜ : Hood edge center height

Computer Simulation (CAL-3D)

Figure 21. Head Impact Velocity, Head Impact Angle and WAD, Influence of Pedestrian Body Size

Impact Angle at Hood Edge. Figure 22 shows the impact angle at the hood edge, obtained as a result of the sled tests, determined from the horizontal and vertical impact force components on the hood edge at the instant the impact force becomes maximum.

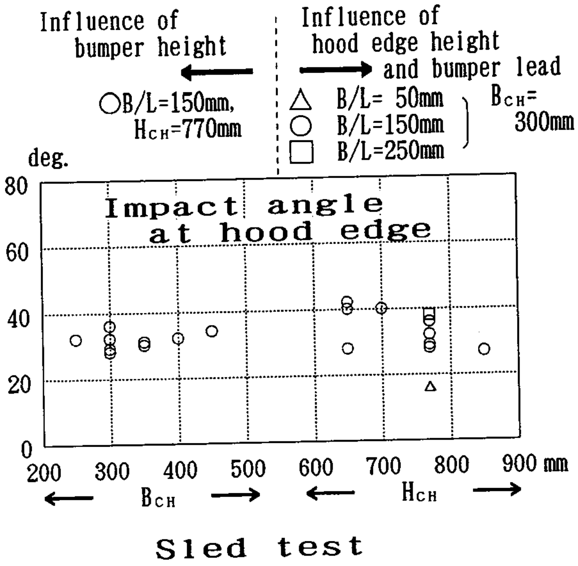


Figure 22. Impact Angle at Hood Edge, Influence of Vehicle Shape, V_0 = 30 km/h

The impact angle at the hood edge varies with the hood edge height and with the bumper lead, but the effect of the bumper height is slight. The impact angle varies within 20 to 40 degrees from the horizontal, and tends to be reduced as the hood edge height is increased and the bumper lead decreased.

Effective Mass. Figure 23 shows the effective mass (m_e) associated with the pedestrian-vehicle impact, and expressed as a percentage relative to the respective pedestrian weight. The abscissa in these graphs represents the offset (L) of the center of gravity of the pedestrian from the hood edge center height or from the bumper center height. The effective mass is determined from the impact force F and acceleration α at the impact point, in accordance with the following formula.

$$m_e = \int_{t_1}^{t_2} m(t)\,dt/(t_2-t_1)$$

where $m(t) = F(t)/\alpha(t)$, $m(t_1) = m(t_2) = m(t)_{max} \times 0.05$.

For adults, the effective mass for head to hood top impacts is not strongly influenced by the vehicle shape and is about 6 - 7% of the respective body weight. For the 6-year old child, it is about 10 - 15% of the body weight and tends to increase as L approaches zero. The effective mass for head to hood top impacts is nearly equal to the head mass of the respective pedestrian itself. Table 6 shows the mean values thereof.

The effective mass for hood edge to upper leg (or chest) impacts is approximately 20 - 30% of the body weight for the adults, and 30 - 35% of the body weight for the 6-year old child, thus tending to increase as L approaches zero. Table 7 shows the mean values thereof.

The effective mass for bumper to leg impacts is approximately 10% of the body weight for the AM50 and AM95, 15% for the AF05, and 25% for the 6-year old child, increasing as the bumper height approaches the center of gravity of the pedestrian. Table 8 shows the mean values thereof.

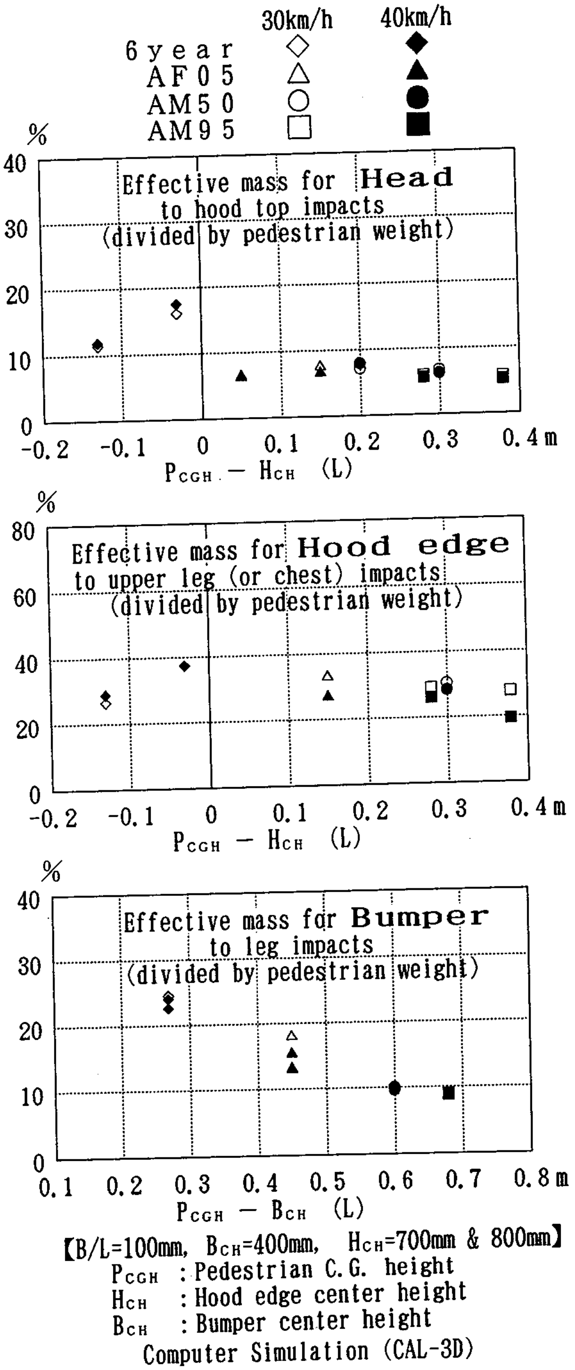


Figure 23. Effective Mass for Pedestrian-Vehicle Impacts, Influence of Pedestrian Body Size

Table 6. Effective Mass for Head to Hood Top Impact

B_{CH}=400mm H_{CH}=700, 800mm	Head mass by GEBOD (kg)	Effective mass (kg)	Effective mass per body weight (%)
6 -year	3.05	3.0±0.5 (n=5)	14.1±2.3 % (n=5)
AF05	3.60	3.2±0.2 (n=5)	7.0±0.4 % (n=5)
AM50	5.18	5.3±0.5 (n=6)	6.7±0.6 % (n=6)
AM95	5.41	5.3±0.3 (n=6)	5.6±0.3 % (n=6)

Table 7. Effective Mass for Hood Edge to Leg (or Chest) Impact

B_{CH}=400mm H_{CH}=700, 800mm	Effective mass (kg)	Effective mass per body weight (%)
6 -year	7.4±1.4 (n=5)	34.7±6.6 % (n=5)
AF05	13.7±1.1 (n=3)	30.2±2.4 % (n=3)
AM50	20.6±3.6 (n=6)	26.2±4.6 % (n=6)
AM95	21.3±5.1 (n=6)	22.5±5.4 % (n=6)

Table 8. Effective Mass for Bumper to Leg Impact

B_{CH}=400mm H_{CH}=700, 800mm	Effective mass (kg)	Effective mass per body weight (%)
6 -year	4.9±0.5 (n=5)	23.0±2.3 % (n=5)
AF05	6.3±1.3 (n=5)	13.9±2.9 % (n=5)
AM50	7.7±0.2 (n=6)	9.8±0.3 % (n=6)
AM95	8.5±0.2 (n=6)	9.0±0.2 % (n=6)

Except for the head to hood top impacts, the effective mass at the impact point increases as the respective impact point approaches the center of gravity of the pedestrian. This variation is attributed to the effect of the apparent mass at the impact point due to the moment of inertia of the pedestrian, and may be explained by the following formula for a rigid body impact.

$$m_e = I/(r^2 + I/m)$$

where m_e is an apparent mass or an effective mass, m is a mass, I is a moment of inertia, and r is an offset of the center of gravity from an impact point.

Conclusions

In Japan, approximately 60% of four-wheel vehicles involved in pedestrian accidents are passenger cars, 70% of the pedestrians involved are struck by the front of the vehicle, and 50% of the fatalities are persons 65 or more years of age. The proportion of elderly persons to the total number of pedestrian fatalities is expected to continue to increase in Japan, due to the rapid increase of the population in this age group, and further the total number of pedestrian fatalities is increasing. Both the fatality rate per population and the fatality rate per number of casualties show a remarkable increase for the age group of 65 or older. The severity and location of the impact on the pedestrian depend upon the body size of the pedestrian and the shape of the front of the car, and important areas of a car are the bumper, the hood edge and the hood top.

The results obtained from parametric studies by using sled tests and computer simulations are as follows:

(1) The shape of the vehicle, particularly the height of the hood edge, greatly influences the pedestrian kinematics after the impact.

(2) The influence of the force-deformation characteristics of the vehicle on the pedestrian kinematics appears to be small as compared with the dependence on the vehicle shape.

(3) The pedestrian kinematics differs according to the pedestrian body size, and is greatly influenced by the offset of the center of gravity of the pedestrian from the hood edge.

(4) The head impact velocity tends to be reduced with a lowering of the center of gravity of the pedestrian relative to the hood edge.

(5) The head impact angle is approximately 50 - 60 degrees from the horizontal for a 6-year old child, and 70 - 80 degrees for adults.

(6) The impact angle at the hood edge varies within 20 to 40 degrees from the horizontal, and tends to be reduced as the hood edge height is increased and the bumper lead decreased.

(7) Except for the head to hood top impacts, the effective mass at the impact point increases as the respective impact point approaches the center of gravity of the pedestrian. The effective mass for the head to hood top impacts is nearly equal to the head mass itself.

Acknowledgements

The authors wish to express their deep appreciation to Dr. Shogo Misawa of Department of Legal Medicine, University of Tsukuba and Dr. Noriyoshi Ohashi of Tsukuba Medical Center Hospital for their great help in the accident analyses, and to all the officers of the police stations in Ibaraki Prefecture and doctors in Ibaraki Medical Association for their cooperation.

References

1. Vallee H., Thomas C. and Tarriere C., Pedestrian Casualties: The Decreasing Statistical Trend, Proceedings of the 12th International Technical Conference on Experimental Safety Vehicles, Göteborg, May 1989.
2. Japan Traffic Safety Association, Statistics of Traffic, 1990.
3. Harris J., A Study of Test Methods to Evaluate Pedestrian Protection for Cars, Proceedings of the 12th International Technical Conference on Experimental Safety Vehicles, Göteborg, May 1989.
4. Kessler J. and Monk M., NHTSA Pedestrian Head Injury Mitigation Research Program - Status Report, Proceedings of the 12th International Technical Conference on Experimental Safety Vehicles, Göteborg, May 1989.
5. Elias J. and Monk M., NHTSA Pedestrian Thoracic Injury Mitigation Program - Status Report, Proceedings of the 12th International Technical Conference on Experimental Safety Vehicles, Göteborg, May 1989.
6. Godwin S. R., Improving Traffic Safety for an Aging Society, Proceedings of the 12th International

Technical Conference on Experimental Safety Vehicles, Göteborg, May 1989.

7. Ohashi H., Ono K., Sasaki N., Ohashi N. and Misawa S., The Present Situation Pedestrian Accident in Japan, 1990 IRCOBI.
8. Ashton S. J., Some Characteristics of the Population Who Suffer Trauma as Pedestrians When Hits by Cars and Some Resulting Implications, IRCOBI 1979.
9. Baughman L. D., Development of an Interactive Computer Program to Produce Body Description Data, AFAMRL-TR-83-058, 1983.

S3-O-06

Proposals for Test Methods to Evaluate Pedestrian Protection for Cars

J. Harris
EEVC Working Group 10
on Pedestrian Protection

Abstract

A programme of co-operative research to develop test methods that evaluate the protection afforded to pedestrians has been undertaken by a European Consortium acting within the auspices of a European Experimental Vehicle Committee Working Group and with financial support from the European Commission. The proposed test methods are intended for inclusion in an EC Directive and consist of three sub-systems tests to separately assess the bumper, the leading edge of the bonnet and the top of the bonnet. Each of the test conditions are generally based on a car to pedestrian impact velocity of 40km/h but for assessment of the leading edge of the bonnet the test requirements are adjusted to compensate for the influence of vehicle shape. The acceptance levels for the tests are based on the characteristics of the weaker sections of the adult population including the aged, who have been shown to be the most susceptible to injury. The proposals are considered to be appropriate for children, but a separate child head impact test has been included to assess their particular requirements. This paper gives a general description of these test methods and also discusses their significance to the design of cars.

Introduction

Test methods to evaluate the protection afforded to pedestrians by the fronts of cars have been developed by a European Consortium acting under contract to the European Commission and working under the auspices of EEVC Working Group 10. The study was requested by ERGA-S, the ad hoc passive safety advisory group of the European Commission and the test methods have been drawn up in the form of a draft regulation. Five Institutions were involved in the research programme for this project: Association Peugeot SA/Renault (APR), Bundesanstalt fur Strassenwesen (BASt), Institut National de Recherche sur les Transports et leur Securite (INRETS), Instituut voor Wegtransportmiddelen (TNO), and Transport and Road Research Laboratory (TRRL), with the Commission partly funding the work.

The improved safety that is expected to result from such test requirements will give a valuable addition to accident avoidance schemes to reduce the frequency and severity of pedestrian injury. In spite of the reduction in pedestrian casualties that occurred in the 1970's to mid 1980's, pedestrians continue to be a significant proportion of all those injured on roads. Accident data for 1989 (1) show that in the European Community the number of pedestrians killed has currently stabilised to be approximately 20 per cent of all traffic fatalities.

Accident Data

Accident studies show that approximately 60 per cent of seriously and fatally injured pedestrians are struck by the fronts of cars (2). Typically in accidents of this type, pedestrians are projected onto the bonnet of a car and then thrown forward to the ground as the car slows under the action of braking.

The most frequent causes of serious injury were impacts of the legs with the bumper, the upper legs, pelvis or abdomen with the leading edge of the bonnet or wings and the head with the top surface of the bonnet and wings, scuttle, windscreen frame or ground (2, 3, 4, 5, 6, 7, 8 and 9). Approximately 80 per cent of injury accidents and 25 per cent of fatal accidents were reported as occurring at speeds of 40km/h or less and safety improvements have been demonstrated that are effective up to this speed (10, 11, 12, 13, 14 and 15).

Objectives of Study

To evaluate these different contacts between cars and pedestrians, three sub-systems tests have been proposed to assess separately the protection afforded by the top of the bonnet, the bumper and the bonnet leading edge. The development of these test methods was led by BASt, INRETS and TRRL respectively and details of the research are reported separately (16, 17 and 18).

The development programme was supported by a series of mathematical computer simulations of cars striking child and adult pedestrian dummies, conducted by TNO (19). This work also included an independent assessment of the three test methods and a study of the classification of vehicle dimensions with respect to the requirements of the test methods (20). The compatibility of the requirements of the proposed test methods with those of existing regulations and the normal functional requirements of cars were studied by both APR and TNO (21 and 20) to give an assessment of the problems that manufacturers may face in complying with the test proposals. Finally, TNO assessed the effectiveness, cost and weight penalties of introducing the safety proposals.

This paper gives a general description of the proposed test methods and discusses their significance to car design.

Test Methods

Pedestrians have a wide range of physical heights, weights and strengths. Those involved in accidents with a car may be struck by any location across the width of the car. In accident studies (2) the pedestrians were most frequently reported to have been struck on their side but the position of the feet may vary, with either foot in contact with the ground. These variations may influence the severity of each of the discrete impacts with the car and also result in head impact to any location on the top of the bonnet or to the windscreen. The vertical position of the contacts to the front face of the car have been shown however by computer simulations to be primarily dependent or general car shape. Because of these variations the aim of the test method is to provide a compliant surface over all of the bumper and bonnet, but especially where the shape of a car gives a section that is particularly dangerous to pedestrians. With the exception of the forward part of the bonnet top (which is most frequently struck by children) the deformation characteristics of the surfaces are generally aimed to meet the protection requirements of the weaker section of the adult pedestrian population, including the aged.

The test methods are all sub-systems tests. This allows testing of any area that is likely to be struck by pedestrians of any height at any location across the width of the car. Sub-systems tests also allow assessment to be either to a complete car, or to such components of a car that are necessary to represent the important interactions between the vehicle structure that is under evaluation and the corresponding body regions that are liable to suffer serious injury from striking it. It is intended that no component of the car will be assessed by more than one of the sub-system tests. Significant increases in the heights of bumpers, if introduced, may however lead to conflict between the bumper and the bonnet edge tests and this is discussed in a following section describing the Upper Leg - Bonnet Leading Edge Test.

Lower Leg Bumper Test

The impactor that has been developed for the bumper sub-systems test was chosen to represent an adult leg being impacted from the side. This was because in accidents at speeds up to 40km/h, adults, particularly the aged, have been shown by accident studies to be more at risk than children to leg injury that may result in permanent disability (3 and 5).

Development of Impactor. The development of the impactor (17) was based on biomechanical data from cadaver testing (22) which showed that knee injury and leg fracture occurs early in an impact with a bumper, before the mass of the torso has begun to have an influence. This demonstrated that a leg form may be used in isolation to evaluate the bumper.

Computer simulations showed that leg inertial forces have a major influence and foot to ground friction only a minor influence on the bending moments generated in the leg during an impact. This shows that foot to ground friction forces may be omitted from a bumper sub-system test.

Impactor. The leg form is 841mm long and weighs 13.4kg. It consists of two foam covered rigid segments representing the upper and lower leg, joined by a knee piece that will rotate laterally (see Figure 1). The lateral bending of the knee joint is resisted by deformable rods that are replaced after each test. The knee is instrumented to measure the angles of rotation that occur between the body of the knee joint and both the upper and lower rigid leg segments. Additionally, an accelerometer is fitted to the top of the lower leg (see Figure 2). The two rotational measurements at the knee joint are added together to give the angle of bending at the knee.

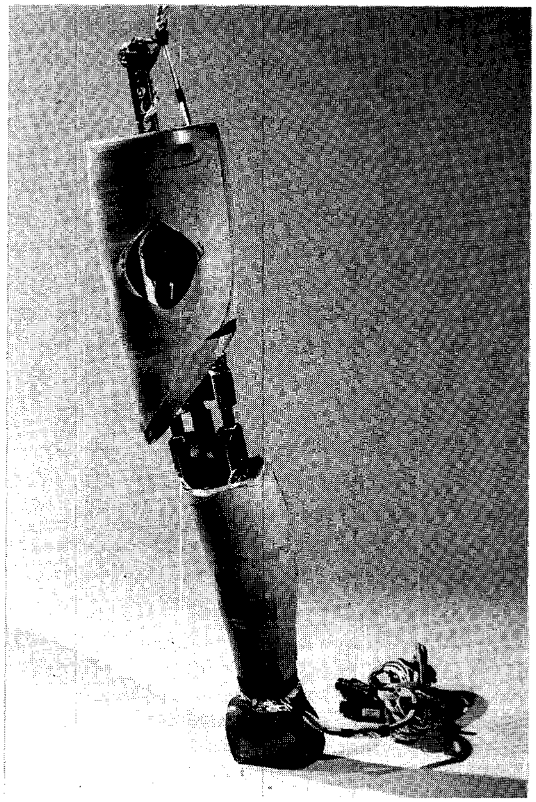

R412/91/1

Figure 1. Lower Leg to Bumper Impactor

The shearing angle is determined from their difference (see Figure 3). The measurement of acceleration is to limit the impact force.

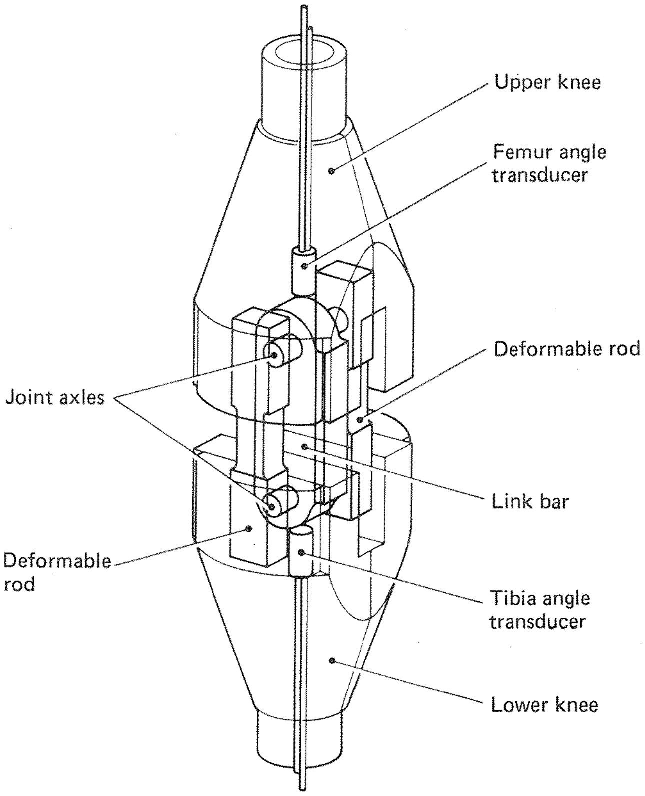


Figure 2. Knee of Lower Leg Impactor

Test Method. During a test the leg form is accelerated to test speed (40km/h is proposed) and then released to free flight in a horizontal direction at a set height above the ground with the impactor axis maintained vertical. The side of the leg form strikes the front of the car at the required test location and the articulated knee responds to the shape and stiffness of the front face of the car. It is recommended that a bumper is tested at a minimum of three locations, one each to the centre and outer thirds, at positions judged to be the most likely to cause injury.

Acceptance Levels. The proposed acceptance levels are 15 degrees of bending rotation and 5 degrees of shear rotation at the knee and 150g acceleration at the top of the lower leg.

Upper Leg - Bonnet leading Edge Test

Full-scale tests have shown that in a pedestrian accident the leading edge of the bonnet of cars most frequently strikes the femur and pelvis of adults and the pelvis, abdomen or femur of children.

Reports, from European accident studies (2, 3, 23) show that for accidents at speeds up to 40km/h pelvic and femur injuries of AIS 3 or worse were more frequently to adults than to children. Child abdominal injury of AIS 3 or worse was rarely seen at speeds of 40km/h or less. As a consequence the impactor that has been developed for this sub-systems test represents a segment of an adult femur (see Figure 4).

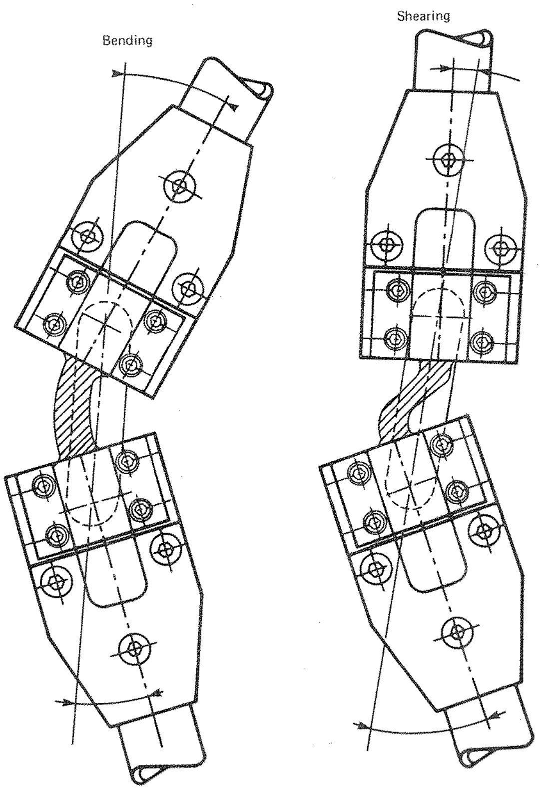


Figure 3. Deformations of the Knee, Lower Leg Impactor

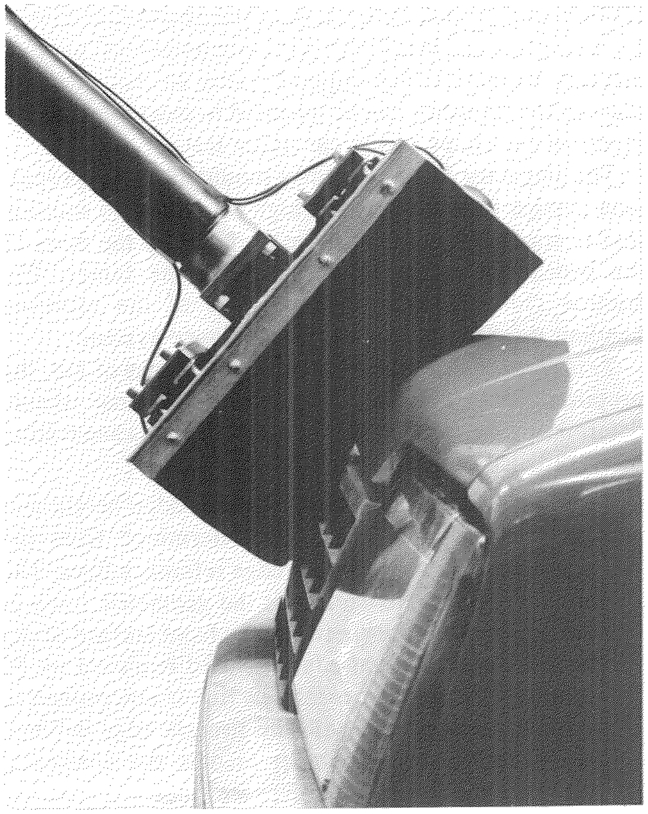


Figure 4. Upper Leg to Bonnet Leading Edge Impactor

Development of Impactor. The objective of the test is to replicate the impact conditions to the leading edge of a bonnet of a car, when an adult pedestrian is hit at a speed of 40km/h. Test data have shown, however, that the severity of bonnet edge impact is very strongly influenced by the general shape of the front of a car. This influence results in variations to the impact velocity, the effective mass and to the direction of this impact.

The magnitude of these variations and the basic design of the impactor were initially determined from the results of full-scale dummy tests (18 and 24). Subsequent tests reproduced actual road accident conditions and also the limited cadaver test data available relating to European type cars. Mathematical computer simulations of car to pedestrian dummy impacts (19) have provided corroborative and more extensive data. They also demonstrated that the height above the ground of pedestrian contact to the area of the bonnet edge is primarily dependent on car shape and not on pedestrian stature. The combined results of the computer simulations and of the tests replicating accident conditions have been used to establish the proposed performance criteria and to adjust the test to give a better representation of the human condition (18).

Impactor. The impactor consists of a foam covered tube of 50mm diameter and 350mm long. The tube is mounted at either end through slotted pin joints and load cells to a support frame. This frame is in turn mounted through a friction clutch to a guidance ram. Additional instrumentation is provided by strain gauges attached to the impactor tube to measure bending moments at the centre and at 50mm either side of the centre (see Figure 5). Provision is made for the attachment of supplementary weights to the support frame so that the total mass of the impactor can be adjusted to meet the requirements of the shape of the car under test.

The impactor is permanently mounted to the propulsion system to reproduce the high resistance to rotation that is normally provided in an accident by the mass of the pedestrian acting on the ends of the femur. The friction clutch limits the magnitude of the resulting bending moments acting on the guidance system.

Test Method. To allow for different shapes of car, the proposed test includes: determining the car shape, determining the corresponding test conditions and testing in accordance with these conditions.

(a) The shape is defined by the bonnet edge height and the bumper lead. These are determined from the bumper and bonnet leading edge reference lines. The bonnet edge reference line is the geometric trace of the points of contact between the front surface of the bonnet and a straight edge inclined rearward by 50 degrees. The bumper reference line is determined in a similar manner but with the straight edge inclined at 20 degrees. The bumper lead is the horizontal distance between these reference lines.

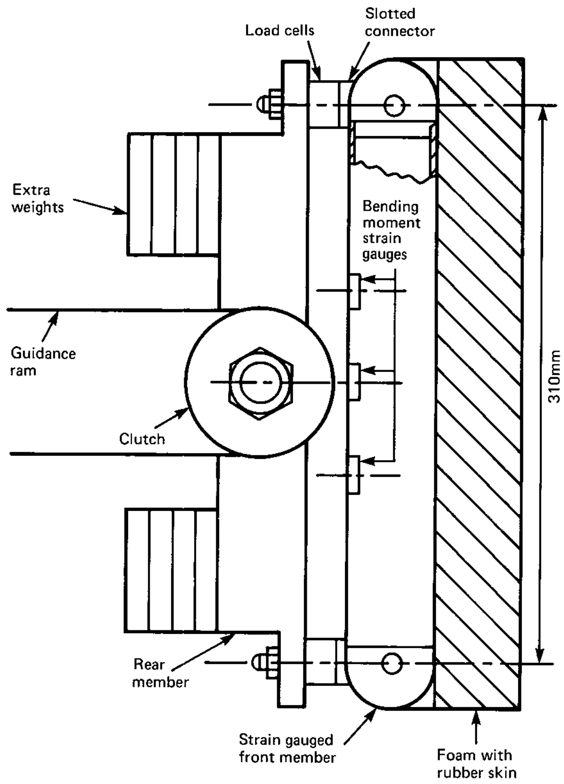


Figure 5. Details of Upper Legform to Bonnet Leading Edge Impactor

(b) Using these values of bonnet height and bumper lead; determine the direction, velocity (V) and kinetic energy (E) of impact from reference graphs (Figures 6, 7 and 8).

(c) Calculate the mass of the impactor using the values determined in (b) where Mass = $2E / V^2$.

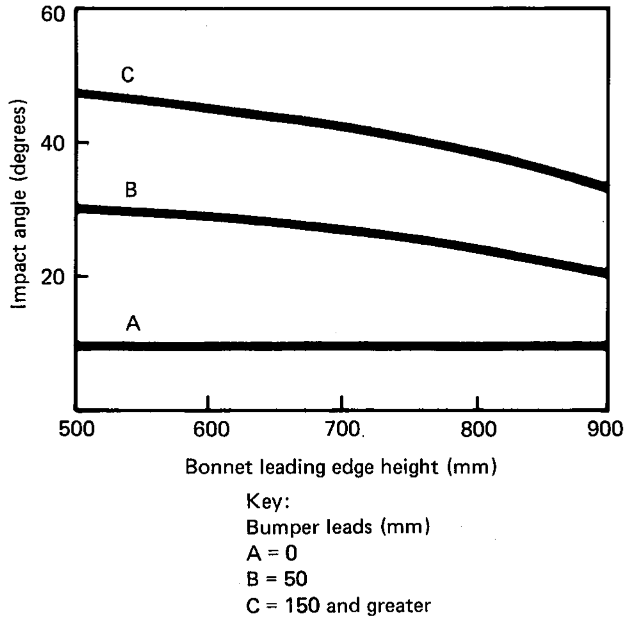
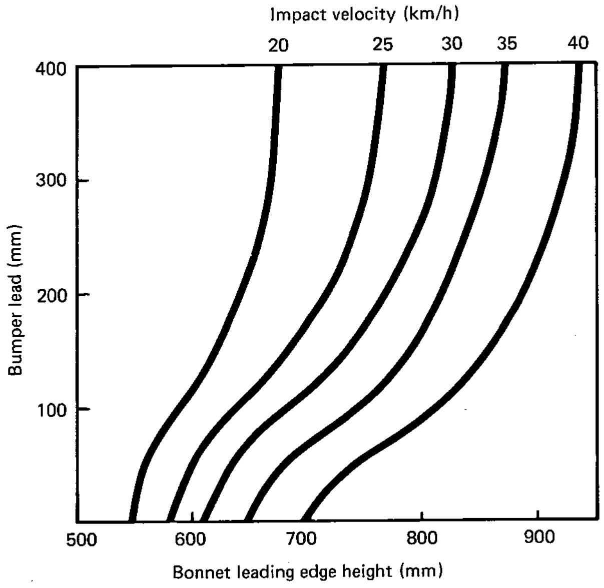


Figure 6. Angle of Impact of Upper Legform Impactor with Respect to Vehicle Shape

(d) Adjust the mass of the impactor to the value determined in (c).

(e) With the impactor centred on the bonnet leading edge as determined in (a) and the impact angle set as determined in (b) impact the test point at the velocity determined in (b).



Notes:
1. Interpolate horizontally between curves
2. Minimum test velocity 20 km/h
3. With configuration above 40 km/h -test at 40 km/h

Figure 7. Velocity of Upper Legform Impactor with Respect to Vehicle Shape

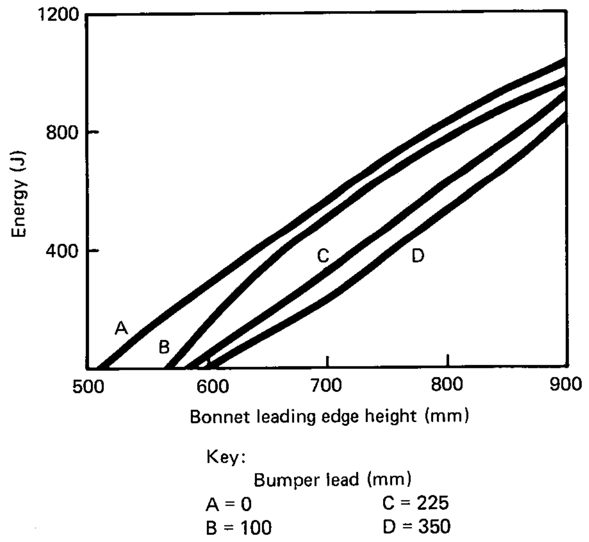


Figure 8. Kinetic Energy of Upper Legform Impactor with Respect to Vehicle Shape

It is recommended that a bonnet leading edge is tested at a minimum of three locations, one each to the centre and outer thirds at positions that are judged to be the most likely to cause injury.

Acceptance Levels. Provisional acceptance levels have been set at a total force of 4kN and bending moment of 220Nm.

Exceptionally High Bumpers. The top edge of some exceptionally high bumpers (600mm or more above the ground) may also be assessed by this test, providing the position of the bonnet leading edge falls between certain limits. The bumper - lower leg impactor primarily evaluates injury to the lower leg and knee. The bonnet leading edge impactor primarily evaluates injury to the upper femur. A high bumper may be a particular risk to the upper femur, a condition that is not assessed by the bumper impactor.

Headform to Bonnet Top Test

Accident data have shown that the head is the body region most frequently suffering life threatening injuries in both child and adult pedestrian accidents. In these cases brain trauma or skull fracture was reported from low speed impacts for all age groups with over 30 per cent of such injury cases occurring from accidents at speeds up to 40km/h (derived from Reference 3). Approximately half of these head injuries were attributable to striking the car. Adult head impacts were most frequently to the most rearward part of the top of the bonnet and wings, and to the windscreen frame and the windscreen. The head impacts of young children were most frequently to the frontal part of the bonnet top (2 and 3).

As a consequence of these findings it is proposed that two assessments will be included in this sub-systems test. One is based on an impactor representing a child headform to evaluate the forward section of the bonnet and wings and the second based on an adult headform to assess the rear of the bonnet, and wings and the scuttle.

Development of Impactors. The performance of the adult headform has been assessed against the results of cadaver tests and these showed good similarities in the time histories of the resultant accelerations (16). In these cadaver tests with a car impact speed of 40km/h, the head impact velocities to the bonnet were between 43 and 50km/h with a direction of impact of approximately 65 degrees to the horizontal. Headform impactor tests to a car body shell with internal components removed (engine and suspension) showed that it would be difficult to achieve a value of Head Injury Criteria (HIC) of less than 1000 from head impact velocities of 45km/h or greater.

Computer simulations of impacts to pedestrians gave corroborative values for the angle of head impact to the bonnet of approximately 65 degrees to the horizontal for adults and between 40 and 55 degrees for children. The simulations also showed that head impacts were nearer to the front of a car and at a reducing head impact velocity for reduced heights of pedestrians.

Impactors. Both of the headforms that have been developed for these tests (16) are of spherical shape (to give more repeatable results) and made of a phenolic resin core, with a 7.5mm thick silicone skin cover (see Figures 9 and 10). The adult impactor weighs 4.8kg and has an overall diameter of 165mm including the silicone cover and meets the existing calibration requirements for Hybrid III dummies. The child impactor weighs 2.5kg and has an overall diameter of 130mm including the silicone cover and meets the calibration requirements according to part 572 Hybrid II. Triaxial accelerometers are fitted at the centre of both headforms.

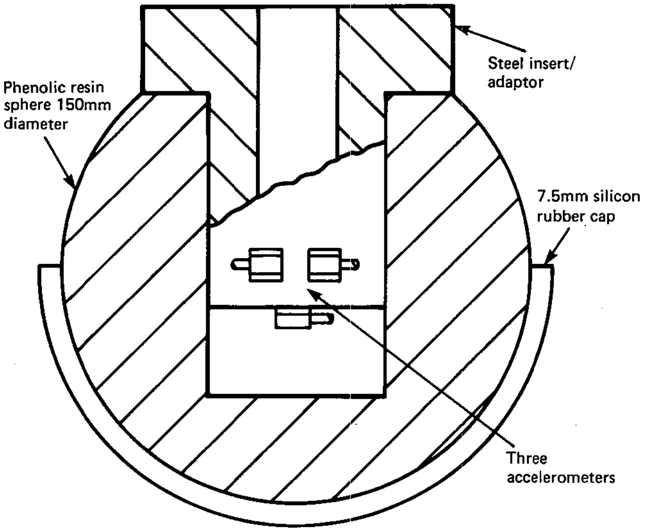


Figure 9. Adult Headform Impactor

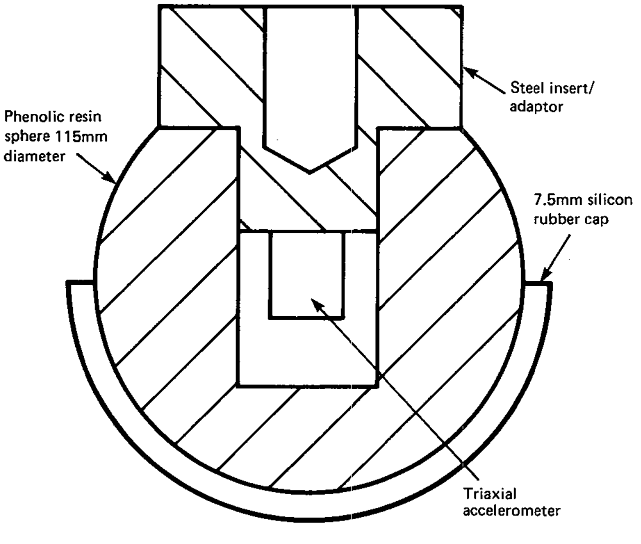


Figure 10. Child Headform Impactor

Test Method. Child headform tests are performed onto the forward section of the bonnet and wings, bounded by wrap around distances of 1000mm and 1500mm. (See Figure 11). The direction of impact is rearward and downward at an angle of 50 degrees to the horizontal. Adult headform tests are performed to the rearward section of the bonnet and wings and to the scuttle, bounded by wrap-around distances of 1500mm and 2100mm. When the windscreen extends forward of the 2100mm wrap-around distance, then the windscreen lower frame is the rear boundary. The direction of impact is rearward and downward at an angle of 65 degrees to the horizontal. For tests adjacent to the lower edge of the windscreen, the headform should not contact the windscreen glass before striking the vehicle structure. For both tests the velocity of impact is 40km/h and the headforms are in free flight at the instant of impact.

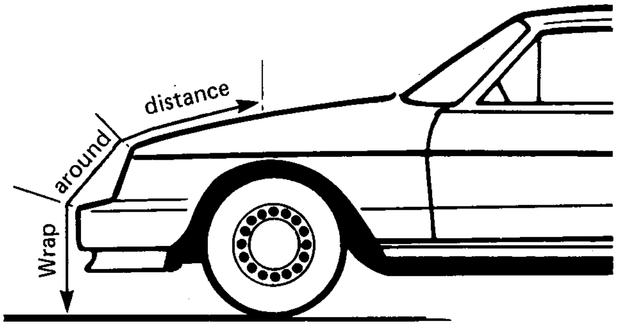


Figure 11. Determination of Wrap Around Distance

It is recommended that nine tests shall be carried out with each headform, three tests each to the middle and the outer thirds of the forward and rearward section of the bonnet at positions judged to be the most likely to cause injury. The tests should be to different types of structure where these vary throughout the area to be assessed.

Acceptance Levels. The proposed acceptance level is that the Head Performance Criteria, calculated from the resultant acceleration of the headform accelerometer time histories shall not exceed 1000.

Compatibility

The basic requirements to improve pedestrian protection have been well documented (20 and 21) and are briefly as follows:

Bumper. A large contact area to reduce local pressure. A low stiffness reduces both the bending moments in the leg and the local crushing force. A low effective bumper height also reduces bending moments in the legs.

Bonnet Leading Edge. A large contact area to reduce local pressure. A low stiffness reduces both the bending moments in the leg and the local crushing force.

Bonnet Top. A low stiffness to reduce head deceleration.

In all of the above requirements it is necessary that the outer shell of the car does not 'bottom out' onto a hard under structure during an impact.

Design Aspects for Pedestrian Safety

Complying with the pedestrian safety proposals in addition to the current operational and regulatory requirements will have the following implications for the three areas of a car under consideration.

Bumper. In recent years the bumper has been developed to give protection to the vehicle in low speed accidents. As a result of the regulations dealing with these vehicle protection requirements, bumpers have tended to be mounted higher above the ground and made stiffer and stronger. These changes potentially give an increased risk of injury to pedestrians.

Designs of bumpers, currently fitted to cars, however, range from rigid (to the pedestrian) relatively narrow devices, to deep plastic outer skins mounted on a strong support frame. The stiff narrow bumper has all the design features that are to the disadvantage of the pedestrian. The deep plastic bumper has many of the advantages and these could be improved further by introducing more compliance between the outer skin and the rigid under-structure. This change in mounting technique may require an increase in vehicle length, but the increase would be small compared to that often introduced for other reasons.

Bonnet Leading Edge. For many cars the bonnet leading edge presents less of a problem than the bumper.

In most of the cars tested the deformation that was reported in accidents was sufficient to limit the severity of resulting injury to AIS 2 or less. The evolution of design of many types of cars in recent years is likely to have resulted in a reduction in the frequency and severity of injury from bonnet leading edge contact. Additional improvements could be achieved where necessary by further isolating the strong under structure from the outer shell. For a small number of cars, of course, these changes would entail considerable modifications in design.

Bonnet Top. The top of the bonnet with respect to head impact presents the widest range of problems to be considered. The features that most frequently cause injury are the traditionally stiff outer surfaces of the scuttle, lower edge of the windscreen and the joint between the bonnet top and wings. Additional to these locations are the regions of the bonnet top that have been stiffened locally or are above hard underlying structures that are near the top surface. These underlying structures may be the suspension, the engine or its ancillary components. The risk of hitting these underlying structures is dependent upon the free space under the bonnet. This free space has been eroded in recent years and current models of car show considerable variations in the space available both with respect to the style of car and between the power units that are fitted. Research has indicated that at least 80 mm of deformation of the bonnet will be necessary to allow a headform to stop from a speed of 40km/h without exceeding a HIC of 1000. This degree of deformation capability most frequently occurs towards the front of the bonnet, in the area associated with child head impact. The areas towards the rear of the bonnet frequently have less free space. In this study, 23 popular cars were examined (20 and 21) and of these, 5 of the cars had more than 80mm depth of clear space below more than 60 per cent of the bonnet surfaces. For 9 of the cars, less than 40 per cent of the bonnet area had 80mm of under space. These results demonstrate that many types of current designs of cars have significant areas of bonnets that cannot give adequate protection against head impact.

An increase in under bonnet space is possible but will require either a small increase in the size of engine compartment or a reduction in the size or relocation of the hard components that are currently packed below the bonnet. Some improvements to all of the stiff areas of the outer shell have been demonstrated (10, 11, 12 and 25).

Introduction of Safety Proposals. In some areas these changes may be considerable and impractical to incorporate into existing models. It should however be feasible to introduce such changes in the design of new models without imposing undue constraints on styling or other design requirements. To facilitate these changes it is recommended that the full requirements of the proposals are phased-in over a period of time.

Estimated Reduction of Injuries

Bumper and Bonnet Leading Edge Tests

Accident studies have shown that nearly 40 per cent of leg and pelvic injuries, of severity AIS 3 or worse, resulted from accidents at speeds of 40km/h or less. Injuries of this type are most frequently attributed to contacts with the bumper or bonnet leading edge, the areas that the proposed test methods are designed to assess.

The introduction of both these test methods, based on an impact speed of 40km/h, has therefore the potential to ameliorate up to nearly 40 per cent of the pelvic or leg injuries of severity AIS 3.

Headform Bonnet Top Test

A headform test at 40km/h is representative of the conditions in a car to pedestrian accident at a speed of about 35km/h. Approximately 25 per cent of all skull fracture and brain trauma injuries were reported as occurring at or below this speed (derived from ref 3). However in an accident sample in which the cause of injury was identified (26) only 40 per cent of the head injuries of severity AIS 3 or worse were attributed to an impact with the areas to be assessed by this test. The other 60 per cent of the injuries resulted from striking the ground or other parts of the car (A posts, header rail, roof etc). Head impacts to the more rearward areas of a car are generally associated with high speed accidents. Nevertheless the introduction of both the headform test methods, based on test velocities of 40km/h, has the potential to ameliorate rather less than 25 per cent of skull fracture and brain trauma injuries.

The magnitude of the savings given above will not be achieved until all the car fleet complies with the test requirements. The improved protection may however give additional reductions of injury in some accidents at speeds above 40km/h.

Conclusions

(1) Three sub-systems test methods have been developed to assess protection afforded to pedestrians by the fronts of cars. These tests separately assess the bumper, the bonnet leading edge and the bonnet top. The test velocities relate to a car to pedestrian accident at 40km/h.

(2) The results of in-depth accident studies suggest that nearly 40 per cent of leg and pelvic injuries of severity AIS 3 or greater occur at speeds of 40km/h or less. It is estimated that most of these leg and pelvic injuries and rather less than 25 per cent of the skull fracture or brain trauma injuries could be saved when all the cars on the road have the proposed improvements.

(3) The impactors for the bumper and bonnet leading edge tests are based only on the characteristics of adults because they are shown by accident statistics to be most at risk. Accident studies have shown that children are more resilient than older adults and these proposals are therefore considered to be of benefit to all age groups. Both child and adult headforms are used for tests to the top of the bonnet to reflect the equal risk to all age groups of pedestrians and the different areas of impact associated with the different heights of pedestrians.

(4) The test to the bumper uses an impactor representing a leg with an articulated knee that is propelled at a fixed height in free flight, into the front of a car. The impactor weighs 13.4kg and is 841mm long. The knee joint is fitted with non elastic stiffeners that control the lateral bending of the knee. Assessment is by measurement of the angle of bending of the knee and the acceleration of the lower leg. Proposed acceptance levels are that knee rotation shall not exceed 15 degrees due to bending and 5 degrees due to shearing. Tibia acceleration shall not exceed 150g.

(5) The test to the leading edge of the bonnet uses an impactor representing an adult femur. The impactor is attached to a propulsion system and projected forward and downward onto the bonnet edge. It is 350mm long and its mass, impact velocity and direction of impact are all adjusted with respect to the general shape of the car under test. Assessment is by measurement of force and bending moment and proposed maximum levels of acceptance are 4kN force and 220Nm bending moment.

(6) The test to the bonnet top includes two impactors that represent adult and child headforms. The impactors are spherical and have masses and diameters of 2.5kg and 130mm respectively for the child and 4.8kg and 165mm for the adult. They are propelled rearward and downward at a velocity of 40km/h on the bonnet top. The child headform impacts the front section of the bonnet at an angle of 50 degrees to the horizontal and the adult headform impacts the rear of the bonnet at an angle of 65 degrees. The proposed level of acceptance for both child and adult headform tests are Head Protection Criteria (HPC) shall not exceed 1000, calculated from the resultant of acceleration time histories.

(7) Introducing such test requirements will have the following implications for car and component manufacturers.

Adapting rigid protruding steel bumpers of relatively narrow section to comply with the proposals will be very difficult. The deep plastic bumpers that are currently in use, mounted from buried mounting points are however potentially far better suited.

The risk of injury from the leading edge of the bonnet has reduced in recent years and for most manufacturers meeting this test's requirements should not present major difficulties. A few styles of cars will however have significant problems in adapting to the requirements of the test and for many cars the headlight surround will require close attention.

The top of the bonnet has two problems, the stiff areas of the outer shell and the restriction to bonnet top deformation that is caused by the proximity of components in the engine compartment to the outer shell. Proposals for reducing the stiffness of the outer shell have been reported in the literature.

Adequate free space under the bonnet in current cars to allow for safe head impact is available from approximately 32 to 75 per cent of the surface area of the bonnet for the 23 types of car tested. An increase in this free space will entail either a small increase in the volume of the engine compartment or a relocation or reduction in the size of the hard components that are packed under the bonnet. This would require significant change for existing models of car with densely packed engine compartments, but it should be feasible to incorporate such changes in the design of new models without imposing undue constraints on styling or other design requirements.

Acknowledgments

The work described in this paper was carried out by APR, BASt, INRETS, TNO and TRRL with partial financial support from the European Commission which is gratefully acknowledged.

References

1. Statistics of Road Traffic Accidents in Europe. United Nations - New York 1990.
2. EEVC Committee. Pedestrian injury accidents Proceedings Ninth International Technical

Conference on Experimental Safety Vehicles. Kyoto, Japan, November 1982.

3. Otte D. Influence of vehicle front geometry or injuries to pedestrians involved in accidents. Study of accident research at Medical University of Hannover under contract to BASt. 1988.
4. EEVC Committee. Study of test methods to evaluate pedestrian protection for cars. Proceedings Twelfth International Technical Conference on Experimental Safety Vehicles, Gothenburg, Sweden May 1989.
5. Ashto S J, G M Mackay. Some characteristics of the population who suffer trauma as pedestrians when hit by cars and some resulting implications. IRCOBI Gothenberg, Sweden 1979.
6. Danner M et al. Injuries to pedestrians in real accidents and their relation to collision and car characterisation. Department of Automotive Engineering Association of Automobile Insurers (HUK Verbarg) 23rd STAPP Car Crash Conference, San Diego, United States, 1975.
7. Hutchinson T P. Factors affecting the time till death of pedestrians killed in road accidents. Injury 6 (1975) 208.
8. Thorp K J, NJ Isongos. Injury severity factors. Traffic pedestrian collisions. University of Houston, Texas. US Department of Transportation. IRCOBI Amsterdam 1976.
9. Appel H et al. Influence of impact speed and vehicle parameters on injuries of children and adults in pedestrian accidents. IRCOBI Birmingham England 1975.
10. Hobbs C A et al. PSC1 - Demonstration car with improvements for pedestrian protection. Proceedings Tenth International Technical Conference on Experimental Safety Vehicles, Oxford, England, July 1985.
11. Huber G. Aspects of passive safety in Mercedes - Benz research car. Proceedings Ninth International Technical Conference on Experimental Safety Vehicles, Kyoto, Japan, November 1982.
12. Kramer M. Improved pedestrian protection by reducing the severity of head impact onto the bonnet. Proceedings Seventh International Technical Conference on Experimental Safety Vehicles, Paris, France, June 1979.
13. Sturtz G. Experimental simulation of the pedestrian impact. Proceedings Tenth International Technical Conference on Experimental Safety Vehicles, Oxford, England, July 1985.
14. Kajzer J et al. Bumper system evaluation using an experimental pedestrian dummy. Proceedings Twelfth International Technical Conference on Experimental Safety Vehicles, Gothenburg, Sweden, May 1989.
15. Grosch L, W. Heiss. Bumper configurations for conflicting requirements: Existing requirements vs pedestrian protection. Proceedings Twelfth International Technical Conference on Experimental Safety Vehicles, Gothenburg, Sweden, May 1989.
16. Glaeser K P. Development of head impact procedure for pedestrian protection. Proceedings of Thirteenth International Technical Conference on Experimental Safety Vehicles, Paris, France, November 1991.
17. Cesari D et al. Sub-system for lower leg and knee protection. Proceedings of Thirteenth International Technical Conference on Experimental Safety Vehicles, Paris, France, November 1991.
18. Lawrence, G J L et al. Bonnet leading edge sub-systems test for cars to assess pedestrian protection. Proceedings of Thirteenth International Technical Conference on Experimental Safety Vehicles, Paris, France, November 1991.
19. Janssen E G, J J Nieboer. Protection of vulnerable road users in the event of collision with a passenger car, Part 1 - Computer simulations. TNO Report No 75405002/1 under Contract No ETD/89/7750/M1/28 to the European Commission December 1990.
20. Janssen E G. Protection of vulnerable road users in the event of a collision with a passenger car, Part II - Sub-systems test method evaluation and compatibility study. TNO Report No - 75405002/II under contract No ETD/89/7750/M1/28 to the European Commission December 1990.
21. APR Compatibility. Association Peugeot SA/Renault report under Contract No ETD/89/7750/M1/28 to the European Commission December 1990.
22. Cesari D et al Interaction between human leg and car bumper in pedestrian tests. Proceedings 1988 IRCOBI Conference. Bergisch Gladbach, Germany. September 1988.
23. Ashton S J et al. Pedestrian injuries and the car exterior. Society of Automotive Engineers Transactions, SAE paper 770092, Warrendale, Society of Automotive Engineers 1977.
24. Lawrence G J L. The influence of car shape on pedestrian impact energies and its application to sub-systems tests. Proceedings Twelfth International Technical Conference on Experimental Safety Vehicles, Gothenburg, Sweden, May 1989.
25. Kessler J W. Development of countermeasures to reduce pedestrian head injury. Proceedings Eleventh International Technical Conference on Experimental Safety Vehicles, Washington, USA, May 1987.
26. Ashton S J. Cause nature and severity of the injuries sustained by pedestrians struck by the fronts of cars or light goods vehicles. Thesis, University of Birmingham, 1978.

Annex 1. List of Participants in EEVC Working Group 10

Mrs F Brun Cassan, APR, France
D Cesari, INRETS, France
The late
G Ferrero, Fiat/Ministero dei Transporti, Italy
K P Glaeser, BASt, Germany
N D Grew, Rover/SMMT, UK
J Harris, TRRL, UK Chairman
W Heiss, Mercedes Benz, Germany
E G Janssen, TNO, Netherlands
G J L Lawrence, TRRL, UK
P Massaia, Fiat/Ministero dei Transporti, Italy
H Mellander, Volvo, Sweden

S3-O-07

Development of a Head Impact Test Procedure for Pedestrian Protection

K.-P. Glaeser
Federal Highway Research Institute (BASt)

Accident Statistics

About 10,000 or 20% of the traffic fatalities in the countries of the European Community are pedestrians [1]. The EEVC WG 7 Report [2,3] gives a detailed description of the pedestrian accident situation in Europe. For a more recent and more detailed analysis the accident statistics of the Federal Republic of Germany (before Oct. 90) was analyzed.

In the Federal Republic of Germany the number of persons killed in pedestrian accidents dropped from 1970 from about 6,000 to about 1,650 in 1989. The overall fatality rate (the number of fatalities per 100 injured) dropped in the same period from 7,3 to 4,0 (Table 1) while the car population doubled, from 14 to nearly 30 million vehicles [4].

Table 1. Number of Pedestrians Killed and Injured in the Federal Republic of Germany

	1970	1975	1980	1985	1989
fatalities	6,056	3,974	3,095	1,790	1,651
injuries (fatal, major, minor)	83,505	64,006	59,546	45,181	41,448
overall accident severity (fatalities/100 injured)	7.3	6.2	5.2	4.0	4.0

The number of children under 15 years killed in pedestrian accidents dropped sharply and steadily from 1,290 in 1970 to 160 in 1989. Whereas the percentage of children under 15 years involved in all pedestrian fatalities was still 20% in 1970, it was only 10% in 1989. The proportion of elderly pedestrians killed in the same time period rose from about 40% to 50%, although the absolute number also dropped from 2,509 in 1970 to 826 in 1989. Both age groups are now at a comparable size of 9 Million people.

It can be stated for both age groups, that about twice as many people died as pedestrians than as car occupants. Apart from the general downward trend in the number of killed and injured persons in pedestrian accidents in the Federal Republic of Germany, a shift in age distribution—from children to the elderly—in the pedestrians involved in accidents has taken place. In the case of the elderly, however, the risk of being killed in a pedestrian accident is about 6 to 7 times higher than for children due to higher mortality.

If the age distributions for men and women are combined, each with the height distribution of the German population [5,6], a height distribution for fatally injured and injured pedestrians can be obtained. Figure 1 shows the height distribution of injured pedestrians (50. percentile, n = 43574).

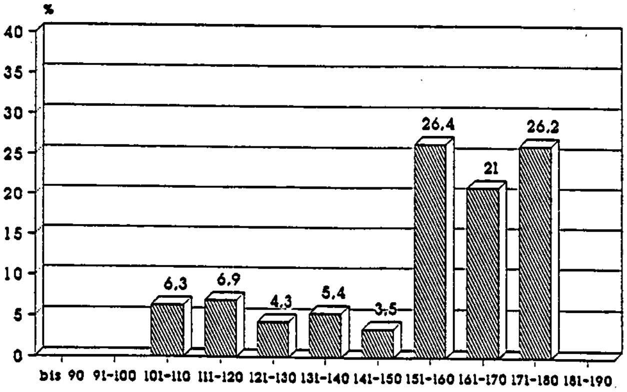


Figure 1. Height Distribution in % of Injured Pedestrians, FRG 1988

Pedestrian Head Injuries

Description and Distribution Head Injuries

The human head can be divided into different zones—the skin and soft parts, the bony skull and the brain—each with its specific injuries.

In the AIS scale, the boundary between reversible and irreversible damage is between AIS 2 and AIS 3. The border between injuries endangering life and not endangering life can assumed between AIS grades 3 and 4.

A special evaluation of the accident material of the Hannover Medical College (Accident Investigation Team) relating to pedestrian head injuries was made at the beginning of the research project and an extract is given here. [7] The vehicle impact speeds recorded in the sample seem to be a bit higher in the selected pedestrian accident cases than in reality.

The material consists of 522 cases of pedestrian accidents with an impact on the front of a passenger car. The age distribution was:

- 41% children < 14 years
- 39% adults > 14 years and < 65 years
- 20% elderly persons > 65 years

The MAIS distribution is shown in Table 2.

Table 2. MAIS—Distribution in %, Pedestrian Accidents, MHH

	TOTAL	children	adults	elderly
uninjured	1.2	1.9	0.6	-
MAIS 1/2	61.7	75.1	57.0	45.1
MAIS 3/4	25.9	14.7	30.2	36.1
MAIS 5/6	11.3	6.2	12.2	18.9
among them deceased	15.0	3.3	13.9	36.9

For these injured pedestrians in the sample the following height distribution is given in Figure 2 with a comparable scaling as in Figure 1.

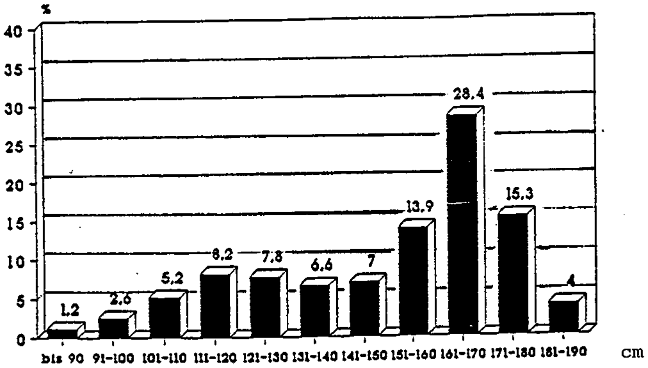


Figure 2. Pedestrian Height Distribution in MHH Sample n=503

Elderly pedestrians more frequently sustained more serious injuries than children, and the mortality rate is much higher.

AIS 5/6 head injuries occur at over 30 km/h and are very frequent at over 50 km/h especially among elderly persons. The AIS head injury distribution for people in different age groups are shown in Figure 3.

In the speed range of relevance for the test procedure, viz. 30-50km/h, a distinction is made between injuries to head bones and brain, Table 3.

The high share of isolated brain traumas seemed to justify a measurement of the resulting acceleration and a calculation of the HIC for a test procedure, although higher levels of severity often involve a combination of fracture and brain trauma.

Car/pedestrian accidents at high collision speeds often result in pedestrian head impacts on windscreens. The likelihood of head impacts on windscreens has also become more widespread in recent years due to the installation of the engine in a position across to the direction of driving and the shorter length of the bonnet of European cars.

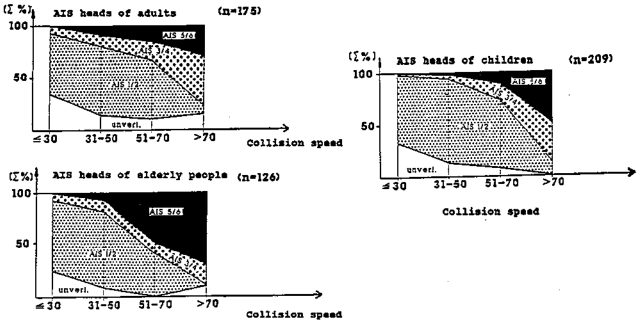


Figure 3. Cumulative Frequency of AIS—Head Injuries in Relation to Collision Speed for Different Age Groups

Table 3. Breakdown of Head Injuries by Isolated Fractures and Isolated Brain Traumas and by Combined Injuries—for Children and Adults

	Total	Car Velocity			
		below 30	31 - 50	51 - 70	over 70
Total persons (n) incl. head injuries none	528 61.9%	147 84.4%	246 64.6%	100 31.0%	35 37.1%
isol. facial frac	1.5%	4.3%	-	1.4%	4.5%
isol. skull frac.	4.0%	-	2.3%	5.8%	9.1%
isol. brain trauma	70.1%	87.0%	80.5%	63.8%	31.8%
face + skull	1.0%	-	-	1.4%	4.5%
face + brain	9.0%	-	6.9%	8.7%	27.3%
skull + brain	6.5%	8.7%	6.9%	2.9%	13.6%
face + skull + brain	8.0%	-	3.4%	15.9%	9.1%
children total (n) incl. head injuries none	213 66.7%	63 88.9%	102 67.6%	39 33.3%	9 44.4%
isol. facial frac	-	-	-	-	-
isol. skull frac	2.8%	-	3.0%	3.8%	-
isol. brain trauma	81.7%	85.7%	88.0%	80.8%	40.0%
face + skull	-	-	-	-	-
face + brain	7.0%	-	3.0%	7.7%	40.0%
skull + brain	2.8%	14.3%	3.0%	-	-
face + skull + brain	5.6%	-	3.0%	7.7%	20.0%
Adults total (n) incl. head injuries none	308 58.1%	83 80.7%	140 61.4%	60 30.0%	25 32.0%
isol. facial frac	2.3%	6.3%	-	2.4%	5.9%
isol. skull frac	3.9%	-	1.9%	4.8%	11.8%
isol. brain trauma	64.3%	87.4%	75.9%	54.8%	29.4%
face + skull	1.6%	-	-	2.4%	5.9%#+
face + brain	10.1%	-	9.3%	9.5%	23.5%
skull + brain	8.5%	6.3%	9.3%	4.8%	17.6%
face + skull + brain	9.3%	-	3.7%	21.4%	5.9%

The max. possible wrap-around length up to the windscreen for the 20 vehicles most often encountered among new registrations in Germany was measured (-60% of the total) [17]. The mean value was 1.8m and the min. and max. values approx. 1.6m and 2.0m resp. These values can differ if account is taken of the braking diving of the vehicle and the sole and heel height of the pedestrian's shoes.

When account is taken of the height distribution for pedestrians above and the ratio of body height to wrap-around distances, it becomes clear that impact on the windscreen is possible or probable for an adult pedestrian upward of 1.7m in height for a speed range of 30 - 50km/h (Fig. 4).

A special analysis was carried out for pedestrian accidents with head-to-windscreen contact, showing that cuts (incl. eye injuries) occur almost entirely in the case of tempered safety glass, while obtuse traumas tend to occur more in the case of laminated glass. [9]

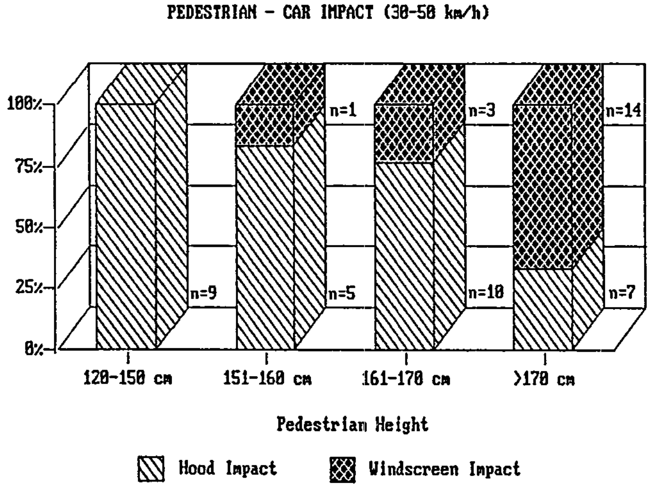


Figure 4. Head-Bonnet and Windscreen Impacts vs. Pedestrian Height Speed Range from 30 - 50km/h (Figures from [7])

Some tests were carried out with leather-lined dummy heads being dashed at 30km/h against tempered safety glass and laminated glass windscreens for one and the same vehicle which showed the same results. [10]

Literature on Pedestrian Cadaver Head Impacts

To obtain a frame of reference for pedestrian head impact test conditions, it is necessary to know the impact points, impact speeds and impact angles for the pedestrian heads. To this end, all the above data were taken, wherever possible, from different literature and plotted in graphs.

Plotting the wrap-around length L and the pedestrian height H reveals an accumulation of *L/H values* between 1.1 and 1.2, as shown in Fig. 5. This is in agreement with the not differentiated cadaver test data in [16].

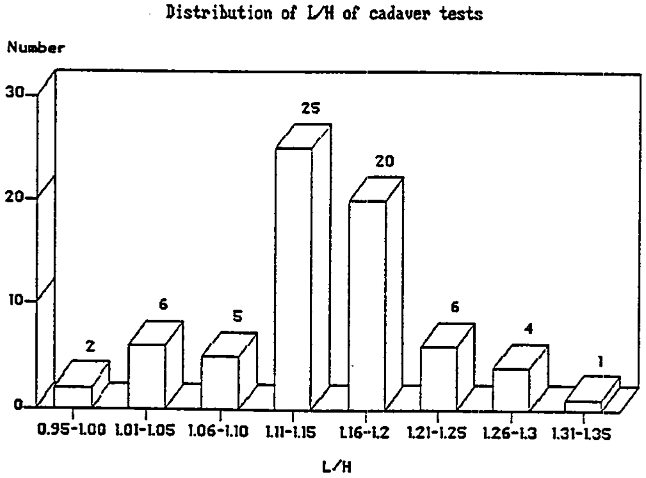
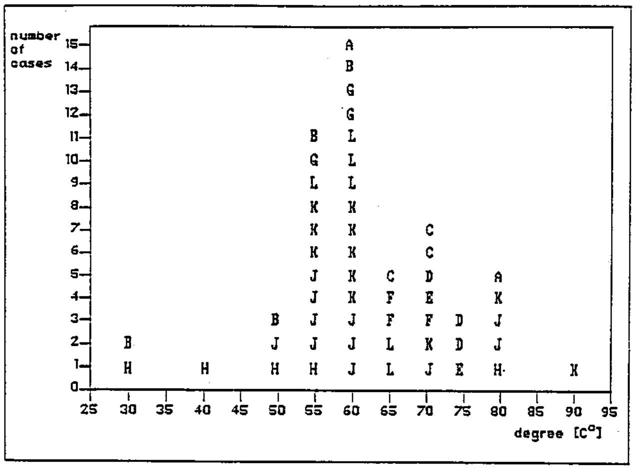


Figure 5. Distribution of L/H of Cadaver Tests and Real Accident Cases from Different Literature Sources [n = 69]

The head impact angle can only be obtained from films of cadaver tests. Fig. 6 shows the angle of impact taken from the literature. This shows an accumulation of cases for a head impact angles of 50° to 80° in the case of adults.

The impact angle for children's heads can only be obtained from mathematical simulation, e.g. [17] or from dummy tests because of the lack of child pedestrian tests.



Cadaver Standing Position	Car
A = facing sideways	Audi 100
B = facing sideways	Citroen GS
C = facing sideways	Citroen GS
D = ?	Audi 100
E = ?	Renault R4
F = ?	Peugeot
G = facing backwards	VW Golf
H = facing backwards	MB
I = frontal	Div.
K = facing sideways	Div.
L = facing sideways	Audi 100

Figure 6. Head Impact Angles from Cadaver Tests in Literature

The literature [16] shows that the head impact speed v_H—related to the collision speed v_O—has a considerable scatter and values v_H/v_O of 0-5 1.5 and even more are possible. An evaluation of other literature, too, shows that a v_H/v_O value of 0.8 - 1.4 can be expected [15, 21, 22, 23]. This scatter is due in part to the arm support on the bonnet in cadaver tests. Without arm supports we could assume an vH/vO value of approx. 1.2 [15] in the case of pontoon-shaped vehicles and even higher values in the case of wedge-shaped vehicles, are possible. Here again, the head impact speed for children can only be obtained from mathematical simulation or dummy tests but these seem more to be in the range of the cars impacting speed. The above remarks apply to the impact speed range of 30 - 50km/h under consideration here.

Test Method Development

Head Impactor Propelling System

The impactor test rig of the BASt was developed to conduct component tests, e.g., to simulate head impact in pedestrian accidents. The system is process-controlled and performs a linear acceleration via an impact piston on which the test specimen is fastened by a holding system. The pressure required for the preset target velocity is generated by a pump in a piston accumulator, which accelerates the piston to the required speed. The hydraulic system can be run in two different test modes. In the "guided flight mode", the specimen is fastened to a carrier frame and the frame onto the obstacle. In the "free flight mode", specimens can be detached from the holding system and allowed to strike the obstacle freely.

The max. speeds and dimensions are: $v_{max} = 50$ km/h, $m_{min} = 4$ kg, $m_{max} = 40$ kg.

In the free flight tests, e.g. the head impact tests, the specimen is held by an electromagnet and released at the time of chosen velocity. With the test rig, the direction of catapulting can be arrested in a range between vertical and horizontal position. An electric drive permits vertical adjustment of the system to the outer dimensions of various vehicles, Fig. 7.

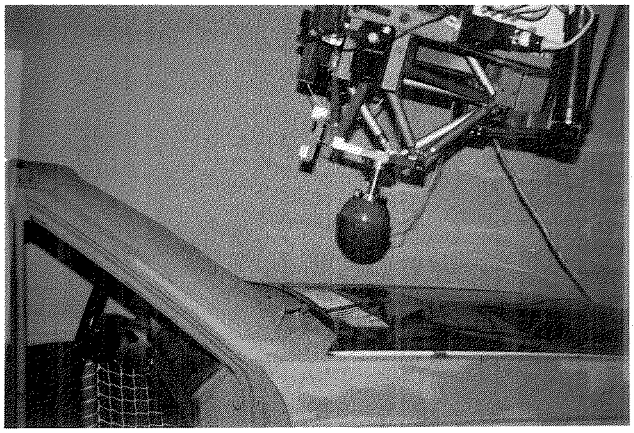


Figure 7. Impactor Propelling Rig

The test parameters for the process control of the system are entered via the control panel. The following variables—mode of impact (free flight or guided), impact speed, specimen weight, impact angle must be set prior to testing.

The system has an ultrasonic speed sensor for measuring the test speed. For the component head impact test procedure, described below only the free impact form was selected, since it takes account of the real situation where the angle of inclination and angle of deflection of the head are not necessarily identical.

Adult Head Impactor Development

Two main parameters must be laid down for a head impactor in its development: outer diameter and mass. Different ECE regulations (17,21,25) specify a diameter of 165mm for an (adult) head impactor, as does [13], and there are no reasons for not adopting this value. Impactor mass in these regulations is 6.8 kg, which appears to be too high relative to real head weights.

In a prior BASt study [8], the idea of shooting a dummy head alone against the bonnet was examined but rejected because of considerable scatter in the measured values.

Table 4 presents an overview of cadaver head weights and impactor weights from the literature.

Table 4. Literature Review of Head Impactors

Head (Impactor)	Weight	Literature
Cadaver head	3.7 - 5.0 kg	Beier 1980
Cadaver head	3.5 - 3.9 kg	Hodgson 1975
Cadaver head (with neck)	3.6 - 5.3 kg	Hodgson 1975
Cadaver head (neck?)	4.3 - 4.9 kg	Harless 1857
Impactor ECE 21	6.8 kg	ECE-Regulation
Dummy head	4.5 kg	Tennant 1974
Dummy head with neck	5.2 kg	own measurements
Specimen for head test pedestrians		
Steel hemisphere	7.1 kg	Kramer 1979
Hybrid II dummy head on pendulum	4.4 - 5.2 kg	Grösch 89/Kaeser 83
Wooden sphere	5.2 kg	Huß 1982
Dummy face and mould	4.5 kg	Pareira 83/Pritz/Hoyt 88
Sphere	6.8 kg	ECE/GRCS 1985
Dummy head Hybrid II	4.8 kg	Ferrero 1990
Dummy head Hybrid II + ballast 1 kg	4.6 - 5.6 kg	Brun-Cassan 1982
Head mass for pedestrian in computation models	5.0 kg 6.0 kg	Janssen 1990 Glöckner 1977

The spheres used so far have been made of metal or hardwood, and some had a skin cover.

For the pedestrian head impactors, Leukorit was chosen as material. This is an impact-resistant pure phenolic resin. It is fitted with a steel insert for 3 centrally located uniaxial accelerometers.

Impactor weight was defined at 4.8 kg in the first iteration of the later comparative tests with pedestrian cadavers. This is slightly above the impactor weight proposed in [11, 12, 14] as test weight in the American proposal for a pedestrian head impact test. Weight is adjusted by fitting steel rings.

For impacts on (what can be) extremely hard exterior car elements a skin cover seemed to be necessary for the pedestrian head impactor. Figure 8 shows the final design. Comparative tests in a BASt preliminary study [8] also showed that a certain damping effect can be achieved even in the case of hard elements located under the bonnet, whereas the skin cover plays only a subordinate role in the case of bonnet sections with large-area deformations. Another consideration in the choice of a skin was the calibration capacity of the impactor. The silicon skins produced met the existing calibration requirement for the heads of Hybrid III dummies. A hardness of 50 shore required a skin thickness of 7.5 mm. The absolute external diameter of 165mm is retained. To meet the above dummy head calibration requirements, the same test weight (4,6 kg) must exist. Fig. 9 shows the design drawing of the impactor and its elements. A calibrating weight of 500 g, which is employed for calibration instead of the additional weight of 700 g used for test (impactor weight 4,8 kg) purposes is needed.

Child Head Impactor Development

The impactor for the simulation of a child head impact should be based on a 6-year-old child. The development of the impactor was based on the proposal in [13] for an external diameter of 130mm and a weight of 2.5kg.

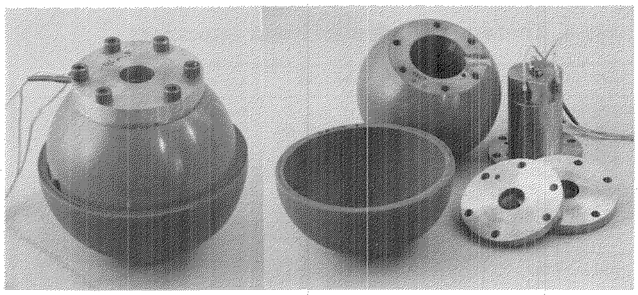


Figure 8. Head Impactor for Adult Pedestrian Tests

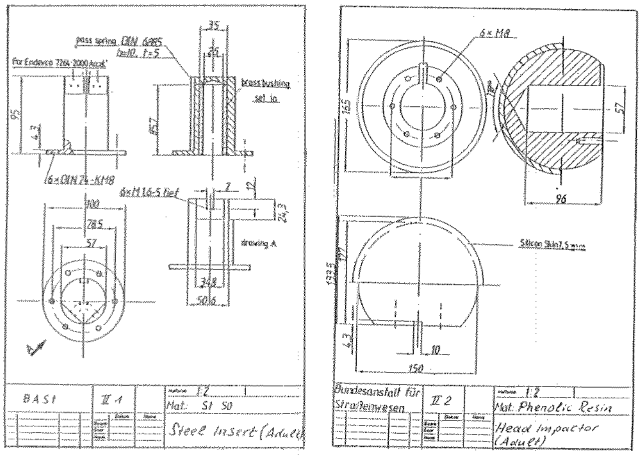


Figure 9. Technical Drawings of the Adult Head Impactor

Figure 10 shows the impactor with skin and steel insert for taking up a 3axis accelerometer. As in the adult impactor, the skin had a thickness of 7.5 mm and a hardness of 50 shore. The diameter of the sphere, again made of Leukorit (a phenolic resin), as simulator thus was 115 mm. The technical drawings are shown in Figure 11. The head meets the test requirements for head impact calibration according to part 572, Hybrid II.

Method Verification for the Impactor Tests

Since none of the previously published data from cadaver tests permit any conclusions to be drawn about the depth of the dents in the bonnet caused by a head impact, the original plan had discarded, and new cadaver tests were carried out. The object was to obtain an equal dent pattern using component tests. Assuming equal dent depth, the same input energy would have been necessary, ensuring comparability of cadaver and component tests.

Test Conditions

The Hannover Medical College was commissioned to make the cadaver tests [15]. The Federal Highway Research Institute made a buck of an Audi 5000, see Fig. 12. A vehicle with a long bonnet was selected to make sure that a head impact area was obtained on the bonnet. The bumper was drawn forward 16 cm in some of the tests. The object was to examine whether such a change in front angle from 63° to 53° has any effect on head impact velocity.

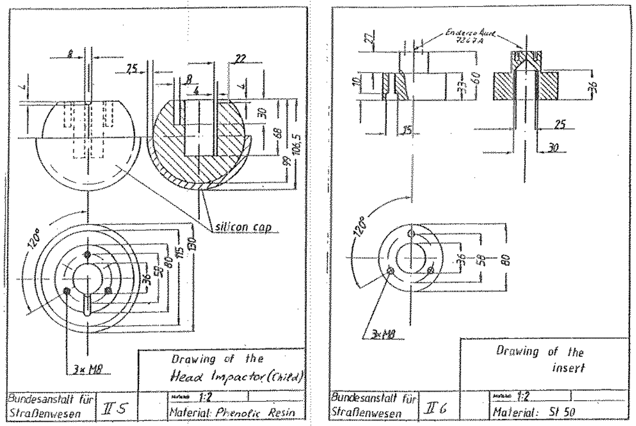


Figure 10. Technical Drawing of the Child Head Impactor

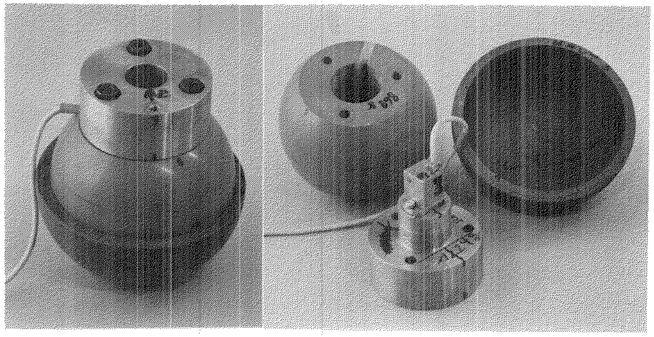


Figure 11. Child Head Impactor

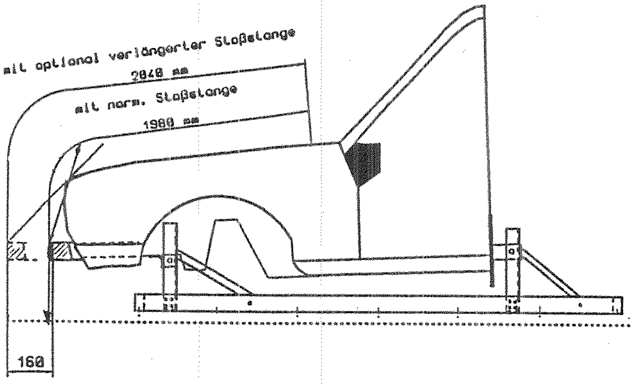


Figure 12. Audi 5000 Buck

Table 5 shows the cadaver test programme. The cadaver standing position was sideways but facing the car without possible arm support on the hood.

Table 5. Test Programme for Cadaver Tests

Test no.	VO [km/h]	Front angle
PAV 1	40	53°
PAV 2	40	53°
PAV 3	40	53°
PAN 4	40	63°
PAN 5	40	63°
PAN 6	40	63°

Test Results

Although a vehicle with a long bonnet was selected for the tests, the head impacted in two tests the windscreen (PAN 05 and PAN 04). One impact was with the windscreen frame and three with the bonnet at the level of the fresh air grill. Fig. 13 shows the positions of the various head impact points .

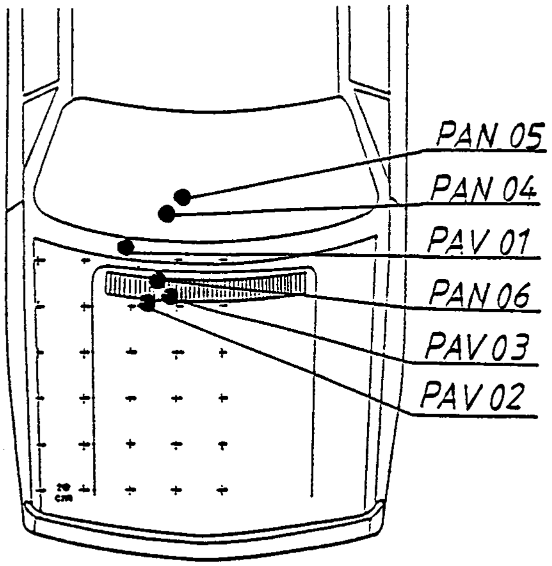


Figure 13. Head Impact Points in Cadaver Tests

Injuries and the anthropometric cadaver data are compiled in Table 6. Table 7 contains particulars on test reproduction by the impactor tests. Tests PAV 02, PAV 03 and PAN 06 were followed three times each and PAV 01 once as impactor tests with the adult impactor described above [19].

Apart from an upper oscillation on the signals, good reproducibility was obtained with the selected impactor weight of 4.8 kg as regards the curve for the signal. The results of measuring values are compiled in Table 7.

Table 6. Cadaver Tests, Anthropometric Data and Injuries

Test No	bumper	V_o	head impact location	cadaver			head* injuries	reproduced by impactor test
				height	age	weight		
PAV 01	pro-truded 16cm	40.3	lower WS frame	180	76	81	skull fracture 7cm	489
PAV 02		39.7	upper bonnet	180	57	74	—	480,481,482
PAV 03		40.2	upper bonnet	170	89	84	multiple lacerations and abraision nose fracture	483,484,485
PAN 04	normal	39.3	windscreen and frame	175	68	88	skull fracture, 10cm	no
PAN 05		40.1	windscreen and frame	177	82	78	laceration 3cm	no
PAN 06		39.5	upper bonnet	166	36	54	—	486,487,489

* no obduction was made, therefore brain injuries could not be identified

At an impact velocity between vehicle and pedestrian of 40 km/h, a head impact speeds of 12 - 14 m/s (43 - 50 km/h) occur if there is no arm support. In the cadaver test, HIC values of 1,000 to 2,500 were obtained. Except for one test (PAV 02), the HIC values from the impactor tests are above the HIC values from the relevant cadaver tests and, depending on the impact point on the bonnet, are between 1,500 and 2,500. On the windscreen frame, an HIC value of 3,300 was obtained. The scatter of the a_{3ms} and HIC values is satisfactory, higher scatters are present at the max. acceleration value because of the aforementioned signal oscillation.

Table 7. Test Results of Cadaver Tests and Impactor Tests (4.8kg)

Test no	v_{head} [m s]	$a_{max\ ms}$	a_{3ms}	HIC	Bonnet deformation Stat. [mm]
PAV 01	13.3	291	168	2453	22*
489	12.9	287.6	183.2	3328	32*
PAV 02	12.5	173	142	1894	37
480	--	---	---	---	---
481	12.3	144.2	116.8	1545	32
482	12.4	133.8	111.6	1377	37
Mean Value	12.3	139.0	114.2	1461	34.5
Coefficient of variation	0.4%	5.3%	1.4%	8.2%	10.2%
PAV 03	11.9	182	109	1034	29
483	12.3	220.8	147.9	1660	22
484	12.5	226.3	148.1	2232	30
485	11.9	285.4	158.3	2179	25
Mean Value	12.2	244.2	151.4	2024	25.6
Coefficient of variation	2.5%	14.7%	3.9%	15.6%	15.8%
PAN 06	14.0	230.5	137.4	1687	19
486	13.6	191.8	143.1	2392.1	25.5
487	13.3	230.7	156.8	2605.1	37
488	13.4	181.4	156.5	2600.2	37
Mean Value	13.4	201.3	152.1	2532.5	33.1
Coefficient of variation	1.3%	12.9%	5.1%	4.8%	20%

(--) no measuring value available
* deformation of the windscreen wiper

In the nature of things, dent shape and depth show greater variations; they depend on material and form. Some very good agreements were obtained, so that, under the given circumstances, satisfactory results for the agreement between "curve shape for acceleration signal" and "dent pattern" were obtained.

An HIC below 1,000 presumably cannot be reached in head impact velocities of 45 - 50 km/h. The impact points at the air grill were without stiffening below or hard sections of the engine. Previous tests at BASt show that an HIC of 700 - 900 can be obtained at such impact points at impact velocities of 40 km/h [8].

Conclusions and Proposal for a Test Method for Pedestrian Head Impacts

An analysis of the literature yielded a zone of possible head impact points for pedestrians involved in accidents (children and adults) involving head/bonnet impact. For the vehicle impact velocity of 40 km/h specified in the award of this project, it was possible to obtain impact velocities and dent patterns for cadaver tests using full-scale tests.

One head impactor each for child and adult were designed and built, and calibration requirements deduced. Satisfactory results were obtained in a comparison of impactor tests and full-scale cadaver tests. Basic tests were performed on the influence of impactor weight, shape, the necessity of an outer skin, min. bonnet deformation, etc.

The underlying conditions for a test of possible head impact points for pedestrians involved in accidents are as described below.

The impactor velocity of 40 km/h chosen for test and acceptance purposes of vehicles is due to the fact that HIC values of below 1,000 at this speed appear to be structurally possible in the development of bonnets.

However, a head impact speed of 40 km/h is equivalent to a vehicle driving speed of only approx. 35 km/h in an adult pedestrian impact.

A test procedure for pedestrian safety in vehicles, specifically the head impact on the bonnet in the present case, should contain the following conditions (Table 8) [20]:

Table 8. Impact Conditions for Pedestrian Head Impactor Tests

Adult head impactor test

impactor velocity	40 km/h
zone on test car*	wrap-around length 1500-2100mm or windscreen complete car width
impactor material	free flight skin covered sphere Leukorit (phenolic resin)
impactor diameter	165 mm (incl. skin)
skin	7.5mm silicon skin 50 shore hardness
measurement	accel. X.Y.Z in sphere centre
tolerance criteria	HIC ≤ 1000
impact angle	65° to horizontal
calibration requirement	PART 572 Hy III a_{RES} = 225-275 g h = 376 mm falling height

*** No. of test not yet specified**

Child Head Impactor Test

impactor velocity	40 km/h
zone on* test car	wrap-around length 1000-1500 mm or windscreen complete car width
impactor material	free flight skin covered sphere Leukorit (phenolic resin)
impactor diameter	130 mm (incl. skin)
skin	7.5mm Silicon skin 50 shore hardness
measurement	accel. X.Y.Z in sphere centre
tolerance criteria	HIC ≤ 1000
impact angle	50° to horizontal
calibration requirement	PART 572 Hy II a_{RES} = 210-260 g h = 254 mm falling height

* No of test not yet specified

The decision on a (min.) number of tests and on whether and how often the limiting value of HIC 1,000 may be exceeded is a political decision and will not be discussed any further in the present context.

In the appendix a list of impactor tests carried out up to now and the plots of cadaver and comparable impactor tests are shown.

Note: The research project was partly funded by the European Commission and was carried out under supervision of the EEVC WG 10.

Literature

[1] Gerondeau: Report on the High Level Expert Group for anEuropean Policy for Road Safety, EEC-Brüssel 2/1991

[2] EEVC: Report of WG 7: Pedestrian Injury Accidents, 9th ESV Conf., Kyoto 1982

[3] Moreau de St. Martin, J. (EEVC WG 7 Chairman): European View of the Pedestrian Accident Situation, SAE paper P121, Detroit 1983.

[4] BMV Hrsg.: Unfallverhütungsbericht Straßenverkehr 1989 und Statistisches Bundesamt, Straßenverkehrs- unfälle, Fachserie 7, Wiesbaden 1989.

[5] DIN: Körpermaße des Menschen, DIN 33 402, Beuth Verlag GmbH, Berlin 1984.

[6] Harbom u.a.: Lehrbuch der speziellen Kinder- und Jugend psychiatrie, Springer Verlag, Berlin 1980.

[7] Otte, U.: Einfluß der Fahrzeugfrontgeometrie auf die Verletzungssituation von verunfallten Fußgängern, Verkehrsunfallforschung der Med. Hochschule Hannover im Auftrag der BASt, 1989.

[8] Zimmerbeutel, B.: Die Simulation des Kopfaufpralls von Fußgängern bei Unfällen mit Pkw, Dipl.-Arb., GH Wuppertal in der BASt, 3/1990.

[9] Otte, D.: Unterschiede im Verletzungsbild verunfall- ter Fußgänger zwischen Einscheiben- und Verbund sicherheitsglas, Bericht im Auftrage der BASt, 10/ 1990.

[10] Glaeser, K.-P., Huß, C.: Der Kopfaufprall von außen auf Windschutzscheiben beim Fußgängerunfall, Verkehrsunfall- und Fahrzeugtechnik, 21/85 S. 11ff.

[11] Pareira, M., Ashton S. J.: Experimental Development of Pedestrian Head Injury Tolerance Data, SAE Paper 830625, 1983.

[12] Pritz, H. B.: Experimental Investigation of Pedestrian Head Impacts on Hood and Fenders of Production Vehicles, NHTSA Report.

[13] ECE/GRCS TRANS SCI/WP 29/GRCS/R 68 Protection of Pedestrians and other Vulnerable Road Users in the Event of Collision with a Passenger Car (from UK), Nov. 1985 (also ERGA S 60 Document).

[14] Hoyt u. a.: Experimental Pedestrian Accident Reconstructions - Head Impacts DOT Report HS 807 288 6/1988.

[15] Schröder, G.: Prüfverfahren zum Fußgängerschutz, Forschungsprojekt der BASt 8343, 1991.

[16] Cavallero C.; Cesari, D.; Ramet, M.: Influence of Shape of Passenger Car-Front Structure upon Pedestrian Injury Evaluation based on 50 Cadaver Tests, SAE Paper P 121, 1983.

[17] Janssen, E.G.: Protection of Vulnerable Road Users in Evenent of a Collision with a Passenger Car, Part I and Part II, Dec. 1990.

[18] APR: Assessment of Test Methods to Evaluate the Protection Afforded to Pedestrians by Cars, 1991.

[19] Fitsch, V.: Simulation des Kopfaufpralls von Fußgängern bei Unfällen, Studierarbeit bei der BASt, GH Wuppertal 1990.

[20] Harris, F.: Proposals for Test Methods to Evaluate Pedestrian Protection for Cars, 13. ESV Conf., Paris 1991.

[21] Kallieris, D.; Schmidt, G.: New Aspects of Pedestrian Protection, Loading and Injury Pattern in Simulated Pedestrian Accidents, 32 Stapp Car Crash Conf., Atlanta 1988.

[22] Kob: Joint Biomechanical Research Project, Final Report, BASt 1982.

[23] Cesari, Faerber, Glaeser, v. Wijk, Wismans: Proposed Standardized Pedestrian Test Methodology, Final Report Phase 3 Biomechanics Programme, 10/1981.

[24] Vasen, J.: Vorbereitung und Durchführung von 24 Fußgängeraufprallversuchen mit der Stoßkolben-katapult-anlage der BASt, Dipl.-Arb. GH Wuppertal, 7/1988.

Appendix

Summary of the test series conducted for this project

10 different test series were carried out at the Federal Highway Research Institute (BASt) to investigate the subject of pedestrian head impacts in collisions with cars:

(a) 12 preliminary tests using a dummy head as impactor, m = 4.4 kg and a VW Golf Al as ear (impactor selection)

(b) 12 preliminary tests using a spherical plastic impactor, m = 4.4 kg and a VW Golf Al as ear (impactor selection)

(c) 4 tests using a skin covered child head impactor, m = 2.5 kg, and a VW Golf Al as ear (dummy test reconstruction)

(d) 12 tests using a skin covered child head impactor, m = 2.5 kg, and an Audi 100 as car (dummy test reconstruction)

(e) 6 tests using a skin covered adult head impactor, m = 6.8 kg, and a VW Golf Al as car (dummy test reconstruction, skin selection)

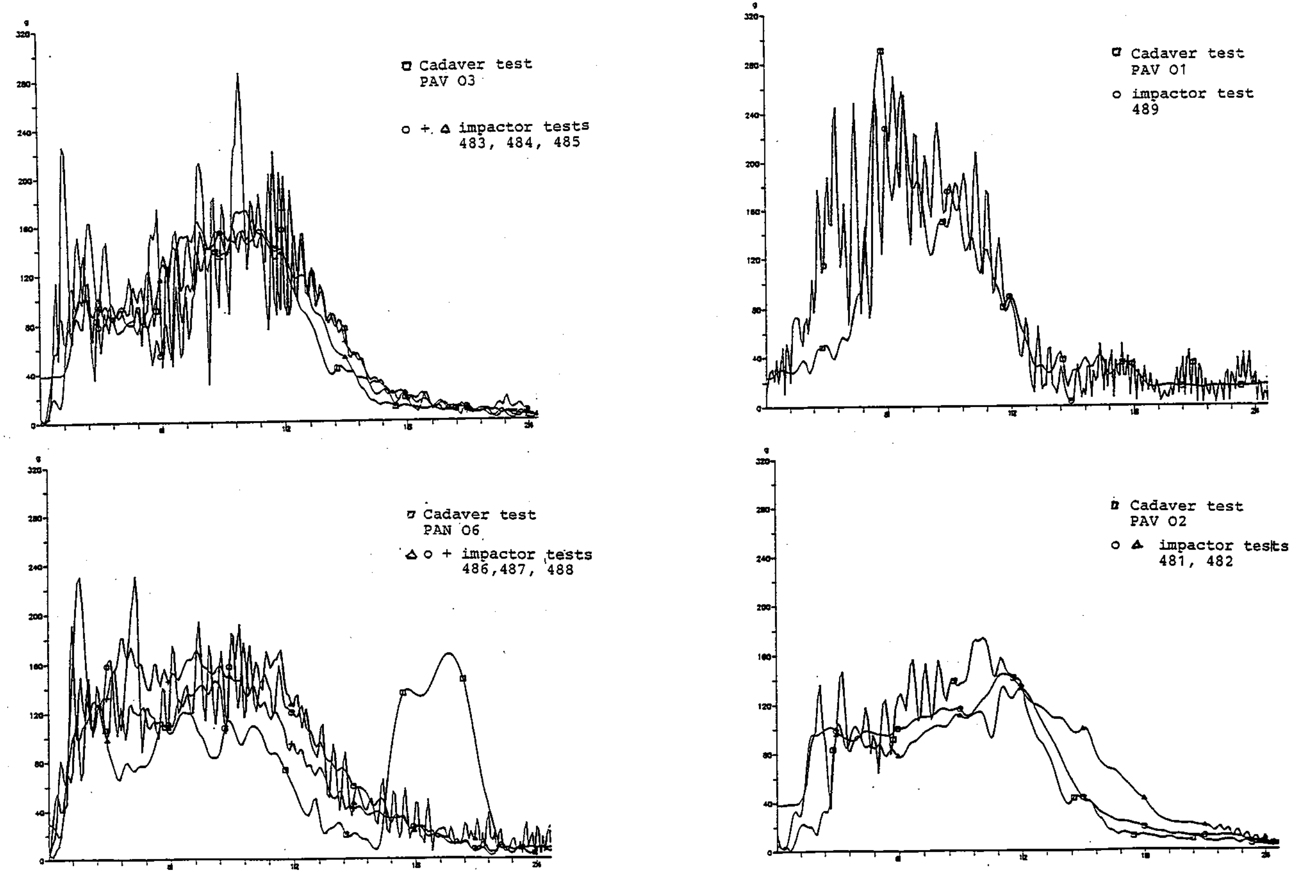
(f) 13 tests using a skin covered adult head impactor, m = 6.8 kg, and an Audi 100 as car (dummy test reconstruction, skin selection)

(g) 17 tests using a skin covered adult head impactor, m = 4.4 kg, m = 6.8 kg and m = 9.2kg and an Audi 100 as ear (impactor weight influence, no stiffening, no hard spot beneath the bonnet)

(h) 11 tests using a skin covered adult head impactor m = 6.8 kg and an Audi 100 as car (hard spot identification)

(i) 10 tests, cadaver test reconstructions (see Chapter 4), with adult head impactor 4.8 kg and Audi 100 as car (method verification tests)

(j) 12 leather skin covered dummy head tests into laminated and tempered windscreens (Citroen GS windscreens) (see Chapter 2.1)



Test Results—Cadaver and Impactor Tests

S3-O-08

Subsystem Test for Pedestrian Lower Leg and Knee Protection

D. Cesari, F. Alonzo, M. Matyjewski
INRETS

Abstract

Several European research institutes developed in a joint programme sponsored by the European Communities a set of subsystem tests to evaluate the protection offered by a car in a pedestrian collision. In this programme we have developed an instrumented mechanical leg to be used in the bumper impact sub system test. The development of this subsystem test took into account the pedestrian accident characteristics, the injury mechanisms and human tolerance. The capability of the mechanical leg to predict the risk of leg injuries was validated with model simulations and impact tests.

Accident Statistical Trends

Pedestrians are unprotected road users. The number of pedestrians killed in traffic decreased up to 1986 and seems stabilized now. As indicated in figure 1, their part in traffic accident fatalities varies from 15% in the USA to 28% in Japan (1). Nevertheless they constitute a large group of accident victims: in 1986 more than 18 000 pedestrians were killed in traffic accidents in the European Community, Japan and USA.

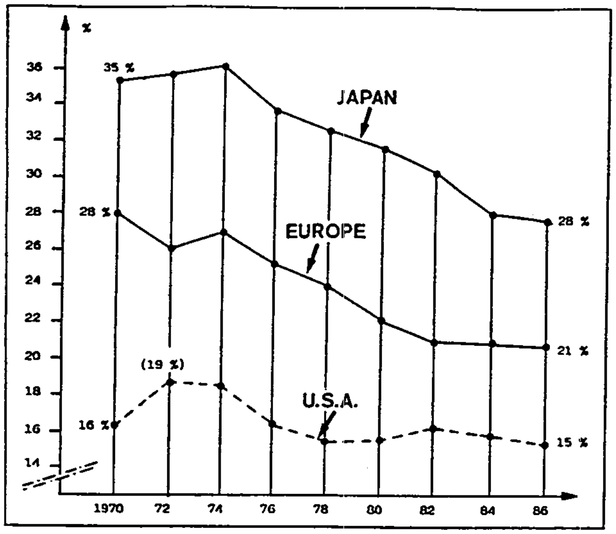


Figure 1. Comparison of Pedestrian Fatalities

Two main age groups comprise the majority of pedestrian accident victims: children and the elderly: considering the fatalities, the average European figures are 15% for children, 42% for the elderly (64 years old or more). Opposite figures are found when non fatal cases are considered: children are more numerous than elderly.

There are few data available concerning accident statistics in developing countries. However it is recognized that in these countries pedestrians constitute a majority of traffic accident victims. For the above reasons improvement of pedestrian protection can be considered as a priority.

Pedestrian Accident Analysis

Detailed analyses of pedestrian accidents have shown that head and lower limbs are the two most frequently involved areas (2), whatever injury severity is considered, as indicated in figure 2. In particular 65% to 80% of pedestrians involved in an accident sustain leg injuries.

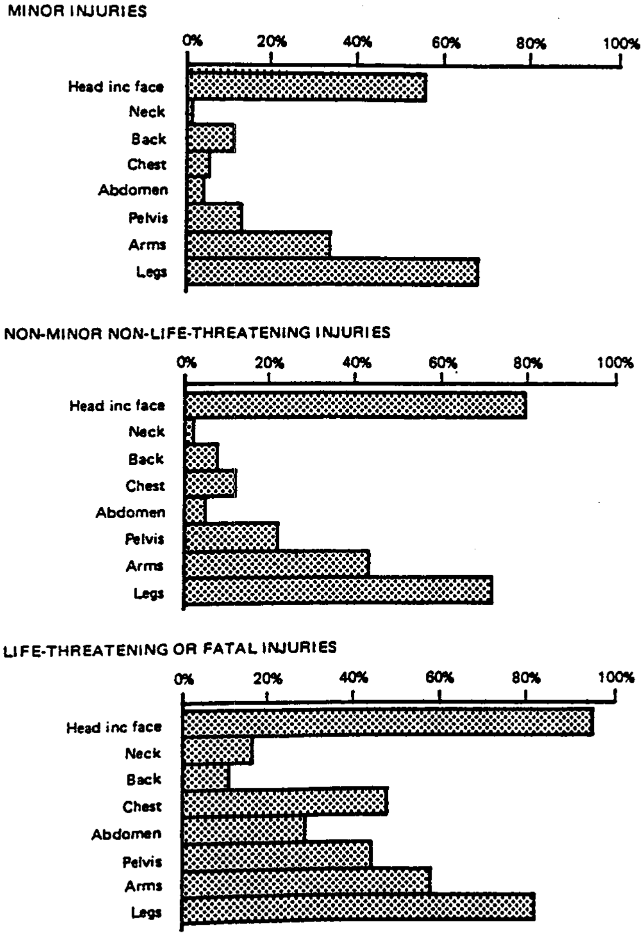


Figure 2. Injury Distribution in Pedestrian Accidents

If leg injuries are typically non life threatening injuries, they can be considered as severe injuries because of their incidence and long term consequences.

Comparison between children, adults and the elderly shows that the risk of severe leg injuries, for impact speeds in the range of 30/50 km/h, varies in the ratio of 1 to 3 to 6 (3) respectively.

Leg injuries can be classified in several types: soft tissue (flesh) injuries, bone fractures and ligament injuries.

Ligament injuries are of particular interest especially because of their consequences in terms of permanent disability. Analysis of the distribution according to impact speed and pedestrian category (adult or child) as indicated in table 1, shows that the risk of ligament injuries to pedestrians mainly concerns adults: in 213 child pedestrian accidents investigated, only one child sustained a knee ligament injury, and this occurred in an accident with an impact speed over 50 km/h. This table also indicates that ligament injuries are very seldom for accident impact speeds under 30 km/h. The largest number of ligament injuries occurs in the speed class 31/50 km/h, and apparently the frequency of such injuries decreases for impact speeds over 50 km/h. There are two explanations of this variation: some ligament injuries are not found at the first medical examination especially those associated with bone fractures of the same leg, those occurring at the same time as fatal injuries may also be missed.

Table 1. Frequency of Knee Ligament Injuries (3)

Collision speed	Children	Adults
Under 30 km/h	0	1.2%
31/50 km/h	0	7.9%
51/70 km/h	2.6%	5.0%
Over 70	0	0

According to car to pedestrian tests performed with cadavers, high speed impacts would more frequently result in bone fracture than ligament rupture and the opposite was found for intermediate speeds (4).

Two main injury mechanisms are able to explain the occurrence of leg injuries in pedestrian accidents: bending moment and shearing force (5).

The two mechanisms are generally combined, however bending moment is predominant in joint injuries and shearing force in long bone fractures.

Design and Specification of Leg to Bumper Subsystem Test

Taking into account the results of accident analysis and pedestrian biomechanical research the following specifications were selected.

- Articulated mechanical leg
- Free motion during the impact
- Humanlike mass distribution between lower leg and thigh
- Adult leg simulation
- Biofidelic force/angle relationship for the knee
- Measurement of bending and shearing deformation at knee level
- Measurement of lower leg acceleration.

To be able to reproduce correctly the mechanisms producing knee injuries, a special knee joint was designed (fig 3). This knee is symmetrical in the horizontal and vertical planes.

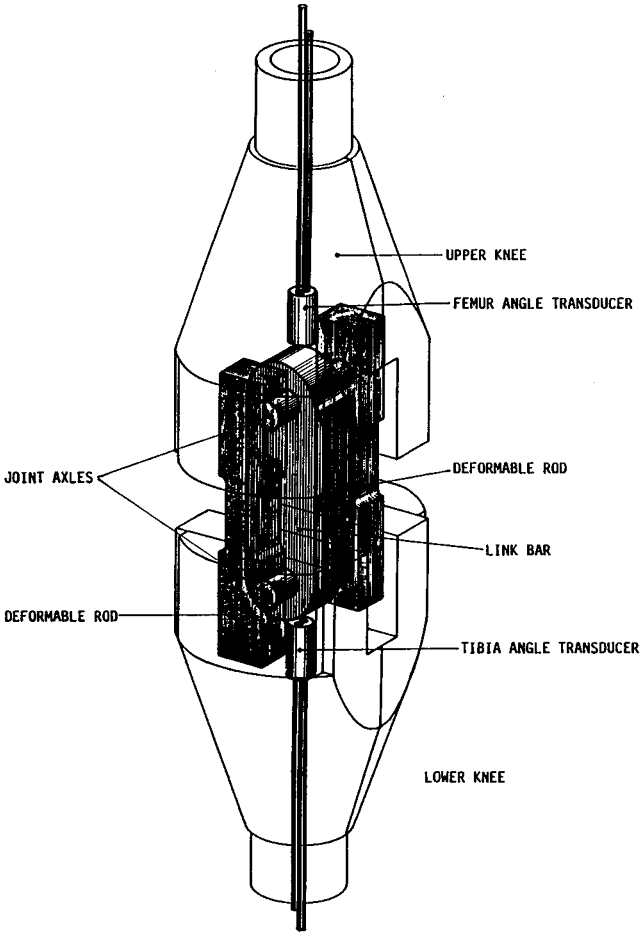


Figure 3. Principle of the New Pedestrian Knee Model

It consists of two main parts connected to the femur and the tibia respectively. Two deformable bars reproduce the biofidelic force/angle history. These square section bars are made of aluminum with a 6mm diameter steel rod inside. This enables recording of the slope of the force/angle history even in the permanent deformation zone of aluminum. The continuity between the thigh and the lower leg is ensured by a rigid link articulated at each extremity.

For the test the mechanical leg is propelled by a small sled which is stopped just before the impact, and then the leg continues in a free motion. In fact during the free travel, because of the gravity effect, the mechanical leg moves also slightly down, but this can be accurately predicted by kinematic theory.

The developed model corresponds to an adult leg. The question of designing a child leg was considered. Accident analysis indicates that children are much less likely to sustain leg injuries, and the few biomechanical data available concerning children suggest that their tolerance to this type of injury is higher than for adults. Moreover because of the lighter mass the forces and moments are lower for the same impact speed. For the above reasons it appeared not necessary to design a specific mechanical child leg.

The knee with the double articulation is also equipped with two identical deformation transducers. Each transducer measures the angle between the link and one of the two main extremities of the leg. Adding these two angles gives the variation in the angle between the thigh and the lower leg. If the two angles have different values, this indicates that a shearing process was involved simultaneously with bending, as indicated in figure 4.

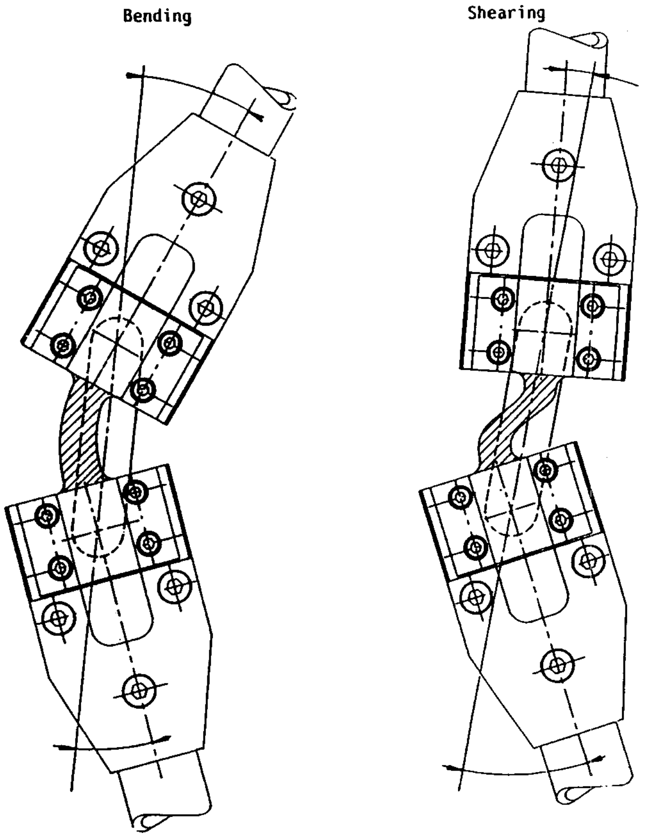


Figure 4. Deformations Process of the Mechanical Knee

The measurement of knee deformation enables the prediction of injuries in the knee area only. To check the protection provided against long bone fractures it is proposed to use the peak acceleration measured at the upper extremity of the tibia, which is directly related to the impact force caused by the bumper.

Protection Criteria

To verify the risk of leg injury in a car to pedestrian impact, three protection criteria should be used. The biomechanical data necessary to establish such parameter values are limited and the proposed values have to be confirmed.

- Limit of angle variation between the thigh and the lower leg: 15°. This is based on cadaver tests (4).
- Limit of shearing displacement between the upper tibia and lower femur extremities. There are few biomechanical data dealing with leg tolerance to shearing load. Based on the results of 20 cadaver tests a limit of 5 mm corresponding to 3 kN is proposed (6).
- Limit of upper tibia longitudinal acceleration (car reference): 150g, based on available biomechanical test results.

Mathematical Simulation of Tests Performed with the Mechanical Leg

The two dimensional MADYMO program was used to simulate car-pedestrian accidents.

The characteristics of the mechanical leg were taken into account as input data for the model. The leg impactor will be used to test car fronts to estimate the severity of the knee joint lesions in car-pedestrian accidents. These injuries occur during the first 30 ms after the impact.

There were three models presented, all of them were based on the MADYMO database part 572 pedestrian dummy (7).

Four bumper heights were simulated:

- 500 mm, impact at the knee joint (bumper position 0 mm)
- 400 mm, impact 100 mm below the knee (-100 mm)
- 300 mm, impact 200 mm below the knee (-200 mm)
- 600 mm, impact 100 mm above the knee (100 mm)

The simulations were made to validate the mechanical leg, compared to the full scale dummy test, and to analyze the effect of the upper body on the impact response of the leg.

The Three Models

Three models were simulated:

1) whole part 572 dummy
2) only one leg of the dummy
3) the leg with a firmly fixed additional mass.

Results from the last two models were compared with the dummy model results. The main criteria were the knee joint torque and the knee joint angle (lateral bending), as these parameters are considered to be the most important for knee joint injury.

The dummy model (fig. 5) is the MADYMO database part 572 dummy with the knee joint bending stiffness changed. The new torque-knee lateral angle characteristic was taken from static tests performed on the mechanical leg.

The leg model is the left leg of the part 572 dummy. There are two ellipses representing the upper leg and four representing the lower leg. For the upper leg one ellipse simulates the leg shape, the other ellipse is defined to calculate contact forces between the upper leg and the car. The lower leg includes the knee and the foot. The fourth ellipse is for contact force interaction.

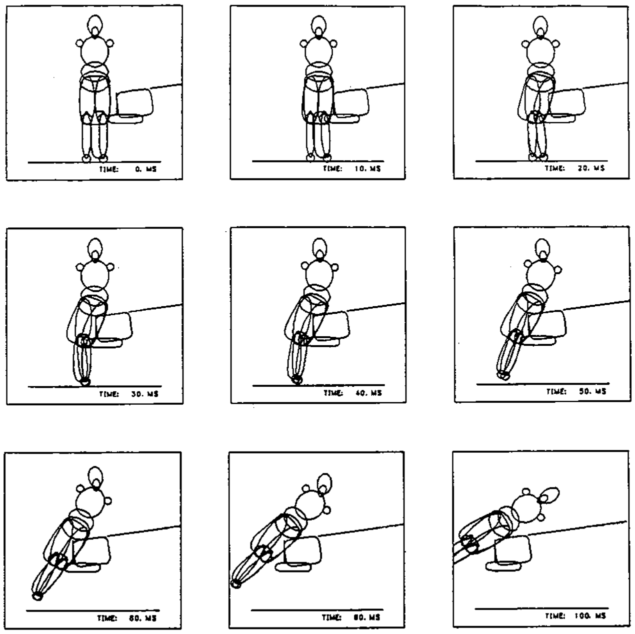


Figure 5. Movement of the Dummy

The leg is thrown at the motionless car front (fig. 6). There is no ground friction in this model. Some additional MADYMO simulations were made, to confirm that ground friction has little influence on the knee joint angle. The reversal of the actual movements (car standing, leg moving) does not change the results significantly.

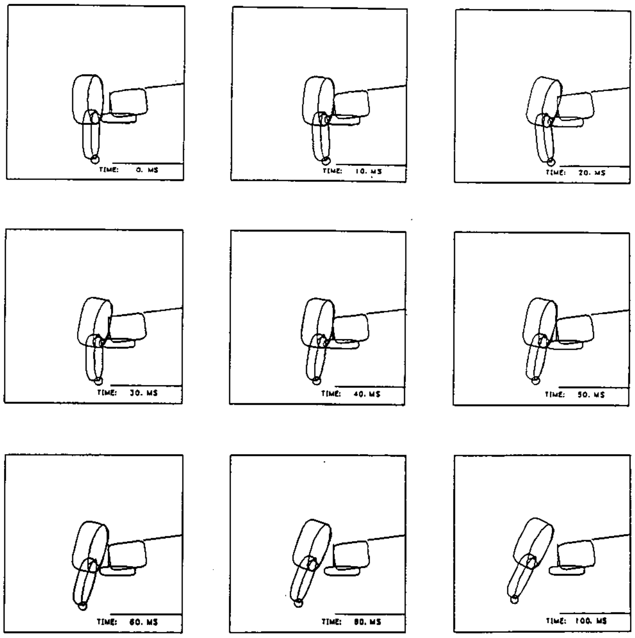


Figure 6. Movement of the Leg Impactor

The third model consists of the leg and a mass representing the upper body. The mass is placed near the hip joint and is fixed firmly to the upper leg. The leg and mass impactor strikes the car front at a speed of 30 km/h.

A parametric study has been done to obtain results from the leg and mass model similar to the results from the dummy model. There were three parameters changed: mass, height of the centre of gravity and moment of inertia. A joint between the upper leg and the mass was also considered, but better results were obtained with rigid attachment. The best fit, of the knee joint torque, for all four bumper heights was obtained for the mass of 6 kilograms, placed 410 mm above the knee joint with the moment of inertia 0.05 kgm^2.

Results

Results of 12 simulations are presented. Most of the results are for the bumper striking at the knee. The movement after impact of the dummy and two impactors is shown in figures 5, 6 and 7.

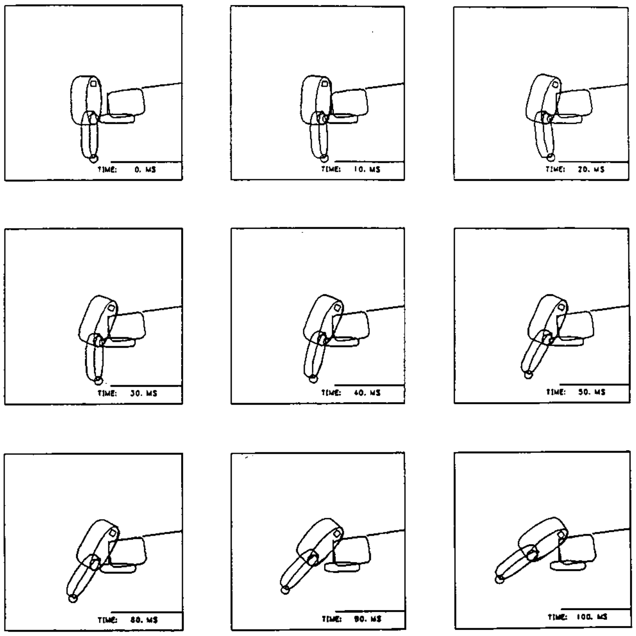


Figure 7. Movement of the Leg and Mass Impactor

For the first 20 ms movement of the leg impactor is similar to the movement of the dummy's leg but subsequently the difference increases. The leg and mass trajectory is much closer to the movement of the leg of the dummy. Noticeable differences start at about 40 ms and up to 100 ms they are very small.

Figures 8 to 11 show for each model at knee impact (0 offset):

- the knee joint resultant torque (sum of elastic and damping torques)

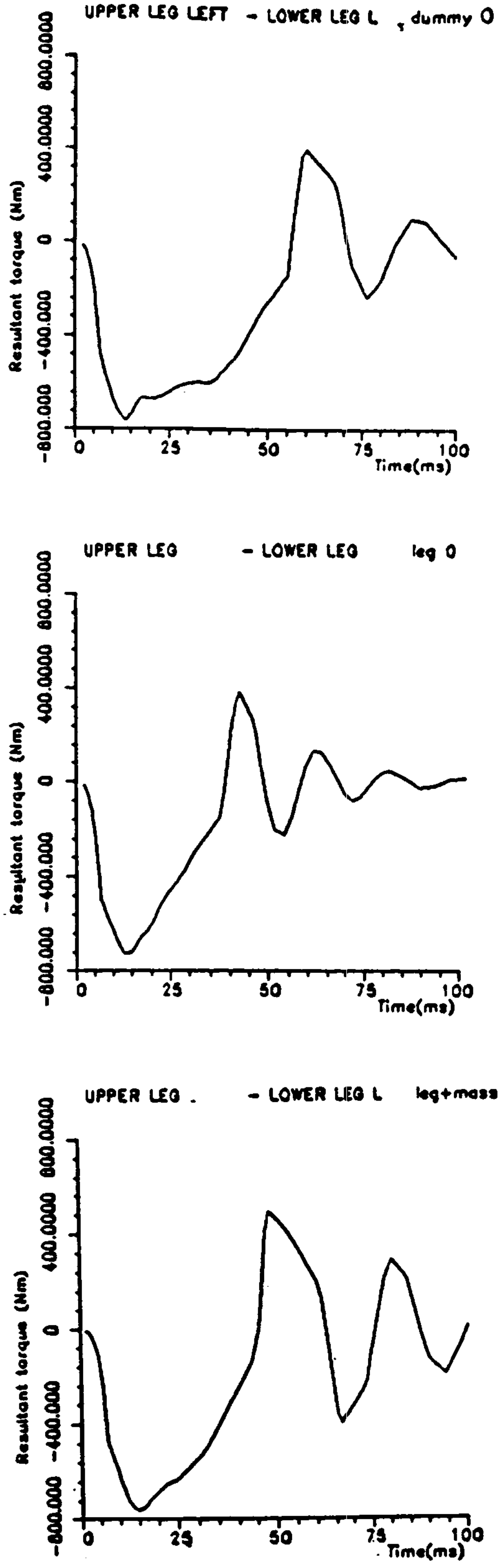


Figure 8. The Knee Joint Torque

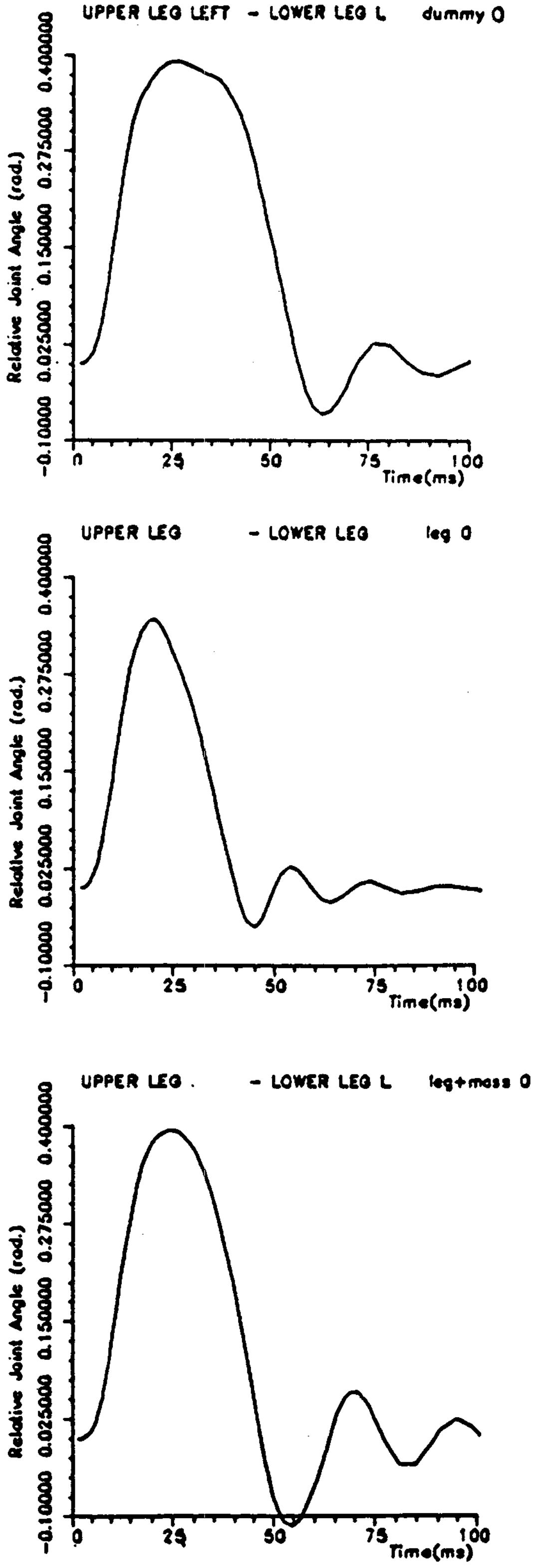


Figure 9. The Knee Joint Angle

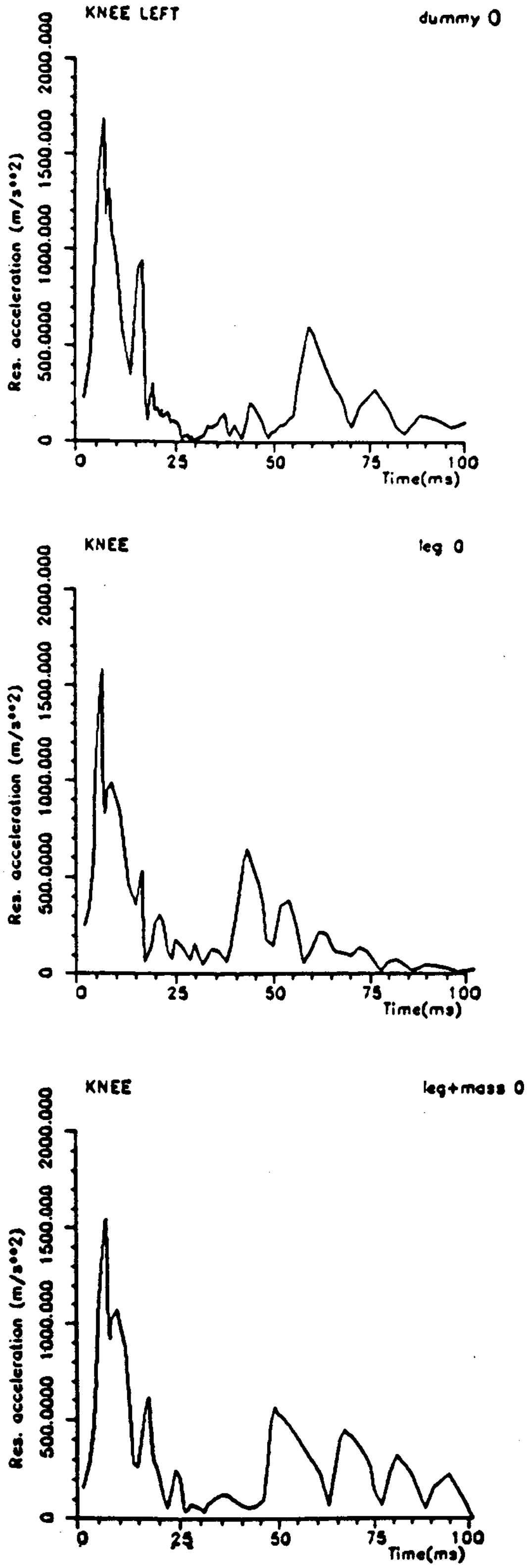


Figure 10. The Top of the Tibia Acceleration

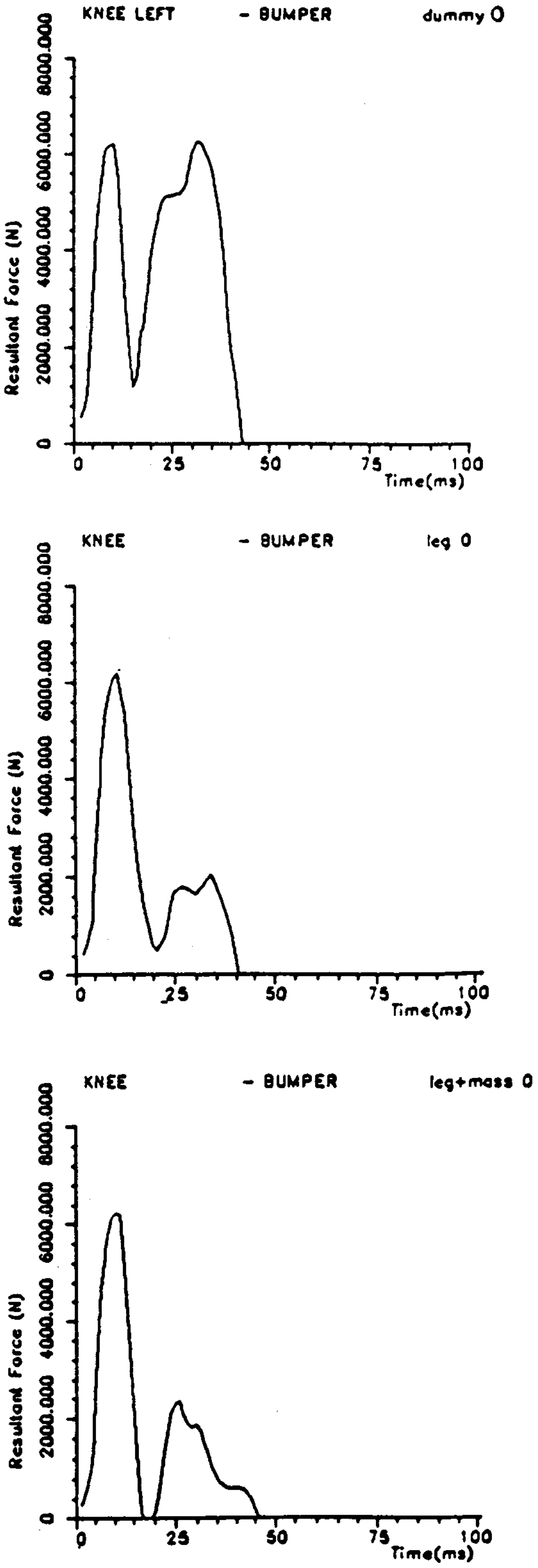


Figure 11. The Knee-bumber Force

- the knee joint angle (and elastic torque, as the elastic torque is proportional to the joint angle)
- the top of the tibia acceleration the knee
- bumper force.

For the bumper striking at the knee joint the differences between the dummy model results and the two impactor model results are not very great. The significant dissimilarity is caused by lack of the second leg in the impactors. We can see in figure 11a that the second peak of the knee-bumper force is much higher than in figures 11b and 11c. Also because of the other leg the knee joint is bent for a longer time in case of the dummy than for the impactors.

Results for other bumper heights i.e. the bumper placed at -100 mm, -200 mm, 100 mm, are indicated in table 2.

Table 2. Summary of the Results—Impact Speed 30 km/h

Simulation name	max torque (Nm)	time (ms)	max joint angle (deg)	time(ms)
dummy - 200	250	17.56	1.87	18.44
leg - 200	334	16.44	2.56	18.22
leg&mass - 200	262	19.31	1.97	20.19
dummy - 100	477	19.25	9.11	23.0
leg - 100	492	20.0	9.86	24.0
leg&mass - 100	485	21.0	9.68	25.50
dummy 0	761	13.50	22.52	25.75
leg 0	725	13.0	19.77	20.75
leg&mass 0	761	14.50	22.58	25.0
dummy 100	663	21.75	20.17	31.75
leg 100	469	21.0	9.28	24.5
leg&mass 100	690	25.25	20.97	29.75

Generally the leg and mass impactor model gives better results than the leg impactor model, especially for above the knee impacts. Maximum torques for the leg and mass model at all bumper heights are only slightly higher than the maximum dummy torques so the errors are on the safe side.

The leg model is applicable only for impacts below the knee joint. When the bumper impacts the leg impactor above the knee joint, contact force is applied close to the upper leg centre of mass, so rotation of the upper leg is small, the result of which is a smaller knee joint angle. Addition of mass moves up the centre of mass.

For the bumper position of -200 mm results for the leg model simulations are much higher than for the dummy simulations. This is because in the leg model the upper leg has a small moment of inertia, so it rotates easily producing a bigger joint angle.

Test Results

Seven leg subsystem tests were performed to validate the mechanical leg. The test conditions are listed in table 3. All the tests were performed in the speed range of 30/32 km/h. and most of the tests were performed with the same car model (car #2).

Table 3. Mechanical Leg Test Conditions

Test n°	Impact Speed	Vehicle Type	Vertical Offset*
GPI 01	29.24 km/h	2	+ 65 mm
GPI 03	31.9	1	+ 90
GPI 04	31. 9	2	0
GPI 05	28.9	2	- 30
GPI 07	29.5	2	+ 20
GPI 08	29.6	2	+ 100
GPI 09	29.64	2	+ 195

* Vertical distance between knee and bumper at impact

In all the tests the mechanical leg hit the central part of the bumper.

During each test we have measured the angles between the knee link and the tibia and the femur, and the upper tibia acceleration in the direction of impact. A high speed video camera was also used in most of the tests.

After each test the two deformable rods were removed and replaced by new ones. Their deformations were analysed. The knee angle variation for each test is indicated in table 4.

Table 4. Static Knee Deformation

Test N°	Knee Angle Variation	Vertical Offset
GPI 01	15°	65 mm
GPI 03	14°	90
GPI 04	25°	0
GPI 05	24°	- 30
GPI 07	19°	20
GPI 08	18°	100
GPI 09	0°	195

The two rods sustained exactly the same angle variation; this confirms the symmetry of the deformation.

Comparison between knee angle variation and knee vertical offset shows that the maximum deformation corresponds to the highest impact point on the leg. Conversely the lowest impact (test GPI 09) which correspond to a bumper 330 mm above the ground did not produce any permanent deformation in the knee.

The mechanical leg model developed in this research program was built as one prototype sample. The angles between the link and the two main parts are measured with two opto-electronic displacement transducers.

In the middle of the test programme one of the two displacement transducers failed and it was not possible to replace it immediately due to a delay in availability. Further more it was not possible to postpone the tests because of the short duration of the contract. This means that one parameter is missing in three tests. This does not imply that the mechanical leg designed in this contract does not work.

The test results are listed in table 5.

Considering tibia acceleration, the test results indicate that vehicle # 1 has apparently a less stiff bumper. For vehicle # 2 most of the values are over the 150 9 limit, the smallest value corresponding to the lowest impact on the leg.

Table 5. Dynamic Test Results

Test N°	Femur peak angle	Tibia peak angle	Tibia peak acceleration
GPI 01	13°	10°	160.5 g
GPI 03	13.5°	7°	128 g
GPI 04	25°	12°	144 g
GPI 05	21°	12°	213 g
GPI 07	17°	NA	195 g
GPI 08	18°	NA	289 g
GPI 09	2°	NA	140 g

This table shows also that the femur angle is always higher than the tibia angle (when available). This means that knee deformation by bending is associated with a shearing process.

Comparison between tables 4 and 5 indicates a good correlation between the static deformation of the knee rods and the output of the angle variation dynamic sensors, with a higher value for the last one, as can be expected.

Conclusions

The aim of this research programme was to evaluate the risk of pedestrian leg injuries when impacted by a car front to do this a mechanical instrumented leg was designed and its performance was evaluated.

The concept selected for this design has been proved to work well: the deformations by bending and by shearing in the knee area and a force related parameter for lower leg impacts can be quantified.

Mathematical simulations comparing the mechanical leg and full dummy responses show the capability of the mechanical leg to integrate the differences in shape and stiffness affecting the risk of injury, and this was confirmed by the tests performed.

The response of the soft tissue of the leg is not optimized. For this first step a standard dummy leg flesh was used; however it seems advisable to replace it by a less elastic foam, having a higher hysteresis.

It will also be necessary to evaluate the repeatability, as well as the durability of the mechanical leg. Both need a large testing programme which was not included in this contract.

References

1) H. Vallée, C. Thomas, C. Tarriere "Pedestrian Casualities: the Decreasing Trend." 12th International Conference on Experimental Safety Vehicles 1989.
2) S.J. Ashton, G.M. Mackay "Car Design for Pedestrian Injury Minimisation" 7th International Conference on Experimental Safety Vehicles 1979.
3) Otte "Influence of Vehicle Front Geometry on the Injury Situation of Injured Pedestrians." Draft: April 1989.
4) D. Cesari, C. Cavallero, H. Roche "Mechanisms producing lower extremity injuries in pedestrian accident situations." Proceedings of the 33rd AAAM Conference 1989.
5) B. Aldman and al "Load transfer from the striking vehicle in pedestrian impacts."
6) J. Kajzer and al "Response of the Knee Joint in Lateral Impact: Effect of Shearing Load, "1990 IRCOBI Conference.
7) "MADYMO Databases," TNO, the Hague, the Netherlands, 1990.

S3-O-09

Finite Element Modelling of Pedestrian Head Impact onto Automobile Hoods

David R. Lemmon, Robert S. Ballinger, Ronald L. Huston
Department of Mechanical, Industrial
and Nuclear Engineering,
University of Cincinnati

John Kessler, Jeff Elias, David Zuby
Vehicle Research and Testing Center
Transportation Research Center of Ohio

Abstract

Accidents involving pedestrian impact have been targeted as an area of automobile safety worthy of study and research. Among the many approaches to this problem is to design automobiles for less severe pedestrian injuries. Of particular concern are injuries to the pedestrian's head caused by impact with the automobile body. Redesign of automobiles for pedestrian safety is obviously a costly undertaking, but it is reasonable to expect that incorporating simple modifications into existing designs can reduce the number and severity of pedestrian head injuries quickly and at low cost. New designs can be proposed and prototypes built and tested using establish techniques. However, in order to make pedestrian head injury mitigation more appealing, a low-cost design technique must be found.

To this end, finite element analysis (FEA) is applied to mitigation of pedestrian head injury. Design prototypes are modelled and impacted by a simulated pedestrian head form using readily available finite element code, namely, ANSYS and DYNA3D. Results are then analyzed, animations studied, and further design improvements proposed and tested. This may be followed

by verification with a test impact of the new prototype. Finite element analysis promises to make pedestrian head injury mitigation appealing and cost effective and thus be incorporated into automobile design.

Introduction

Head injury is undoubtedly the most devastating result of vehicle/pedestrian impact. Head injury is always debilitating, and if it is severe enough, the negative effects can be irreversible and permanent. Unfortunately, head injury is a frequent result of vehicle/pedestrian impact. Indeed, 35% of pedestrian injuries from vehicle impacts of 30 mph or less are due to head impact [1]. The major portion of these injuries occur when the pedestrian's head strikes the hood region.

Attempts have been made to mitigate head injuries through redesign of the automobile hood and surrounding regions. The design objective has been to increase the compliance in these regions, and thus, "soften the blow" by structural design.

The National Highway Traffic Safety Administration (NHTSA) has taken an active role in addressing the problem of pedestrian impact. Recognizing that head impact from vehicle faces (grilles and leading edges of hoods and fenders) and from top surfaces of hoods and fenders cause the most serious of the injuries, NHTSA has established the Advanced Pedestrian Protection Program (APPP) [2]. A major aspect of the APPP is the experimental testing of production automobile hoods to determine which are the most and least harmful in terms of the Head Injury Criterion (HIC) [3,4,5]. The experimental tests consist of thrusting a head form onto the automobile hood under controlled conditions; specifically, the head form is attached to an impactor ram which is accelerated in uniaxial motion by pneumatic pressure. The head form has a spherical surface which is covered with Hybrid III dummy skin [6]. These experiments have been and are being conducted at the Vehicle Research and Test Center (VRTC) at the Transportation Research Center (TRC) of Ohio. Excellent results have been obtained in modelling field data [7,8,9]. Indeed, these experiments provide an excellent accident reconstruction tool.

It is useful to supplement the test data with parameter studies evaluating proposed design modifications. Finite element analysis (FEA) has now been developed to the point where it can be used to simulate the nonlinear dynamics and nonlinear hood deformation of the impact phenomena. In particular, the finite element codes ANSYS [10] and DYNA3D [11] are considered. ANSYS has general capabilities and a large installed customer base. DYNA3D, a code specialized and optimized for nonlinear dynamics of impact, is gaining popularity in industry and in the research of vehicle crashworthiness [12].

The focus of the initial analysis is the impact response of a 1985 Oldsmobile Ciera hood. In addition, the hood-fender region of a 1989 Ford Taurus is presented to demonstrate the use of finite element analysis in parameter studies of proposed designs. These particular models were chosen because of simplicity of design and widespread popularity, and thus great potential of pedestrian injury mitigation. Progress made to date with the FEA approach includes: a) construction and validation of the Ciera/head impact model and b) parameter studies of proposed Ford Taurus fender designs for impacts in the hood-fender region.

Head Form Impact Testing

The Vehicle Research and Test Center (VRTC), located at the Transportation Research Center (TRC) of Ohio has conducted an extensive series of head form impacts onto production automobile hoods [9]. During the TRC tests the head form is thrust onto a vehicle mounted hood. The head form impactor, a spherical section covered with vinyl Hybrid III dummy skin [6], is mounted on the end of a pneumatically driven ram. The head form and ram, which together weigh 10 lbs. (4.5 kg) are assumed to closely approximate the mass of the head of a 50^{th} percentile human adult. Once the head form reaches impact velocity it becomes a free projectile with constant, uniaxial velocity until impact. The head form ram can be adjusted to impact the hood at any angle, but generally these impacts are perpendicular to the hood surface.

Accident data show that nearly 90% of pedestrian/automobile impacts occur at vehicle speeds of 25 mph (40 km/h) or less [2]. Computer modelling (MADYMO) and analysis of cadaver pedestrian experiments have shown that vehicle speeds of 25-30 mph (40-48 km/h) produce head/hood impact speeds of 23-27 mph (37-43 km/h). These findings led to the choice of a 23 mph (37 km/h) head impact speed for simulations discussed here.

Both the acceleration and displacement of the head form are recorded during the impact event. From this data the head injury criterion (HIC) is calculated to indicate the probability of severe injury.

Finite Element Modelling of Head Form Impact

The objective of FEA in this application is to simulate the dynamics of impact testing and obtain the same results one would from an actual test. The first step is, therefore, to develop a model for comparison with test results. For validation a 1985 Oldsmobile Ciera hood was chosen due to its good performance in impact tests [9]. Two locations were chosen (Figure 1), and finite element analyses were performed first using ANSYS, and later, DYNA3D. The region of the hood/fender interface is also investigated. A 1988 Ford Taurus fender is modelled and impacted, and results are compared with test data. In all cases, head form displacement and acceleration time histories, as well as HIC, are used as a basis of comparison.

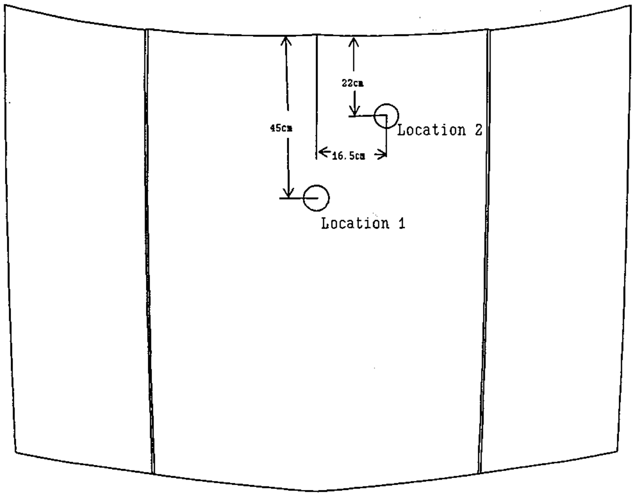


Figure 1. Impact Locations 1 and 2 on the Oldsmobile Ciera Hood

1985 Oldsmobile Ciera Hood Impact

A finite element mesh was first created using I-DEAS from SDRC [13] as a pre-processor. Quadri- and trilateral shell elements were used in discretizing the hood's surface and support ribs. Boundary conditions on the hood restrained translation at the latch and vertical restraint at the hinges, supports, and at hood interface with the firewall. Material properties were given for steel with elastic/plastic behavior, using a two line (bilinear) stress-strain curve.

Analysis using ANSYS. The most challenging part of using FEA in impact analysis is solving the transient dynamic behavior of deformable impacting bodies. ANSYS supports such analysis by supplying gap elements for contacting bodies and a Newmark time step integration method [14] for solution of the transient, dynamic behavior.

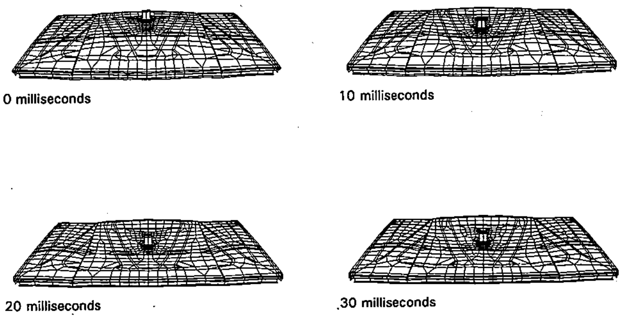
The head form was modelled by nodes in a spherical arrangement connected to the hood with gap elements. A mass was attached to one of the nodes, which were rigidly connected and restrained to move along an axis. No attempt was made to simulate the dummy skin of the head form. Contact between the top surface and the supporting ribs was accomplished by coupling the translation of nodes.

The transient analysis had to be divided into twenty time steps each one millisecond in duration. Twenty convergence iterations were specified for each time step, so acceleration and displacement data could be obtained for each of the twenty time steps. The nodes modelling the head form were forced to move at a constant velocity of 23 miles per hour (37 km/hr) for 4 milliseconds prior to impact. After this the head form interacts only with the impacting hood. After solving twenty milliseconds of transient dynamic response, the analysis was terminated.

Analysis using DYNA3D. The ANSYS package is a general purpose code which supports dynamic analysis, while DYNA3D is specifically written for solving the dynamics of impact. Developed at the Lawrence Livermore National Laboratory (LLNL), DYNA3D is a public domain code which employs the explicit central difference method for time discretization [11]. Time step specification is automatic, and initial velocities of bodies can be input directly. In addition, DYNA3D provides surface-to-surface sliding contact without the use of gap elements.

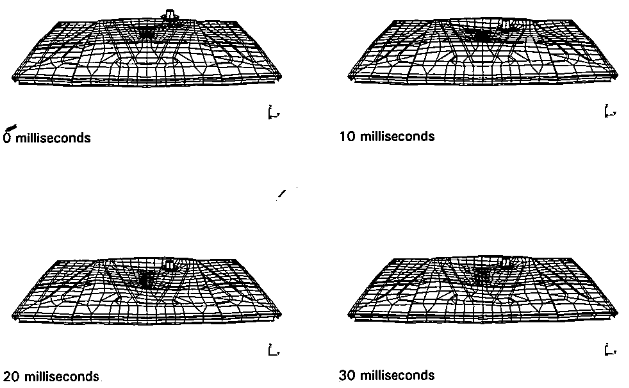
A solid finite element model of the head form was placed in the hood model. This head form model was given elastic material properties of aluminum, which is the actual head form material. A rigid mass was added to make the total head form mass 10 lbs. (4.5 kg). Sliding contact was specified between the hood surface and the head form, as well as between the surface metal and the supporting ribs. The hood interface with the firewall was given 0.5 inches (1.3 cm) clearance as in the actual vehicle. Head form initial velocity of 23 miles per hour (37 km/hr) was specified and the analysis solved 40 milliseconds of transient dynamic response. Head form acceleration and displacement data was obtained every 0.1 milliseconds, though finer resolution is possible.

Deformations of the hood calculated by DYNA3D are shown for impact locations 1 (figure 2) and 2 (figure 3).



0 milliseconds
10 milliseconds
20 milliseconds
30 milliseconds

Figure 2. Hood Deformations from Impact at Location 1



0 milliseconds
10 milliseconds
20 milliseconds
30 milliseconds

Figure 3. Hood Deformations from Impact at Location 2

Comparison With Test Data. Head form displacement data from both ANSYS and DYNA3D are shown compared to test results for impact locations 1 (figure 4) and 2 (figure 5). DYNA3D matched the maximum head form displacement, leading by about 5 milliseconds.

ANSYS matched experimental results up until about 12 milliseconds after initial contact, and then diverged. For impact location 2, maximum displacement from DYNA3D differed from test results by about 1.2 cm, while ANSYS results differed by 0.8 cm. This indicates that the FEA model is more stiff than the actual hood in that region.

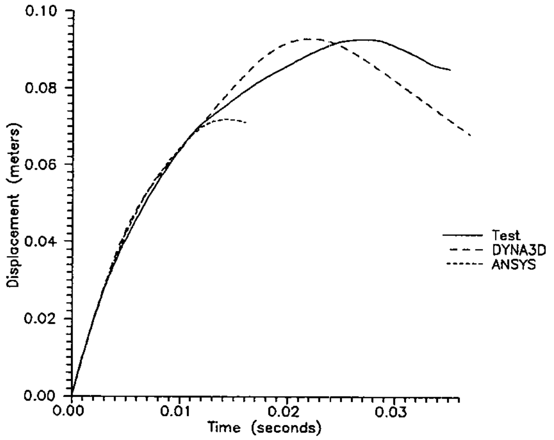


Figure 4. Head Form Displacement, Impact Location 1

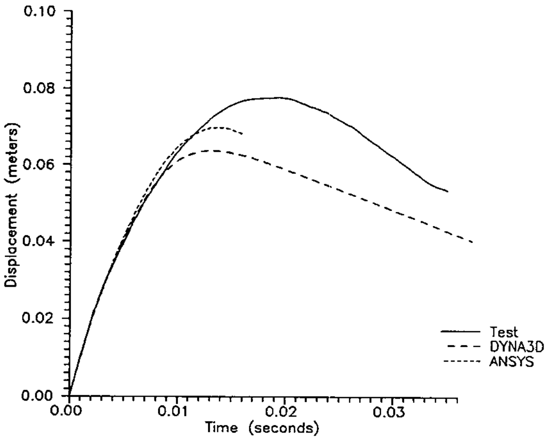


Figure 5. Head Form Displacement, Impact Location 2

Acceleration of the head form data are shown for impact locations 1 (figure 6) and 2 (figure 7). The magnitude of the initial acceleration peak was matched for location 1 by ANSYS and DYNA3D, though they lagged test results by about 2 milliseconds. This suggests that such discrepancies are due to the finite element model itself, since both analyses used the same basic mesh. ANSYS and DYNA3D results show similar pulse shape up to about 10 milliseconds and then diverge, most likely due to differences in solution techniques. Again, at impact location 2, ANSYS and DYNA3D are similar to test data through the initial peak, diverging afterward. In both cases, DYNA3D results follow the overall shape of the experimental acceleration curve better than ANSYS results.

Calculations of the Head Injury Criterion for test and FEA data are shown (table 1). HIC values are generally higher for FEA results due to prolonged initial acceleration peaks and stronger secondary peaks. FEA results were a better match of test results for impact location 1. Based on results from impact location 1, in which FEA proved to effectively model the actual hood, DYNA3D exhibits usefulness as a tool for predicting HIC.

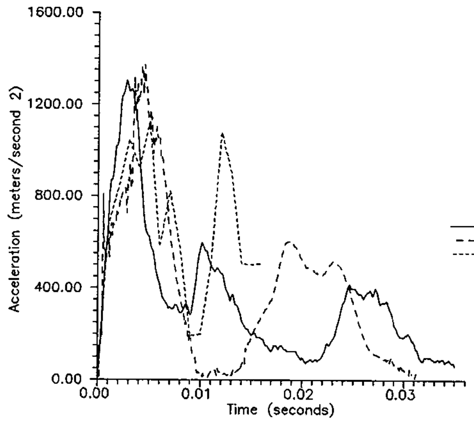


Figure 6. Head Form Acceleration for Impact Location 1

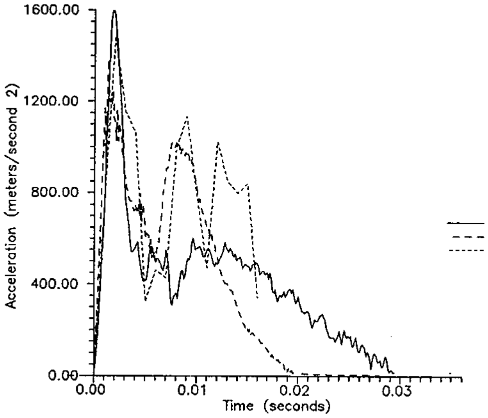


Figure 7. Head Form Acceleration for Impact Location 2

Table 1. HIC Comparison Between Test and Finite Element Results

	Test	ANSYS	DYNA3D
Ciera hood, Location 1	421	597	555
Ciera hood, Location 2	460	929	820
Taurus Fender	2684	N/A	2412

1988 Ford Taurus Fender Impact

An area of concern in head impact is the hood/fender region. This nearly rigid area, located where the fender and hood meet, has great potential for improving pedestrian safety. As a preliminary step in proposing pedestrian injury countermeasures for the hood/fender region, study was made of impact on the fender without the hood structure. A 1988 Ford Taurus fender was chosen to demonstrate the feasibility of design countermeasures in a popular model with contemporary styling.

The impact location is 23 inches (58 cm) forward from the rear of the hood. This location represents a typical head impact location in accidents in which the pedestrian is a child. The head form is oriented so that its center contacts the edge of the hood and fender upon impact. Finite element results are compared with tests performed on the fender without the hood.

Analysis Using DYNA3D. The Taurus fender model consists of a curved surface on the outside and a flat surface hidden beneath the hood. The FEA model of the fender is cut off just above the wheel opening, and fully restrained along three edges. The edge which is not fully restrained is where the fender is attached to the vehicle structure. Here restraints are applied at bolt locations.

A mesh size of 0.25 inches (0.6 cm) was created in the impact area to increase accuracy under the severe deformations caused by buckling. The initial speed of the head form was, again, 23 miles per hour. The time range of the analysis was shortened to 20 milliseconds due to the short duration of impact with this stiff structure.

The vertical, flat surface inside the hood is the source of most of the stiffness in the fender. In head impacts, this surface must buckle in order to yield. In the DYNA3D model, "single-surface" sliding contact is specified for this surface to prohibit the metal surface from penetrating itself during buckling.

Comparison With Test Results. The DYNA3D analysis, like the test of the actual fender, produced severe permanent deformation of the fender in the impact area (figure 8). Maximum head form displacement was 3.7 cm from initial contact, compared to 3.4 cm from test results (figure 9). The head form rebounded at a higher velocity in FEM results than in test data. The acceleration pulse is highly similar to the experiment in magnitude and shape (figure 10). As a result, a HIC of 2412, very close to the experimental 2684, is calculated (table 1). Notice that this high HIC indicates a high probability of severe injury or fatality.

Indeed, it is expected that the fender model should produce more accurate results than the hood model due to the finer mesh. This model indicates that, with higher mesh accuracy and a finer mesh size, improved fidelity can be obtained, and HIC values can be predicted.

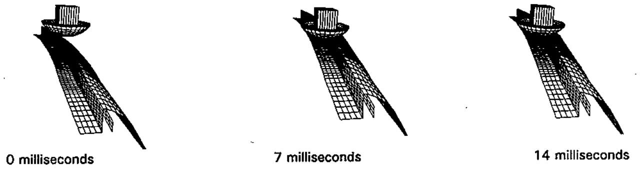


Figure 8. Deformations of Ford Taurus Fender

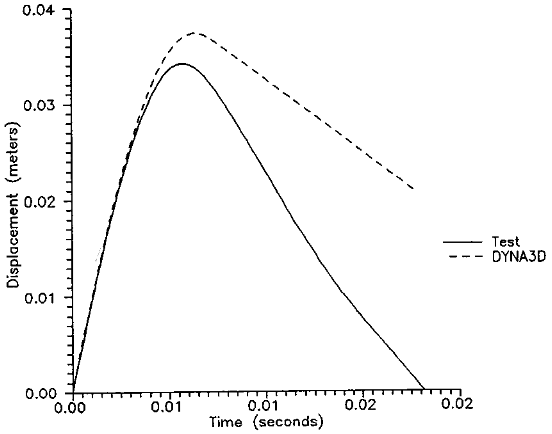


Figure 9. Head Form Displacement, Taurus Fender

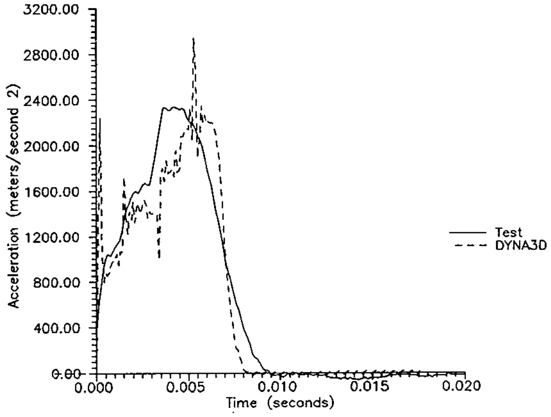


Figure 10. Head Form Deformations, Ford Taurus Fender

Parameter Studies Using FEA

The Ford Taurus fender was chosen as a preliminary study in pedestrian head injury countermeasures. The proposed modifications are a lengthening of the vertical section inside the fender from 1.5 inches (3.8 cm) to 2.25 inches (5.7 cm). In addition, holes or slots may be punched in this surface to weaken it and promote buckling without altering the vehicle's outward appearance. Studies were made of different sizes of vertical slots to learn their effects on HIC values, as well as differing material thicknesses. The goal of these studies is to find an improved design which can reduce injury by energy of deformation. By increasing the height of the flat surface, it is hoped that more distance may be used to decelerate the head, and hence, more energy may be absorbed.

Ford Taurus Fender, Vertical Slots

For the parameter study, a base model of the modified fender was created with the standard wall thickness of 0.030 inches (0.076 cm). Vertical slots are made in the fender by simply removing elements and nodes from the model in the pre-processing stage. Using this method, numerous design iterations were made. It was found that slots 0.5 inches (1.3 cm) wide and spaced 1 inch (2.5 cm) apart produced the best results. Furthermore, it was found that if the slots were made lower on the flat surface of the fender, then acceleration peaks were reduced or eliminated, thus reducing the resultant HIC. Arrangement of vertical slots are shown with the mesh of the flat surface (figure 11).

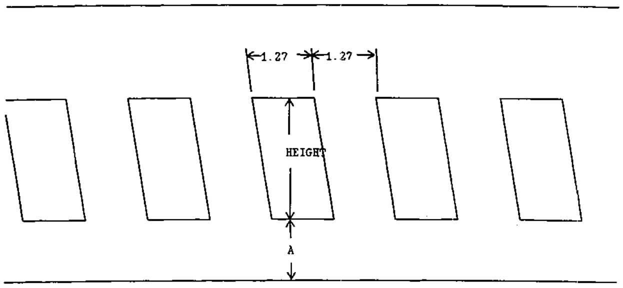


Figure 11. Dimensions of Verticle Slots for the Modified Taurus Fender

Two series of results were studied. In the first series the slots were located 0.25 inches (0.63 cm) from the base of the flat surface, and the second series was located at the base of the flat surface. Slot height and locations are plotted against HIC is shown (figure 12).

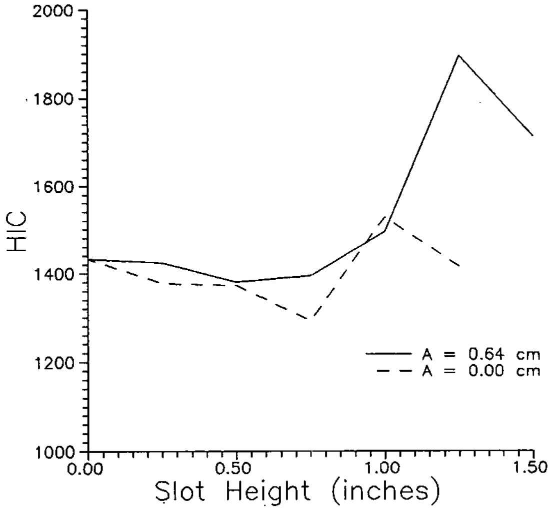


Figure 12. Slot Dimensions vs HIC

Though HIC still indicates high probability of severe injury to impacts in this region, marked reduction in impact severity is produced by employing slots of this type.

Ford Taurus Fender, Material Thickness Variation

Varying sheet metal thickness of the fender is another method of controlling head form deceleration. HIC for various material thicknesses is shown (figure 13).

Conclusions

Advances in the capabilities of finite element analysis (FEA) have enabled analytical study of complex impact dynamics. Pedestrian safety is an increasingly important design consideration in the automotive industry. Readily available finite element codes have been shown to be useful design tools in predicting head injury criteria (HIC) of pedestrian head impact tests. Though not a replacement of test procedures, the finite element method can be used effectively in parameter studies of pedestrian head injury countermeasures.

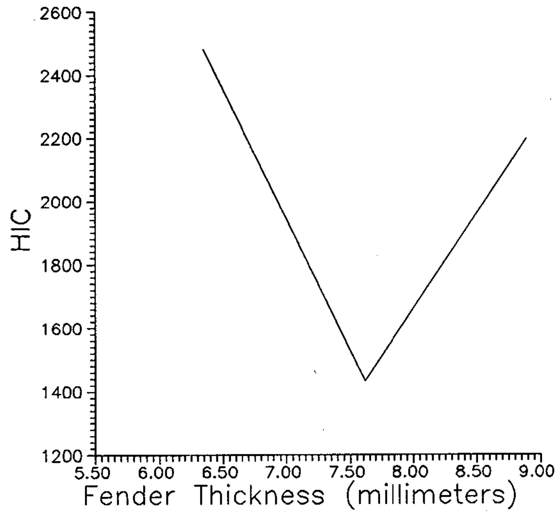


Figure 13. Fender Thickness vs HIC

Furthermore, FEA codes designed for impact dynamics, such as DYNA3D, are readily available and currently in use in industry. By applying this technology to design for pedestrian safety, many pedestrian injuries can be reduced and lives saved without an inordinate amount of research and development effort.

Acknowledgements

The authors wish to thank the NHTSA Vehicle Research and Test Center and the Transportation Research Center for their support and interest in this study.

References

1. Malliaris, A.C., Hitchcock, R., and Hausen, M., "Harm Causation and Ranking in Car Crashes," SAE Paper No. 850090, 1985.
2. MacLaughlin, T.F., Hoyt, T.A., and Chu, S.M., "NHTSA's Advanced Pedestrian Protection Program," 11th ESV Conference, Washington, D.C. 1987.
3. Gadd, C.W., "Use of a Weighted Impulse Criterion for Estimating Injury Hazard," *Proceedings Tenth Stapp Car Crash Conferences*, SAE Paper No. 660793, 1966.
4. Versace, J., "A Review of the Severity Index," *Proceedings Fifteenth Stapp Car Crash Conference*, SAE Paper No. 710881, 1971.
5. Hess, R.L., Weber, K., and Melvin, J.W., "A Review of Research on Head Impact Tolerance and Injury Criteria Related to Occupant Protection," *Head and Neck Injury Criteria*, National Highway Traffic Safety Administration Workshop, 1981.
6. Pritz, H.B., "Experimental Investigations of Pedestrians Head Impacts on Hoods and Fenders of Production Vehicles," SAE Paper No. 830055, 1983.

7. MacLaughlin, T.F., Hoyt, T.A., and Kessler, J.W., "Experimental Pedestrian Accident Reconstructions - Head Impacts," Report DOT HS 807 288, National Highway Traffic Safety Administration, 1988.
8. Kessler, J.W., Hoyt, T.A., and Monk, M.W., "Pedestrian Head Injury Reduction Concepts," Report DOT HS 807 432, National Highway Traffic Safety Administration, 1988.
9. MacLaughlin, T.F., Kessler, J.W., "Pedestrian Head Impact Against the Central Hood of Motor Vehicles—Test Procedure and Results," *Thirty-fourth Stapp Car Crash Conference Proceedings*, SAE Paper No. 902315, 1990.
10. DeSalvo G.J., Gorman, R.W., *ANSYS, Engineering Analysis System User's Manual*, Swanson Analysis Systems, Inc., Houston, Pennsylvania, 15342, May, 1989.
11. Wirley, R.G., *DYNA3D A Nonlinear, Explicit, Three-Dimensional Finite Element Code For Solid and Structural Mechanics - User Manual*, Lawrence Livermore National Laboratory, Report UCRL-MA-107254, May, 1991.
12. Hallquist J.O., and Benson, D.J., "DYNA3D - An Explicit Finite Element Program for Impact Calculations," *Crashworthiness and Occupant Protection in Transportation Systems*, (Edited by T.B. Khalil and A.I. King) AMD-Vol 106, BED-Vol 13, American Society of Mechanical Engineers, New York, 1989.
13. *I-DEAS Finite Element Modelling User's Guide*, Structural Dynamics Research Corporation, Milford, Ohio, 45150, 1990.
14. *ANSYS Engineering Analysis System Theoretical Manual*, Swanson Analysis Systems, Inc., Houston, Pennsylvania, 15342, 1989.

S3-O-10

The Effect of the Vehicle Structure's Characteristics on Pedestrian Behavior

Kazuo Higuchi, Akihiko Akiyama
Honda R&D Co., Ltd.)

Abstract

In every country in the world, pedestrians are being killed in traffic accidents. This serious social problem needs to be dealt with as soon as possible. Most pedestrian fatalities are due to the forces transmitted to the head from contact with vehicle bodies. To reduce the number of deaths in such accidents, it is necessary to study how to protect pedestrian's head. To investigate ways to protect the head, the locations of head contact with the vehicle body and the corresponding velocities need to be studied. This paper describes our tests that used a full scale sled to determine how the orientation of pedestrians, shape of the front bumper and hood edge, and energy absorbing characteristics of those parts affect the head injuries of adult and child pedestrians. Computer simulation was also used in some cases to check the results of the actual tests. Prior to our study it was thought that bumper lead and hood height had individual effects on pedestrian injuries, but it was ascertained, as a result of our study, that these two conditions are interactive which leads to a more complex injury mechanism.

Introduction

The number of accidents in Japan involving pedestrians during 1990 was 79,634; the number of injured pedestrians was 80,017; and the number of pedestrians killed was 3,042. The number of pedestrians killed was 27.1% of all traffic accident deaths. Because this percentage is so high, pedestrian fatalities is a problem that needs to be solved as soon as possible.

In fatal pedestrian traffic accidents, the person involved is killed mainly because of injuries to the head as a result of contact with the vehicle body. To reduce such fatalities, a study on protecting the head is required. It must also be studied what area and at what speed the head is colliding with the vehicle.

This paper describes full scale sled tests that were used to simulate different car shapes and the effects of these shapes on head injuries to pedestrians. Pedestrian orientation to the vehicle, size of the pedestrian and the energy absorbing characteristics of the front area of the car were also investigated. Computer simulation was also used to analyze some of the cases.

Test Conditions

Dummy

The adult dummy used in the tests was a HYBRID-IIP (pedestrian type). The child dummies were models C6Y and C3Y. In some of the tests, neck load and moment were measured using the head and the neck of a HYBRID-III dummy.

Vehicle

Figure 1 shows the test sled and its dimensions. The bumper and hood were made of foamed plastic.

Test Method

The tests were conducted as follows:

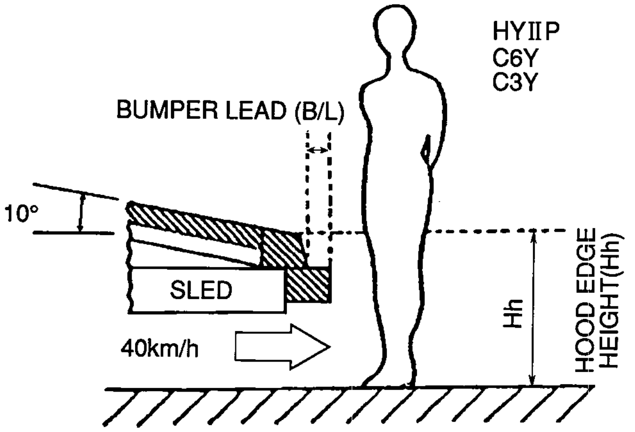


Figure 1. Test Configuration

Speed

The impact speed of the vehicle (sled) to the pedestrian was 40km/h.

Dummy Set-up

As shown in Figure 2, the dummy was positioned at a point along the longitudinal center line of the sled, with its fore part of body pointed in a direction 30 degrees inward from a perpendicular to the center line. This was fixed as a base position of the dummy. Both arms of the dummy were positioned behind its back with the wrists tied together with adhesive tape. The dummy was suspended with a rope from the head to a magnetic coupling. The coupling was set to disengage at 500 ms before collision.

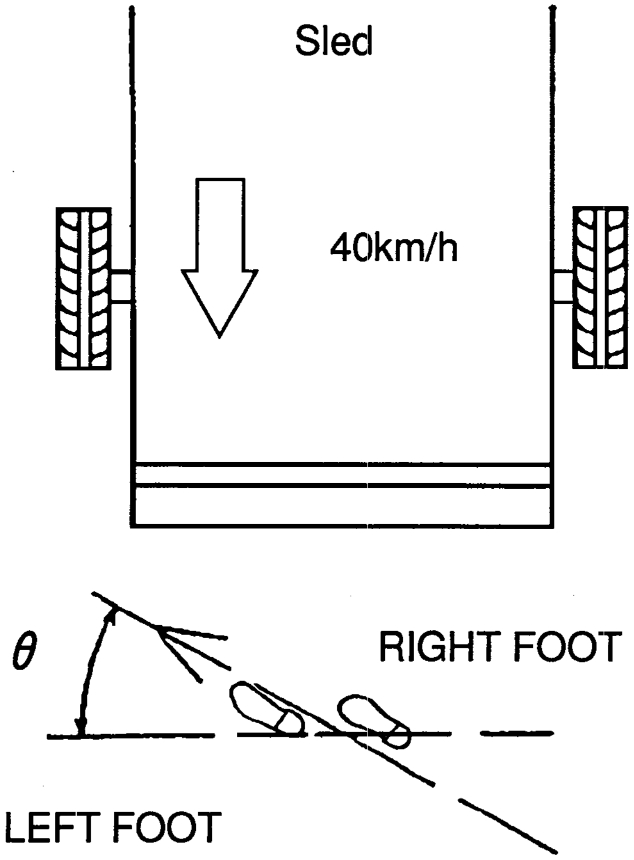


Figure 2. Dummy Set-up

Brake

The sled was set to brake at 200 ms or later after the collision, to avoid any braking influence on the dummy behavior.

Parameters

Parameters varied as follows:

Orientation of Pedestrian

Besides the 30 degree direction of the dummy, 0 degree, 60 degree and 90 degree (dummy facing straight at the sled) direction were also tested.

Hood Height (Hh)

The base test height was 680 mm from the ground to the leading edge of the hood. Tests at 755 mm and 830 mm were also conducted.

Bumper Lead (B/L)

The base bumper lead was 140 mm, with some tests using 40 mm.

Crush Characteristics of the Bumper

Figure 3 shows 3 kinds of crush characteristics of bumper. A indicates the base crush characteristic.

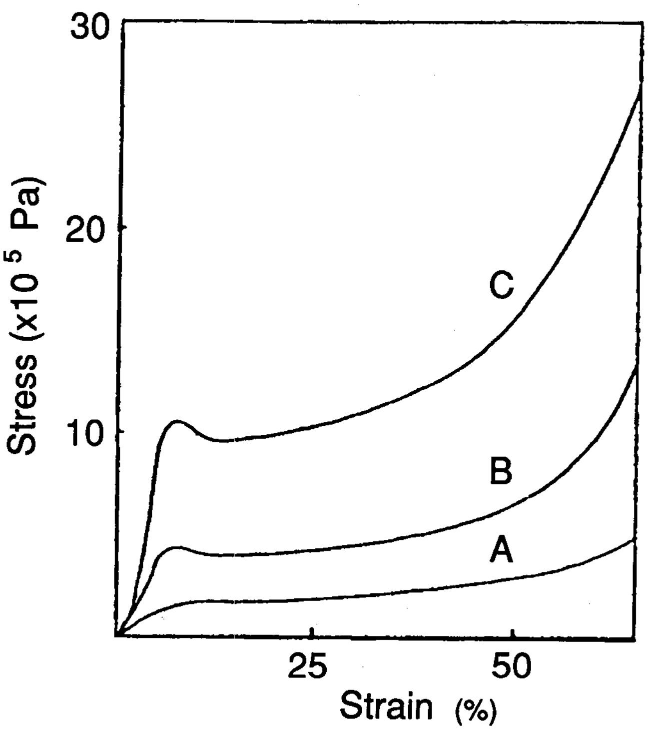


Figure 3. Crush Characteristics of the Bumper

Crush Characteristics of the Hood Edge

Figure 4 shows 3 kinds of crush characteristics of hood edge. B indicate the base crush characteristic.

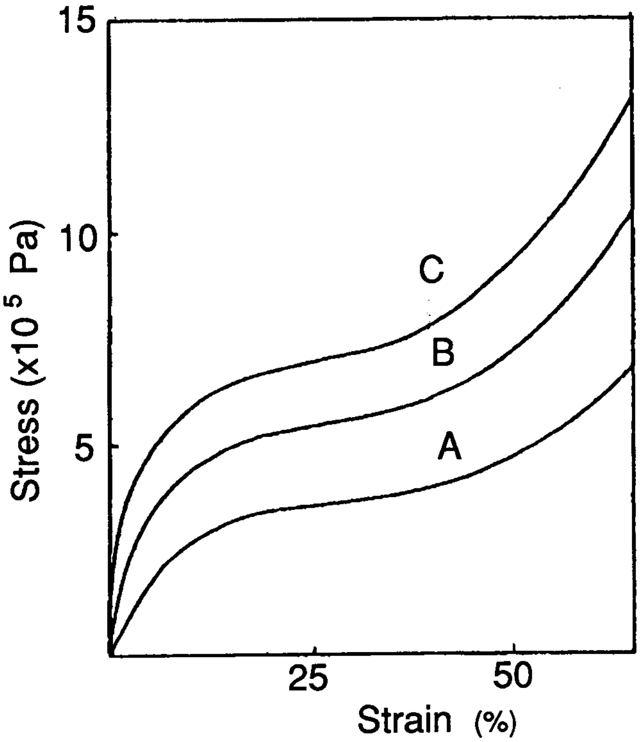


Figure 4. Crush Characteristics of the Hood Edge

Computer Simulation

A three dimensional mathematical model, CAL-3D(CVS) was used for the computer simulation. The model of the pedestrian was based on an AM 50% dummy and had fifteen segments and fourteen joints.

As with the tests using the sled, the computer simulation was applied to confirm the combined effects of bumper lead and hood height.

Test Result

Table 1 shows all of the test conditions and results.

Table 1. Test Conditions and Results

No.	Specification	HIC	Head impact speed [m/s]	WAD [mm]
01	Base condition	1590	11.8	1940
02	Base condition	1449	11.5	1830
03	Hood edge 755mm	1303	11.0	1850
04	Hood edge 830mm	464	8.0	1840
05	Hood edge stiffness A, Hood stiffness B	1305	11.4	1830
06	Hood edge stiffness B		12.7	1900
07	Bumper stiffness A	1788	12.3	1770
08	Bumper stiffness A	1438	12.2	1830
09	Bumper stiffness C	1549	12.3	1970
10	Bumper lead 40mm	698	9.2	1820
11	Hood edge height 830mm, Bumper lead 40mm	1002	9.9	1650
12	Hood edge height 830mm, Bumper lead 40mm	947	9.5	1690
13	Dummy angle 20°	1305	9.5	2040
14	Dummy angle 60°	2248	13.0	1820
15	Dummy angle 90°	2912	13.3	1840
16	Dummy size C3Y	2122	0.0	780
17	Dummy size C6Y	925	7.3	1110
18	Dummy size C6Y,Hood edge stiffness B	1174	7.7	1080
19	Dummy size C6Y,Bumper stiffness A	1614	9.3	1120
20	Dummy size C6Y,Bumper stiffness C	2303	9.5	1060

Reproducibility of Tests

To check the test methods for reproducibility, tests using the standard bumper and tests using a softer bumper were performed twice each. The results showed consistency in the head injury criterion (HIC) and head impact speed between the two tests of each type.

Head Impact Speed and HIC

Figure 5 shows the relationship between the vertical component of the head collision speed (Vh) and HIC. A correlation between them can be observed. By measuring the head collision speed we can estimate the corresponding HIC.

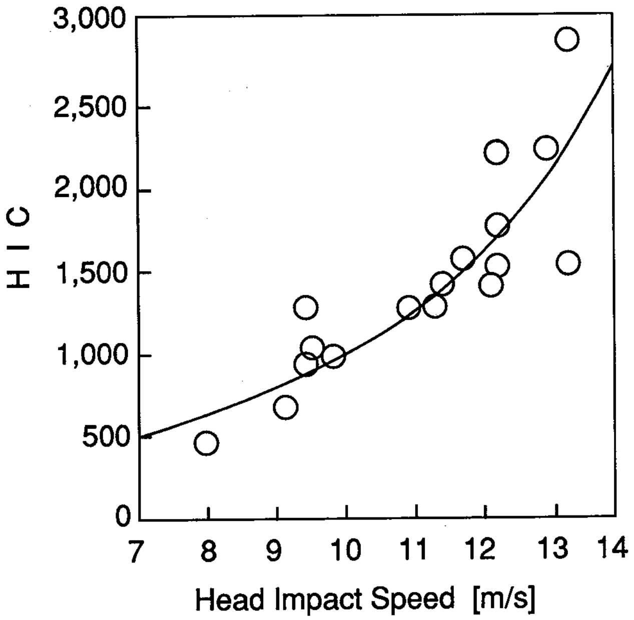


Figure 5. Head Impact Speed vs HIC

Orientation of Pedestrian

Figures 6 and 7 show how pedestrian orientation to the vehicle influences HIC and head impact speed of the pedestrian. It can be seen that the angle of orientation of the pedestrian to the vehicles is fairly proportional to HIC level and head impact speed. As the angle becomes smaller, i. e. the dummy's direction is more perpendicular to the vehicle's direction, HIC levels are reduced. This is primarily due to the effects of the shoulder contact. At this orientation the shoulder contacts the hood before the head, thereby reducing the head impact speed. Depending on the orientation of the pedestrian, head impact speed vary by as much as 35%.

Figures 8 and 9 show the influence of the hood edge height and bumper lead to pedestrian head injuries. With a long bumper lead, the head impact speed increases as the hood edge height is reduced. With a short bumper, hood edge height has little influence on head impact speed.

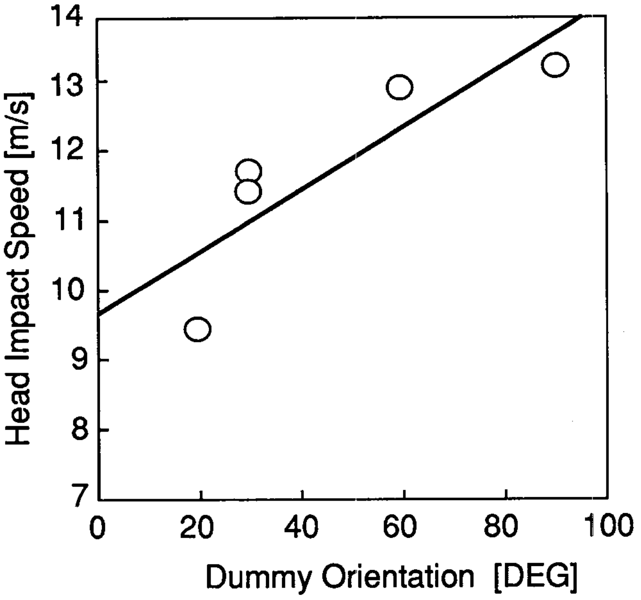


Figure 6. Influence of Dummy Orientation on Head Impact Speed

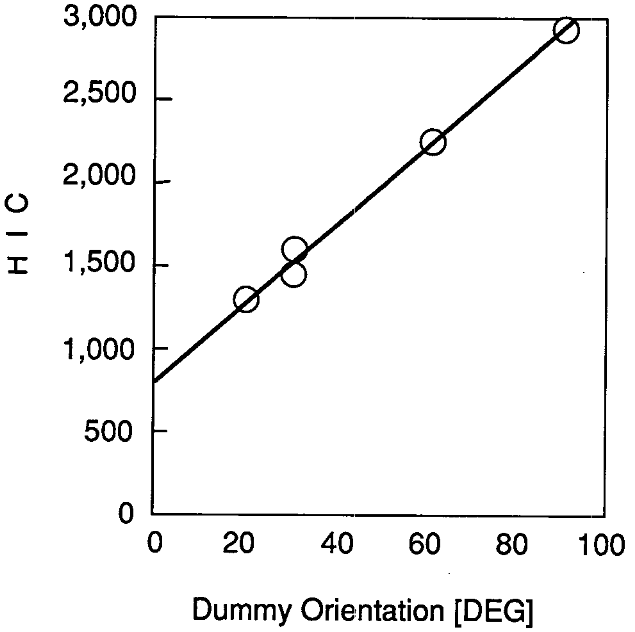


Figure 7. Influence of Dummy Orientation on HIC

These results were also found using the CVS model, shown in Figures 10 and 11. The simulation results were the same as the full scale sled data.

Thus there is a correlation between the hood edge height and the bumper lead, and if either is varied independently, an unexpected counter effect may occur.

Crush Characteristics of Hood Edge and Bumper

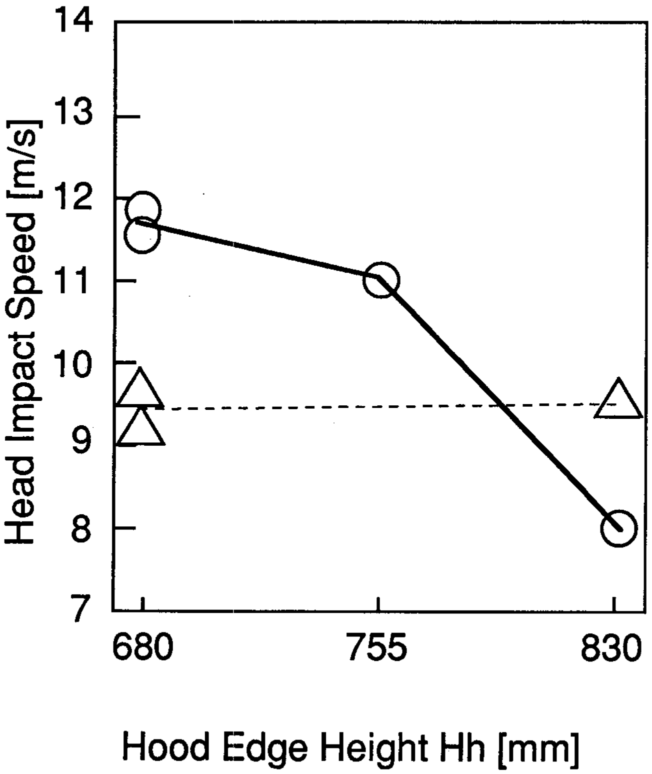


Figure 8. Influence of Hood Edge Height (Hh) and Bumper Lead (B/L) on Head Impact Speed

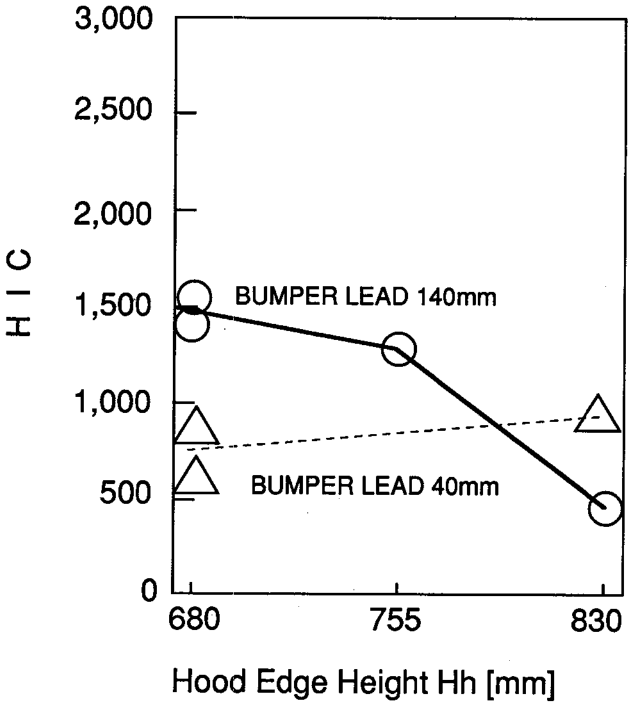


Figure 9. Influence of Hood Edge Height (Hh) and Bumper Lead (B/L) on HIC

Figures 12 to 15 show the results of tests in which the crush characteristics of the hood edge and the bumper were varied. The pedestrian dummies represented an adult and a six year old child.

There is no significant influence on the adult HIC level when the crush characteristics of the bumper is

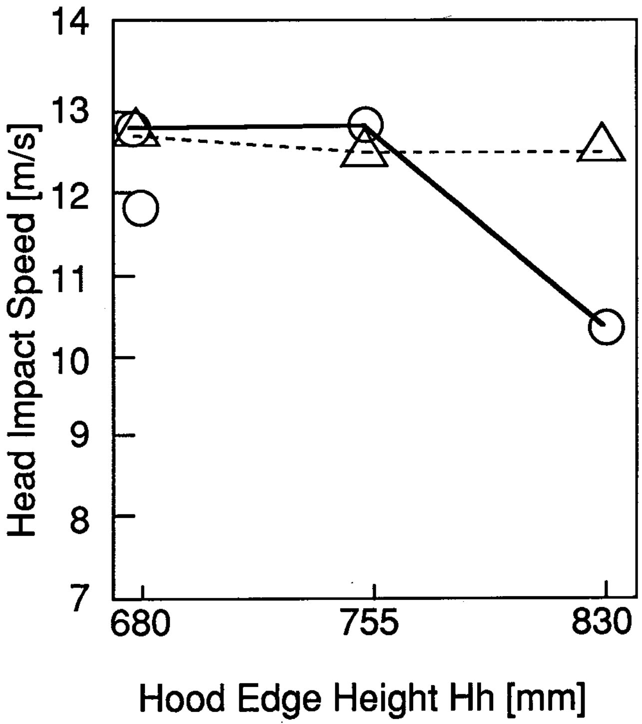


Figure 10. Influence of Hood Edge Height (Hh) and Bumper Lead (B/L) on Head Impact Speed (CVS Simulation)

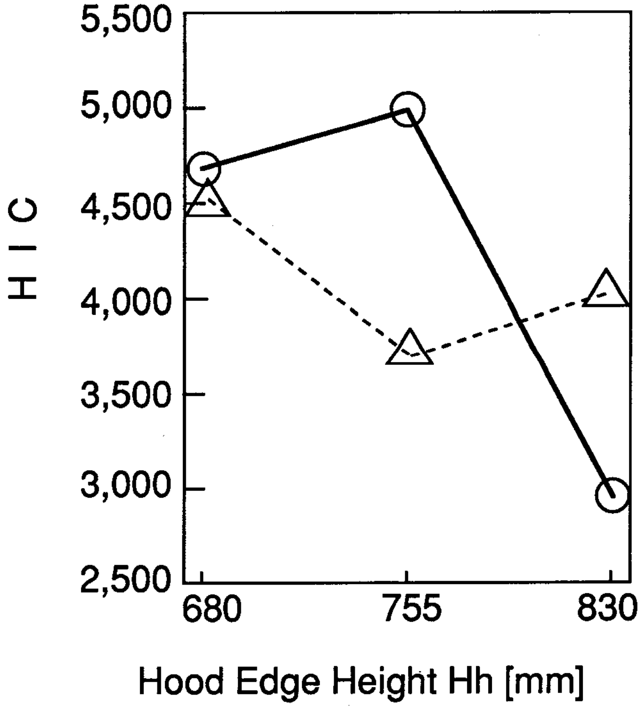


Figure 11. Influence of Hood Edge Height (Hh) and Bumper Lead (B/L) on HIC (CVS Simulation)

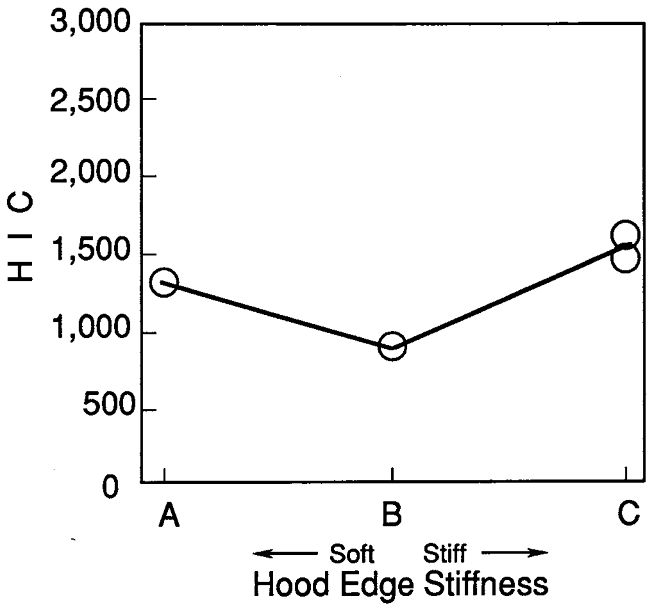


Figure 12. Influence of Hood Edge Stiffness on HIC

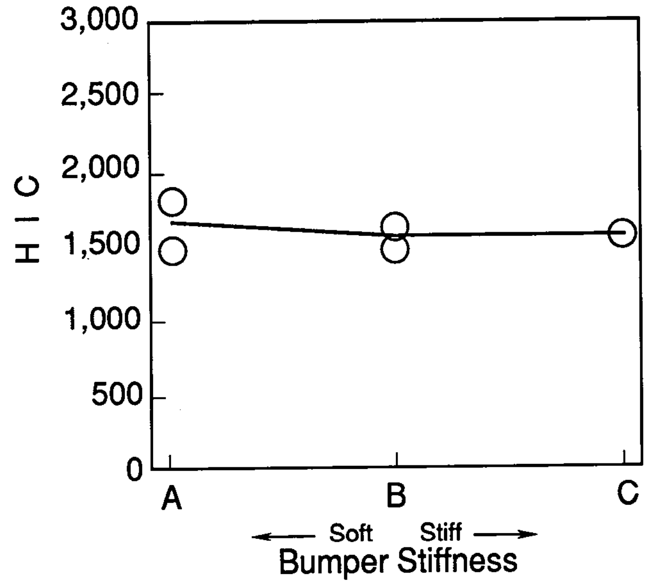


Figure 13. Influence of Bumper Stiffness on HIC

varied. HIC levels for the child dummy are the lowest for the bumper of standard crush characteristics compared to the stiffer and softer bumpers. The reason for this is unclear. The effect of parameter variations is not monotonous and there is a possibility to record the minimum HIC similar to the correlation between the hood edge height and the bumper lead as mentioned above.

The effect to the adult by the crush characteristics of the hood edge does not increase or decrease linearly and may have a relationship to the six year old child and bumper crush characteristics.

Child

The HIC of the six year old child was lower than that of the adult. However,because of a direct hit to the pelvis by the bumper, the pelvis acceleration of the child was remarkably greater than that of the adult.

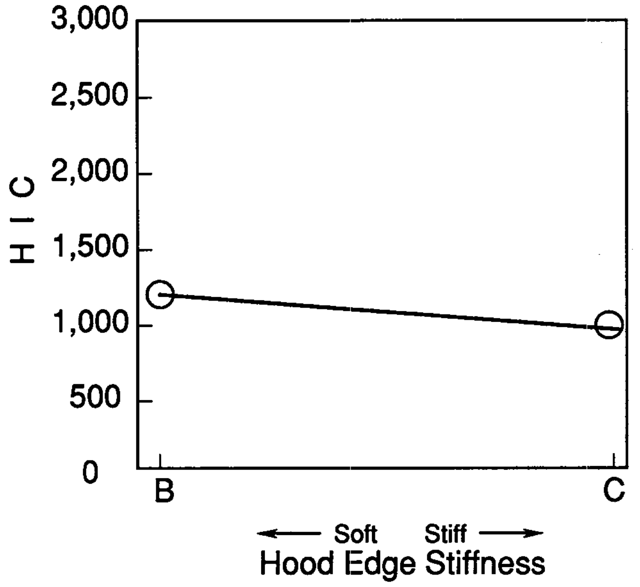


Figure 14. Influence of Hood Edge Stiffness on HIC with 6 Year Old Child

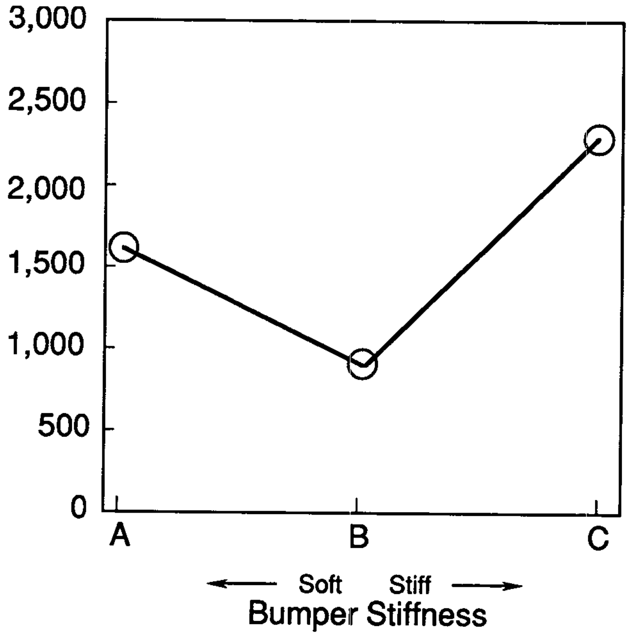


Figure 15. Influence of Bumper Stiffness on HIC with 6 Year Old Child

The HIC and chest acceleration of the three year old child were remarkably worse than those of the adult because the entire body was contacted by the front of the vehicle.

The ratio of height to Wrap Around Distance (WAD) for an adult is about 1.1. A six year and three year old child are about 1. and 0.8 respectively.

Children have a smaller ratio of height to WAD than adults have.

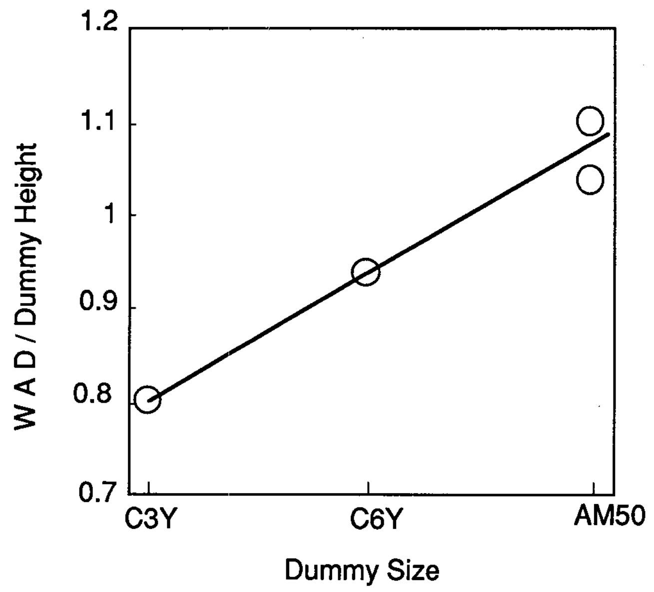


Figure 16. Dummy Size vs WAD/Height

WAD

The WAD was about 1800 mm-1900 mm for all the vehicle configurations. There was no significant correlation between WAD and vehicle bumper/hood edge configurations.

Load on Neck

The relation of the load and moment on the neck to the height of the hood edge was measured. As shown in Figure 17, compression force on the neck decreases as the height of the hood edge increases. An increased hood

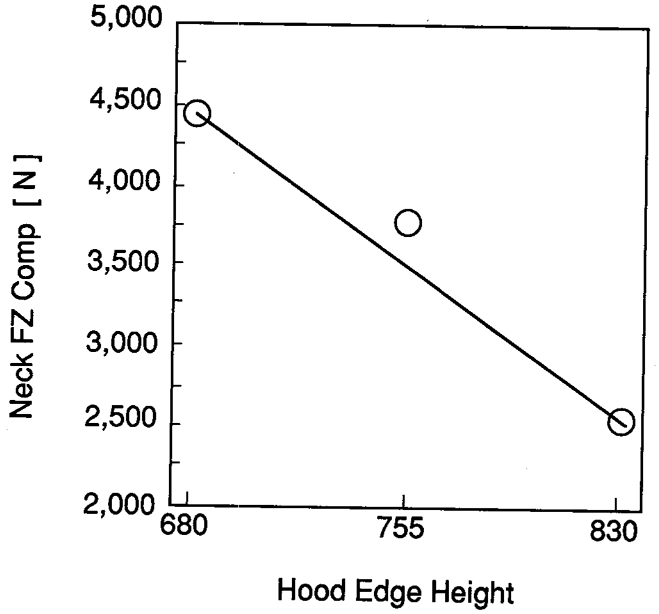


Figure 17. Influence of Hood Edge Height (Hh) on Load to Neck

edge height is thought to result in a decreased effective mass of the body on collision of the head with the hood.

Because foam plastic was used in this test instead of an actual hood, the friction coefficient between the hood and the head is different from the coefficient given by actual car. The load levels were also different from those given by actual car, but the relationship would have been similar. If the hood rigidity of an actual car is reduced to protect the head of a pedestrian, the same tendencies described above are likely to occur.

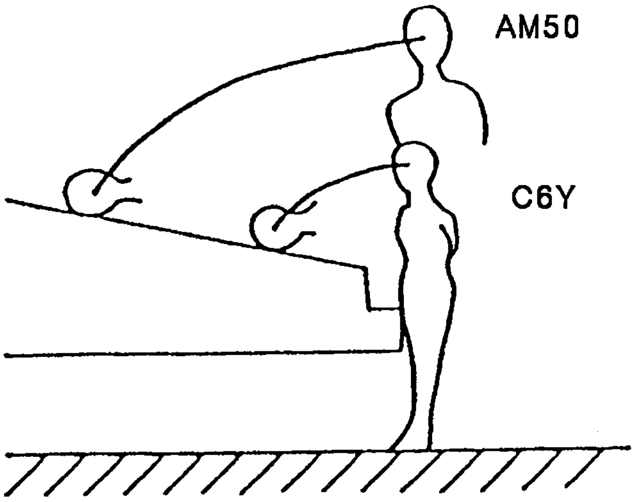


Figure 18. Head Trajectory

Conclusion

To protect pedestrians from being killed by collisions with vehicles, the effects of pedestrian orientation to the vehicle and the shape and crush characteristics of the front of the vehicles was studied. The impact speed of the head and HIC levels were measured. The results obtained from the tests are as follows.

1. The relationship of the angle formed between the walking direction of the pedestrian and the running direction of the vehicle and HIC, and the relationship of that angle and WAD are nearly proportional. As the pedestrian's body is turned more sideways, HIC is reduced. This is due to the pedestrian's shoulder contact with the hood before the head contact. Test conditions greatly influence the results, so careful determination of these conditions is required.
2. The effect of the height of the hood edge and the bumper lead are interactive. The effect of one parameter variation can be influenced sensitively by another parameter variation. As previously studied, bumper height is also thought to be interactive with those factors described above. When studying ways to protect pedestrians' heads, all interactions of the parameters need to be checked in order to obtain the optimum condition. Otherwise, an action to reduce injury to the pedestrian may in fact worsen certain injury levels.
3. We could not find any clear relationship between crush characteristics of the hood edge and the HIC level or between the crush characteristics of the bumper and HIC. However, according to the test data, the effect of crush characteristics may have some complex non-linear relationship to HIC. Certain maximum or minimum HICs may exist in each respective sets of data.
4. The size of the pedestrian is related to the injury level. A six year old child has lower HIC than does an adult. It is thought that the smaller radius of rotation of the child's head lowers the head's collision speed with the hood. However, the three year old pedestrian's head collides directly with the front of the vehicle resulting in serious HIC levels. The chest accelerations for this size pedestrian is also very severe. The reason seems to be the small mass of the child, which results in the body being sent flying by the impacting vehicle.

References

Safer Cars for Pedestrian. J. Harris and C.P. Radley. Transport and Road Research Laboratory. Department of the Environment-Department of Transport. 7th International Technical Conference on Experimental Safety Vehicles.

Experimental and Mathematical Simulation of Pedestrian-Vehicle and Cyclist-Vehicle Accidents. E. Janssen and J. Wismans. Research Institute for Road Vehicles TNO. 10th International Technical Conference on Experimental Safety Vehicles.

Experimental Research on Pedestrian Protection Using Mobile Deformable Barrier. L. Maestripieri. Alfa Romeo Auto S.P.A. 10th International Technical Conference on Experimental Safety Vehicles.

Research Concentrated on an Experimental Method for Protecting Pedestrians. K. Maeda, H. Isobe, Y. Sakuma, and Y. Kurihara. Nissan Motor Company Ltd. 10th International Technical Conference on Experimental Safety Vehicles.

The Influence of Car Design on Pedestrian Protection. H. Harris and N. Grew. Transport and Road Research Laboratory. Austin Rover Group Ltd. 10th International Technical Conference on Experimental Safety Vehicles.

Car to Pedestrian Impact Energies and their Application to Sub-System Testing. G. J. L. Lawrence and J. Harris. Transport and Road Research Laboratory. 11th International Technical Conference on Experimental Safety Vehicles.

The Influence of Car Shape on Pedestrian Impact Energies and its Application to Sub-system Testing. G. J. L. Lawrence. Transport and Road Research Laboratory. 12th International Technical Conference on Experimental Safety Vehicles.

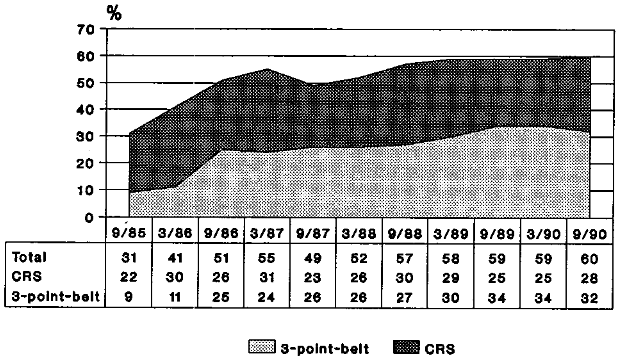
S3-O-12

New Aspects for Optimizing Child Restraint Systems: Experiences from Accidents, Trolley Tests and Interviews

K. Langwieder, Th. Hummel
HUK-Verband

Abstract

Restraining children in cars is essential if their safety is to be increased. The experience with child restraint systems (CRSs) is positive, but improvements in system characteristics, handling and acceptance are necessary. Dynamic trolley tests have been carried out with different kinds of CRSs on the basis of previously published injury patterns in children. These tests showed that in addition to the force loading on children caused by the type of CRS the major problem that exists is connected with the CRS's characteristics for fastening it to the car. The relative belt geometry of the cars and problems of slack may often lead to unfavourable movements of the CRS, and these were observed in the tests. Some of the conditions of the compliance testing according to ECE-R 44 no longer represent actual real-life conditions. Proposals for improvement are given. Problems of misuse and CRS handling and acceptance are discussed. These findings are based on extensive interviews with 1,282 parents on problems they had with CRSs. We received information on a total of 1,903 products. The results are subdivided into 9 different types of CRSs. Proposals for future CRS development which go beyond purely technical safety measures are also derived from this investigation.

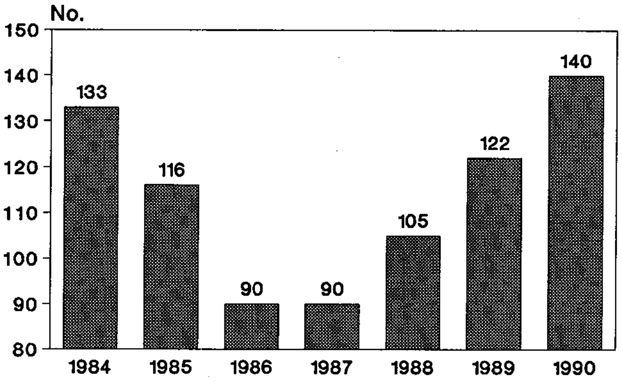


	9/85	3/86	9/86	3/87	9/87	3/88	9/88	3/89	9/89	3/90	9/90
Total	31	41	51	55	49	52	57	58	59	59	60
CRS	22	30	26	31	23	26	30	29	25	25	28
3-point-belt	9	11	25	24	26	26	27	30	34	34	32

CRS = Child Restraint System

Source: [1]

Figure 1. Use Rates of Special Child Restraint Systems and 3-Point-Belts on the Rear-Seats of Cars



Source: [5]

Figure 2. Number of Children (0-14 Years) Killed in Cars in West Germany

Introduction

In the last few years it has been possible to notice a stepping up of activities in the matter of children's safety in cars. This observation, however, seems only to apply to the level of vehicle and children's seat manufacturers and to various institutions which deal with traffic safety, but not to the level of the parents. Thus, for example, the total restraint rates of children in cars in West Germany (Figure 1) have remained unchanged with only slight fluctuations for several years [1]. As a consequence of this unsatisfactory willingness to use the CRS, the number of children killed in the years 1988 to 1990 has risen by about 15% each year (Figure 2). While in 1987 only 90 children were killed in cars, by 1990 the figure was 140 (an increase of 56%). Against the background of a generally constant trend in the number of car occupants killed while mileage increased, this development can certainly be described as dramatic and alarming.

In view of these facts, the legal requirements in Germany pertaining to the restraint of children in cars is also one aspect which should therefore be fundamentally reconsidered. In the Federal Republic of Germany there is at present the following legal regulation for the use of CRSs: since 1976 it has been laid down by law that children aged from 0 to 12 years must in principle be seated on the rear seats of cars. Only if all the rear seats are occupied by children may a further child be additionally transported on the front passenger seat. In 1988 this regulation was amended. According to this, a child may sit on the front seat if it is restrained by a CRS of an ECE-R 44 tested type [3]. The international testing regulation for CRSs (ECE-R 44) was also integrated into national law. That CRSs which are fitted in cars must be used on the rear seats also applies. Since 1989 offering CRSs for sale that are not tested according to ECE-R 44 has not been allowed. These regulations have thus not yet achieved a mandatory obligation to restrain children in cars; transporting children on the rear seats without CRSs is therefore still permitted.

This situation in the Federal Republic of Germany warrants the continued and intensive study of the subject of child safety. Thus the HUK-Verband's Automobile Engineering Department has for many years dedicated itself to the subject of children in cars, and today it is one of the tenets of the HUK's philosophy to pursue all kinds of accident research. That means that we include the knowledge gained from real-life accidents and also the experience obtained from crash tests and interviews in our research work. This comprehensive approach to research and the findings resulting from it are described in this paper.

Experiences from Accident Studies

The latest findings from our studies of real-life accidents with children in cars [2] were published within the framework of the 12th ESV Conference; in that paper the structure of our extensive material, which today covers some 1,200 children (restrained and unrestrained), was described.

The Injury Risk for Restrained and Unrestrained Children

The analysis of the accidents had shown (Figure 3) that unrestrained children are injured far more frequently than restrained children (51.4% compared with 17.3%). If the serious to fatal injuries (MAIS 3-6) are combined (Figure 4), a relative proportion for the restrained children of only 0.5% emerges for this range of injury severity; unrestrained children, however, show a relative proportion of 3.5%. According to our study, the risk of serious/fatal injuries for the children who are unrestrained is thus seven times higher than for those that are restrained.

MAIS	Unrestrained (N • 288)		Restrained (N • 865)	
0	48.6%		83.7%	
1	41.3%	*51.4%*	15.9%	*17.3%*
2	6.6%		0.9%	
3	1.7%		0.1%	
4/5	1.1%		0.2%	
6	0.7%		0.2%	
Total	100.0%		100.0%	

Figure 3. MAIS Distribution of Unrestrained and Restrained Children

A considerable injury risk in the case of unrestrained children exists especially when they are ejected out of the car, an occurrence which can be almost ruled out if the child is properly restrained.

Injury Patterns of Restrained and Unrestrained Children

Different injury patterns resulted from the relative frequency of the individual injuries for restrained and unrestrained children; in the case of unrestrained children they are characterized by head injuries (55.4%), injuries to the arms (21.6%) and to the legs (21.0%) and bruises and abrasions over the whole body (14.9%). The severe injuries (MAIS 3) are distributed over all age groups in the case of unrestrained children.

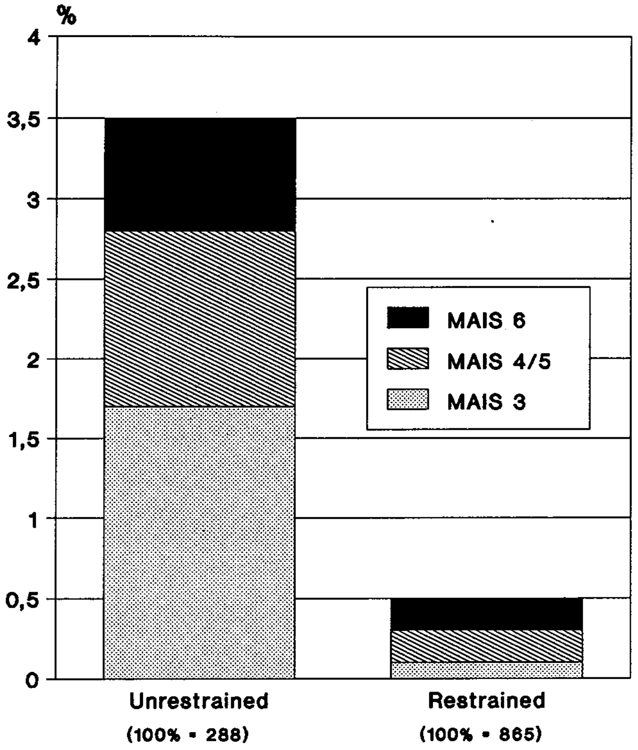


Figure 4. Injury Severity MAIS 3-6 of Unrestrained and Restrained Children

When injuries occur at all to restrained children, head injuries also dominate with 60.4%; but the following priorities change: neck injuries come second with 15.3%, followed in third place by abdominal injuries with 13.9%.

It is the head that is injured most frequently in both restrained and unrestrained children, but the risk of a moderate to fatal head injury (AIS 2-6) is many times higher for unrestrained than restrained children (Figure 5). There is also a clear reduction in the AIS 2-6 injuries to the abdomen/pelvis and the extremities. The injuries to the neck frequently observed in restrained children are mainly due to the fact that many *slight* neck injuries (AIS 1) occur, although neck fractures did occur in our accident material, albeit very rarely.

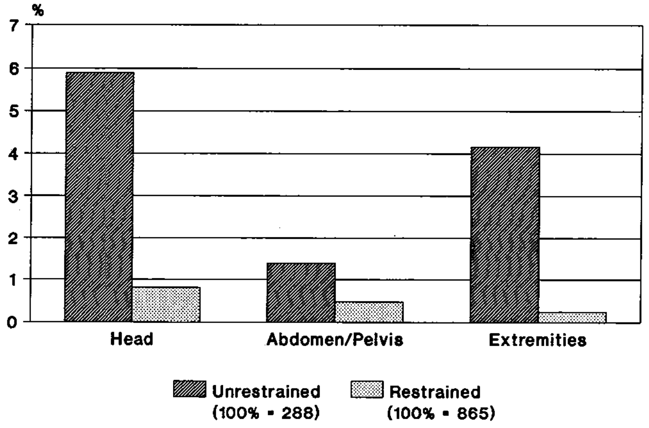


Figure 5. Frequency as AIS 2-6 Injuries to Different Parts of the Body of Unrestrained and Restrained Children

While no preponderance of injuries according to age groups could be observed in unrestrained children, serious/fatal injuries (MAIS ≥ 3) to restrained children were concentrated on the age between 0 and 2 years. It is not known at present which factors are responsible for this phenomenon.

The Problem of the Adult's Belt

In [2] it also turned out that many parents tend to restrain their children solely with belts for adults too early (about 32% of the children restrained with an adult's belt were shorter than 120 cm, 62% shorter than 140 cm). Our accident material provided no evidence—because of the specific structure of the material—of an increased risk for children who use the adults' belt too early. Nevertheless, the premature use of an adult's belt, because of its unfavourable position, can result in considerable injuries, especially in the region of the abdomen, the chest and also of the spine. According to our findings, therefore, children should not be restrained by an adult's 3-point-belt until they have a height of 120-140 cm. It is absolutely inadvisable to use the lap belt only (or the lap belt part with the shoulder belt behind the child's back).

Recommendations from the Point of View of Accident Research

The following recommendations can be derived for the future from what we know at present:

- Up to an age of 1.5 years children should be restrained in rearward-facing systems.
- To make it possible to design more compact rearward-facing systems for children above 9 months of age the ECE-Group 0 should be extended upwards (up to about 12 kg); a change of CRS from Group 0 to Group I at the child's age of about 9 months—being a critical age of injury risk—could thus be avoided.
- In the event of the ECE-Group 0 being extended the ECE Group I could be extended upwards to 20 kg (about a 5-year-old child).
- The present ECE-Groups II and III could be combined to form a new ECE-Group II (20 - 36 kg).
- It should also be considered whether a group specially for babies up to the "sitting age" (about 6 months) should be formed; this would provide a chance to develop small restraint systems for transporting babies in a lying position (especially advisable from a medical point of view).
- Besides revising the ECE-Groups, new dummies which also enable neck and abdominal loadings to be measured would be particularly desirable.

Experiences from Trolley Tests

Our accident studies had resulted in indications that certain kinds of injuries to restrained children could be dependent on the restraint system used. We had noticed, for example, severe neck injuries mainly to children in forward-facing restraint systems with 4-point-belts. In our accident material a strong dependence of severe injuries on the age of the restrained children had also been observed: serious injuries (MAIS ≥ 3) only occurred up to the age of two years. What influences are responsible for these observations from real-life accidents could, however, not be clearly ascertained in retrospect, since very many factors influence the injuries to restrained children.

Trolley tests were therefore used in an attempt to mark the limits of individual parameters more accurately. The tests were also intended to explain how far the fastenings of CRSs in cars and the fastening of the dummies in the child's chair exert an influence on the loading of the dummies. Joint publications with the Bundesanstalt fur Strassenwesen (BASt) and the German Automobile Club ADAC have already reported on the tests [4, 6]; the essential results and the conclusions drawn from them are given here once again.

Tests with Carry-cots (ECE-Group 0)

According to ECE-R 44, carry-cots with proper belts can be tested as restraint systems for children in ECE-Group 0. Eleven trolley tests—carried out by the BASt [6]—were performed with the P0 (British standard) and P3/4 (TNO) dummy. The chest acceleration was measured (only P3/4 dummy), and the head displacement was ascertained by using photos recorded on film.

Combinations of different carry-cots and harness systems were tested. The crash tests at 50 kph were performed only head-on in accordance with ECE-R 44. Without going into detail about the various models of carry-cots and harness systems, the following points can be noted:

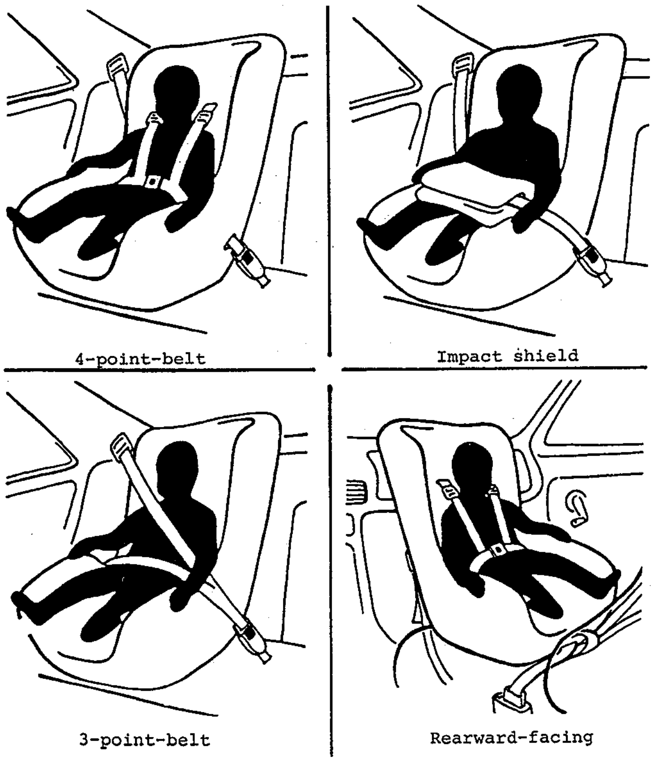
In all tests using the P0 dummy, the only assessment criterion (horizontal head displacement) was satisfied, with displacements lying below the threshold value of 550 mm. In all the tests using the P3/4 dummy, however, one of the threshold values—head displacement or chest acceleration—was exceeded. With a strict interpretation of the regulation, therefore, all the harnesses and carry-cots in the various test combinations failed.

The majority of carry-cots are obviously not specially designed to withstand the great stresses during an accident, so that the side walls, which are sometimes only made of pasteboard, collapse and the baby is stopped suddenly by the harness. Where harnesses are used which have two separate belts running over the carry-cot, the baby is restrained at the neck and knees. Although no measuring values are available, severe injury in the area of the neck must be expected in this case.

The results for the harnesses used were rather better than those for the carry-cots; all the belts tested were completely undamaged even after several tests. The fasteners on all the belts could be opened without difficulty after the tests. ECER 44 defines the safety of child restraint devices only for 0° collisions. In the case of an oblique impact, however, it must be feared that the carry-cots could slip out of the harnesses completely and be catapulted around inside the car.

Tests with CRSs in the ECE-Group I

In cooperation with the ADAC, CRSs in the ECE-Group I were tested [4] which can be allocated to four different systems (Figure 6). The tests were carried out on a dynamic trolley in compliance with ECE-R 44. However, in order to obtain results that are as reliable as possible and in keeping with real life, some of the minor conditions laid down there were modified or extended. The following test parameters applied:



4-point-belt

Impact shield

3-point-belt

Rearward-facing

Figure 6. Schematic Presentation of Four Different Child Restraint Systems in ECE-Group I

- *Dummies:* Each of the tests was conducted with a modified TNO P3/4 and P3 dummy using the following measuring equipment: three-axial acceleration sensors for head and chest loadings, a multi-component sensor for neck loadings, a two-component sensor for abdominal loadings.
- *Position in the vehicle:* The ECE-R 44 specifications on the test seat and the belt anchorage points are no longer in keeping with real-life conditions; so the following sitting positions with the available belt anchorage points of a large-scale production car in the lower medium range (VW Golf) were used for the tests:

  - Rear outer seat with 3-point-belt
  - Middle rear seat with 2-point lap belt
  - Front passenger seat with 3-point-belt.

  The tests on the front passenger seat were conducted in a car body torso and thus in real-life surroundings.
- *Type of Impact:* The systems were tested in a 0° head-on collision and at an impact speed of 50 kph. For the rearward-facing systems only, rear-end impact tests were also conducted with a 20° angle of impact to the car's longitudinal axis and an impact speed of 30 kph. The aim of this test was to increase the probability of the dummy striking the B-pillar. In view of the fact that forward-facing systems with a backrest support the child over a large surface area and thus especially safely in the event of a rear-end impact, no rear-end impact tests were carried out with these systems.

Figure 7 shows a compilation of the mean values, calculated from the maximum measured loading figures, for the systems examined in the test; this makes a direct comparison of the systems possible.

System	Head [g]	Head disp. *)	Neck [kN]	Chest [g]	Abdomen [kN]
4-point-belt	106	-	3.2	53	1.4
Impact shield	104	0	2.4	37	0.5
3-point-belt	68	++	2.6	43	0.7
Rearward-facing	50	+	0.5	48	0.1

Note: *) + + very few / + few / 0 sufficient (about 550 mm) / - deficient / -- worse

Figure 7. Mean Values Calculated from the Maximum Measured Loading Figures for the Four Systems Tested

In the case of *head deceleration* surprisingly high figures of over 100 g are observed for the 4-point-belt and the impact shield systems; surprisingly high when it is taken into consideration that the biomechanical limit in the adult dummy is fixed at 80 g. With the 4-point-belt system these high deceleration figures are likely to be due to the relatively large amount of effective belt slack when the safety chairs are held back by the standard belt as a consequence of the unfavourable belt geometry. With the shield system the impact of the head against the shield may be a possible cause.

With regard to the unknown response behaviour of the dummies' heads, it cannot be assumed from the results which correlations exist between the measured head acceleration and the head injuries in real-life accidents.

The greatest *head displacements* occur with the 4-point-belt system. The above-mentioned belt slack is likely to be the cause. The slight head displacements with the other systems, especially with the 3-point-belt systems, were conspicuous.

The maximum *neck loadings* were found with an average force of 3.2 kN to the neck with the 4-point-belt system. This may be an explanation for the fact that the cases of tetraplegia, which are actually relatively rare, are primarily known from accidents with this system.

The high figures might be caused by the belt slack between the CRS and the car's standard belt. Here the results for the impact shield and the 3-point-belt system are noticeably lower, although still relatively high compared with the rearward-facing system. The best results here were clearly achieved by the rearward-facing system.

High rates of *chest deceleration* occur with the 4-point-belt system. On average it is 53 g, and is thus close to the biomechanical limit of 55 g specified in ECE-R 44. The lowest figures—on average only 37 g—were found with the impact shield system.

Matters are very similar in the case of *abdominal loading*. Here the 4-point-belt system produces on average 1.4 kN. Mainly responsible for this high figure is the unfavourable position of the belt's buckle in the region of the abdomen. The lowest loadings occur here with the rearward-facing system. They are also relatively low in the case of the impact shield and 3-point-belt systems.

The influence of *front and rear-end impacts* with the rearward-facing system is presented in Figure 8. It emerges that, at least in the case of the 0° front impact, the loadings are mostly clearly lower than in the case of the rear-end impact. Here considerable head displacements occur. It can be seen that the inadequate attachment of the system to the front passenger seat results not only in displacements of the whole system but also in a very hard impact of the dummy's head, for example against the B-pillar. It is conceivable that as a result of slight changes in the fringe conditions (for example, the angle of the direction of impact) the movement sequences and loadings might undergo clear changes, and may be worse in a front collision, too, as a consequence of the inadequate anchorage of the system in the car.

	Head [g]	Head disp. *)	Neck [kN]	Chest [g]	Abdomen [kN]
Front impact	50	+	0.5	48	0.1
Rear-end impact	89	--	1.1	34	0.2

Note: *) + + very few / + few / 0 sufficient (about 550 mm) / - deficient / -- worse

Figure 8. Mean Values Calculated from the Maximum Measured Loading Figures for the Rearward-Facing Systems in Front and Rear-End Impacts

As expected, front collisions lead to especially low neck loading rates due to the support given to the trunk and head in one plane.

Conclusions from the trolley tests

The following demands and conclusions can be deduced from the tests described:

- It is very inadvisable to use carry-cots, since most of the products tested are not strong enough and the head displacement or the chest acceleration with the P3/4 dummy was too high in the case of all products.
- The anchorage belts themselves are very strong and well able to withstand the loads arising in a 0° impact; in the case of oblique collisions, however, there is a risk that the carry-cots slip out of the anchorage belts and are thrown around inside the car as a consequence.
- Especially in the case of the 4-point-belt and rearward-facing systems in the ECE-Group I, it is not always possible to fix the systems firmly in the car using the belts for adults; a large displacement of the seat on impact leads to considerable additional loading.
- Using additional systems (e.g. tether straps) or a completely different way of fastening the CRS (e.g. ISOFIX [8]) it would be possible to anchor the systems far more firmly in the car.
- In order to avoid using unsuitable CRSs each car manufacturer should give recommendations as to which CRSs are suitable for his car models.
- CRSs should therefore also be tested in cars to create conditions closer to reality (rigidity of seats, danger from parts of the car's interior).
- When revising test regulations for CRSs, oblique and side collisions should also be taken into consideration.

Experiences from Interviews

Objectives

There are many aspects to the subject area "Restraining children in cars;" it extends far beyond what is purely of a technological nature and includes behavioural research. Not only in retrospect, i.e. from the consideration of accidents that have already happened or from tests, can conclusions be drawn from sources of error in engineering or in human behaviour, but also the everyday behaviour of road users is becoming the focus of research interests. For this reason we carried out interviews of parents [7] with the aim of finding out what reasons there might be for the low use rate of CRSs, how parents assess their children's restraint systems, what demands they make on the product CRS, how parents behave when purchasing CRSs, when installing them in the car and using them in everyday life and what problems they encounter when doing so. Another aim was to make the motives of their actions, the acceptance of different systems and the conditions for possible forms of misuse more transparent.

Method and Experience

The positive experience we had with our written survey on accidents with children in cars [2] encouraged us to choose the device of a written interview once again. From a comparable pool of addresses as described in [2] 6,110 people were written to who had reported to us in connection with a competition that they had problems "when choosing and buying" and "when installing and using“ CRSs. A questionnaire, consisting of

20 questions, was developed in cooperation with a psychologist for this project. The subject areas on which the parents could provide information and the acceptance of the questionnaire by the parents were ascertained in pretests.

The persons written to (referred to below mostly as "parents") were asked to fill in *one* questionnaire per CRS. We thus received usable information from 1,282 parents on altogether 1,903 CRSs ("products"), representing 37 different models. In view of the extensive questionnaire with 20 questions and an additional "Statistics Section" the return rate of 22% can be seen as quite satisfactory.

Two interesting details in connection with our project should be mentioned here:

a) The parents were written to in two separate blocks (each block over 3,000 communications) at two-monthly intervals; a comparison of the return rates produced an excellent agreement of both blocks (21.8199% compared with 21.8134%).

b) About 80% of all the replies had been received only two weeks after sending out the questionnaires.

Subject Areas Selected

Figure 9 shows the allocation of the 37 different models to the ECE-Groups and the division into 9 different systems to which the remarks below will basically refer.

Systems	Frequency of products Number	relative to ECE-Group [%]	relative to total number [%]
ECE-Group 0 (about 0-9 months) N = 144 (7.6%)			
Rearward-facing	133	92.4	7.0
Car-bed	11	7.6	0.6
ECE-Group I (about 9 months to 4 years) N = 1285 (67.5%)			
Impact shield	620	48.3	32.6
4-point-belt	532	41.4	27.9
3-point-belt	129	10.0	6.8
Rearward-facing	4	0.3	0.2
ECE-Group II/III (about 3-10 years) N = 474 (24.9%)			
Booster cushion	264	55.7	13.9
Impact shield	168	35.4	8.8
Booster cushion + impact shield	42	8.9	2.2

Figure 9. Frequency of Different Child Restraint Systems Divided into ECE-Groups (N=1,903 products)

Acquiring and Selecting a CRS

Ways of acquisition. Over three-quarters of the 1,903 products in our random sample (75.9%) were bought new, according to the information of the parents. Nevertheless, the number of products acquired second-hand is considerable (13.7%). In 9.7% of the cases the child's chair was a present. Besides that, some were borrowed (0.4%) and exchanged (0.1%).

Criteria of selection. In the questionnaire the parents could give reasons for choosing their CRS. Figure 10 shows the selection criteria in the frequency with which they were named.

Selection criteria for the products	Frequency of namings Number	relative to N_1 [%]	relative to N_2 [%]
- Especially good marks in test reports	974	31.8	51.2
- Inspection in department store	562	18.3	29.5
- Recommended by friends	552	18.0	29.0
- Especially good value for money	289	9.4	15.2
- Model fitted the existing seat belts	222	7.3	11.7
- Convincing manufacturer's advertising	136	4.4	7.1
- Specially recommended as suitable for one's own car	75	2.5	3.9
- Recommended on radio and television	41	1.3	2.2
* Other selection criteria	213	7.0	11.2
Total:	3,064	100.0	--

Note: * Answers not given in questionnaire
Multiple responses possible

Figure 10. Selection Criteria when Acquiring a Child Restraint System (N_1=3,064 responses; N_2=1,903 products)

For the 1,903 products 3,064 criteria were named. The distribution of the answers shows the strong influence of consumer test reports on the decision to purchase. This applied to half of all products and was mentioned in one-third of all answers. The inspection in a department store and friends' recommendations are factors of almost equal value for the decision to purchase. The price of the products appears in fourth place in this list. The CRS manufacturers' advertising also apparently plays a subordinate role—this no doubt mainly because very little advertising is made for CRSs in Germany. Only relatively few parents state that the criterion for their decision to purchase was that they bought a product that fitted into their car.

Information Given on the Children and the Periods of Time when the CRS was Used

Number of children. The 1,903 products were used by 2,695 children, the product being used exclusively by one child according to the parents—in 63.7% of the cases, by two children in 31.2% and by three in 4.7% of the cases. Only six times (0.3%) was the use of a product by four children mentioned.

Periods of time it was used. The parents could state for each child at which age of the child they used the CRS and in which period of time. Figure 11 shows the periods of time when use began combined into four classes. According to this, only about 5% of the CRSs were used in a period of time which is no longer recent (1971-1979); in exactly 50% of the cases the initial use was between 1987 and 1990.

Entry and exit ages. If the period in which the children used the CRS is examined rather more closely, it is possible to distinguish between the beginning ("entry age") and the end ("exit age") of use. Figure 12 shows the entry age for the individual systems. Numbers outside the framed area in Figure 12 are not in accordance with the manufacturers' recommendations; they indicate that here the child was placed into the CRS when it was too young or too old. This applies to about 8% of the cases recorded. The figures of the premature use of models clearly dominate here. This applies in particular to the systems in the ECE-Group II/III, which in 25% of all cases were used too early. In the ECE-Group I these cases account for only 2.2%.

Figure 13 gives an overview of the exit ages. 12.1% of the answers show that the children apparently used the systems longer than the manufacturers recommend. It can be seen that it is mainly the systems in the ECE-Group I (here, however, solely the 4-point-belt and impact shield systems) that are used too long (13.7% of the cases). For the ECE-Group 0 and II/III the respective figures are 4.9% and 9.2% of the cases. Even if it is taken into consideration that the information given by the parents is not absolutely reliable and the height and weight of some children are outside the norm, a high proportion of misuse is likely to become apparent here.

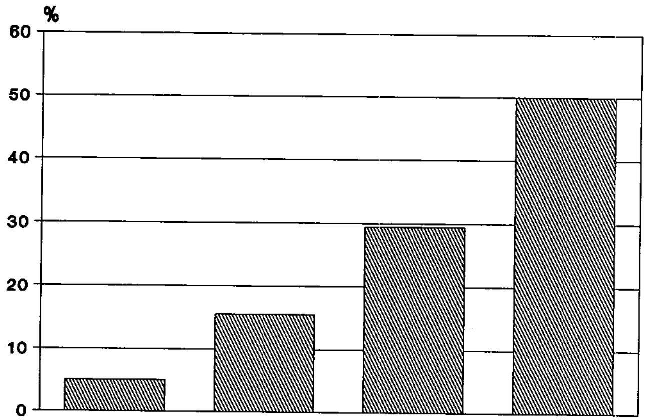


Figure 11. Beginning of Use of Child Restraint System (N = 2,583 responses)

	System designation								
Entry age	1	2	3	4	5	6	7	8	9
0	153	14	10	22	5	1			
0.5	2	2	293	238	33	1			
1	1		283	413	69			5	6
1.5	1		70	146	33	1	1	8	2
2			14	44	15	1	13	16	8
2.5			2	11	6		45	40	9
3			2	15	4		82	68	12
3.5			1	2			46	34	5
4				2	1		65	50	5
4.5				1			11	9	1
5			1	1	1		24	15	4
5.5							7	2	
6							9	2	
6.5									
7							2		
7.5							2		
8									
8.5									
9							1		
9.5							1		
10							1	1	
11									
12									
Total	157	16	676	895	167	4	310	250	52

Note: Figures of absolute frequency
Values inside frame correspond to the instructions given by the manufacturers

ECE-Group 0
1 = Rearward-facing
2 = Car-bed

ECE-Group I
3 = 4-point-belt
4 = Impact shield
5 = 3-point-belt
6 = Rearward-facing

ECE-Group II/III
7 = Booster cushion
8 = Impact shield
9 = Booster cushion + impact shield

Figure 12. Ages from Which Children Use Restraint Systems ("Entry Age")

	System designation								
Exit age	1	2	3	4	5	6	7	8	9
0.5	19	5							
1	120	10	1	3	4	1			
1.5	3		10	12	2			1	
2	1	1	39	37	3				
2.5	2		69	66	6				
3	1		129	172	20		1	1	2
3.5			71	109	24		2	3	1
4			60	182	20	1	5	9	10
4.5			14	34	6		4	11	1
5			18	69	5		8	22	3
5.5			2	11	5		7	9	1
6			2	12	6		22	30	2
6.5				2			5	14	2
7				5	1		20	23	1
7.5							3	3	1
8							8	7	2
8.5							2		1
9							5	6	
9.5							3		
10							7		
11							5	3	
11.5							1		
12							4	2	
13								1	
Total	146	16	415	714	102	2	112	145	27

Note: Figures of absolute frequency
Values inside frame correspond to the instructions given by the manufacturers

ECE-Group 0
1 = Rearward-facing
2 = Car-bed

ECE-Group I
3 = 4-point-belt
4 = Impact shield
5 = 3-point-belt
6 = Rearward-facing

ECE-Group II/III
7 = Booster cushion
8 = Impact shield
9 = Booster cushion + impact shield

Figure 13. Ages Up to Which Children Use Restraint Systems ("Exit Age")

Installing and Fastening the CRS in the Vehicle

Instructions for installing and using. 96% of the parents say that they installed the CRS in their car themselves. 19.4% of the respondents could no longer remember the instructions for installing and using the particular model; for the rest (1,533 products) the instructions were assessed as follows:

- 35.4% very good,
- 58.7% satisfactory,
- 5.9% very inadequate.

There are significant differences between the individual systems in assessing the instructions for installation and use. The following tended to be assessed positively:

- rearward-facing systems in the ECE-Group 0,
- 3-point-belt systems in the ECE-Group I,
- booster cushions in the ECE-Group II/III.

The following tended to be assessed negatively:

- 4-point-belt and
- impact shield systems in the ECE-Group I.

Position in car. The position where the CRS was installed can be seen from Figure 14; the parents could give several positions. It turned out that in only about 8% of the cases the position of the CRS in the vehicle is changed.

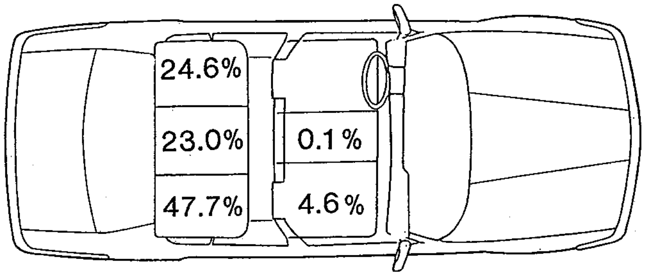


Figure 14. Position of Fastening the Child Restraint System in the Cars (N = 3,534 positions)

The position "rear right" is preferred by 47.7% of the parents; followed by about a quarter for each of the answers for the sitting positions "rear left" (24.6%) and "rear centre" (23.0%). The position "front right" has a proportion of only 4.6%; this is chiefly accounted for by rearward-facing systems.

A very similar distribution of the sitting positions of restrained children was observed in our accident study [2]:

- front right, 1.6%
- rear left, 28.7%
- rear centre, 22.0%
- rear right, 47.7%

This high measure of agreement from two completely different studies (one of them accident studies, the other interviews) is a clear indication that this distribution of the sitting positions of restrained children really does reflect reality.

Fastening the systems. Whenever the word "fastening" is used in connection with CRSs two aspects have to be distinguished:

a) fastening, or anchoring, the system in the vehicle,
b) fastening, or restraining, the child in the CRS.

In some systems both is achieved at the same time using the existing car safety belts (e.g. 3-point-belt system), in others only the CRS is fastened with the car's seat belts, while the child is restrained with a belt integrated into the CRS (e.g. Y-belt in the rearward-facing systems in the ECE Group 0).

According to the parents' information, the car safety belts or the adapters and additional belts, which are supplied by the CRS manufacturers are adequate for fastening CRSs in just under 90% of the cases, but in our survey 12.2% of the parents said they used their own additional constructions or further aids to fasten the CRS and to restrain the child in the system. The additional constructions and aids for fastening are a further indication of misuse.

(Dis)satisfaction with the fastening. The question of whether they were satisfied with the possible ways of fastening the system in the car was answered by 39.3% of the parents with "No"; the number of those who are dissatisfied is thus considerable.

The individual systems differ significantly from one another in this respect. Figure 15 shows an increased dissatisfaction with the 4-point-belt and the impact shield systems in the ECE-Group I. A disproportionately large number of parents are satisfied with the fastening of the 3-point-belt and booster cushion systems.

System designation	Satisfied with the possible ways of fastening yes	no	Total
ECE-Group 0			
Rearward-facing	136 *(123.9)*	68 *(80.1)*	204
Car-bed	8 *(9.7)*	8 *(6.3)*	16
ECE-Group I			
4-point-belt	483 *(545.9)*	416 *(353.1)*	899
Impact shield	620 *(683.2)*	505 *(441.8)*	1,125
3-point-belt	177 *(143.9)*	60 *(93.1)*	237
Rearward-facing	4 *(3.0)*	1 *(2.0)*	5
ECE-Group II/III			
Booster cushion	349 *(265.4)*	88 *(171.6)*	437
Impact shield	168 *(168.8)*	110 *(109.2)*	278
Booster cushion + Impact shield	42 *(43.1)*	29 *(27.9)*	71
Total	1,987	1,285	3,272

Note: Figures of observed value and *(expectation value)*
Cramer's $V = 0.16$; $p < 0.001$

Figure 15. (Dis)Satisfaction with Installation and Fixing of Child Restraint Systems in the Car Related to the System (N = 1,405 responses)

Figure 16 lists the reasons given for the dissatisfaction with the fastening. They refer to both the anchorage of the CRS in the vehicle and to the restraint system itself and the specific combination of vehicle and restraint system.

Reasons given	Number	%
Fastening inadequate	362	25.8
Installing/removing awkward	275	19.5
Additional material necessary	112	8.0
Belt guide too complicated	108	7.7
Belt position inconvenient	76	5.4
System not anchored firmly	72	5.1
Existing belts unusable	72	5.1
Anchorage points missing	66	4.7
Inconvenient to use	64	4.6
Belt very short	55	3.9
Belt difficult to buckle	48	3.4
No belts on rear seats	34	2.4
Only static belts in the car	16	1.1
Only lap belt in the car	15	1.1
Belt guide wears out	11	0.8
Belt difficult to adjust (static belt)	10	0.7
Adaptor belt cannot be used	9	0.7
Total:	1,405	100.0

Note: all answers not given in questionnaire

Figure 16. Reasons for Dissatisfaction With Installation and Fixing of the Child Restraint systems in the Car (N = 1,405 responses)

Problems of Use and Reasons for Not Using the CRS

Use problems. In about two-thirds of all cases (67.3%) the parents stated that they had problems with the use of the CRS; the causes for these problems are listed in Figure 17. The nature and frequency of the use problems depend on the restraint system used; the rearward-facing systems, 3-pointbelt and booster cushion systems tend to be positively assessed. On the other hand, the 4-point-belt systems, impact shield systems in the ECE-Group I and the combination of booster cushion + impact shield in the ECE-Group II/III seem to cause a disproportionately large number of problems.

Problems of use	Frequency of namings Number	relative to N_1 [%]	relative to N_2 [%]
- Seat is difficult to clean	360	13.4	18.9
- Lap belt always has to be readjusted	354	13.2	18.6
- Shoulder belt runs across child's neck	347	12.9	18.2
- Removing seat from car troublesome	286	10.6	15.0
- Buckles difficult to open and close	252	9.4	13.2
- Seat material not long-lasting	243	9.1	12.8
- Fastening belt slips out of guide	236	8.8	12.4
- Fastening belts are too short	161	6.0	8.5
- Seat is never in a straight position because of wheel casing	119	4.4	6.3
* Other use problems	327	12.2	17.2
Total:	2,685	100.0	--

Note: * Answers not given in questionnaire
Multiple responses possible

Figure 17. Kinds of Problems in Using the Child Restraint Systems (N_1 = 2,685 responses; N_2 = 1,903 products)

Not using the CRS. The question of whether the CRS is always used, i.e. whenever the child is in the car, was answered in the negative in 19.4% of the cases. Figure 18 shows the reasons why the CRS is not always used. Failure to use the CRS is apparently less a matter of space requirements (e.g. for carrying adults or goods) than of the child's refusal to sit in the restraint system; long trips also have an important influence. But even for short trips or when they are in a hurry the parents apparently 'forget' to use it quite often.

Reasons for not using the CRS	Number	%
- Child refuses to sit down in the child's seat	140	26.6
- Long, strenuous drives (incl. holiday drives)	117	22.2
- Restraint system happens not to be in the car	74	14.0
- Especially urgent situation	67	12.7
- Short rides	63	12.0
* Carrying adults or several children	38	7.2
* Transporting goods	11	2.1
* Other reasons	17	3.2
Total:	527	100.0

Note: * Answers not given in questionnaire
Multiple responses possible

Figure 18. Reasons for Not Using the Child Restraint Systems (N = 527 responses)

CRSs as Seen by the Child

As parents are familiar with their children's world of experience, we also asked them whether they thought their child liked sitting in the restraint system used. In 50.0% of all cases the parents believe that their child does not enjoy sitting in the CRS. In more than half of the cases the respondents gave two or more reasons for the lack of acceptance of the CRS by the child.

If we distinguish according to systems, the situation turns out as presented in Figure 19, many of the problems being caused by the system:

System designation	Narrow	Perspiration	Bad view	Too big/ too heavy	Bad experience	Cannot go to sleep	No chance to play	Cannot bend legs	Distribution of the reasons for rejection
ECE-Group 0									
Rearward-facing	12 (13.6)	15 (14.5)	7 (8.7)	11 (1.3)	0 (0.5)	5 (7.4)	4 (6.7)	6 (8.6)	60
Car-bed	0 (0.4)	1 (0.5)	1 (0.3)	--	--	0 (0.2)	0 (0.2)	0 (0.3)	2
ECE-Group I									
4-point-belt	80 (70.9)	97 (85.3)	8 (51.1)	10 (7.9)	2 (2.8)	20 (43.7)	80 (39.4)	15 (50.7)	312
Impact shield	205 (180.7)	247 (192.8)	130 (116.4)	14 (17.9)	7 (6.3)	70 (96.9)	74 (89.0)	132 (114.5)	879
3-point-belt	13 (26.5)	37 (27.2)	13 (16.3)	0 (2.5)	1 (0.9)	17 (14.0)	7 (12.6)	17 (16.2)	105
Rearward-facing	0 (1.3)	1 (1.4)	2 (0.8)	0 (0.1)	--	1 (0.7)	0 (0.6)	0 (0.8)	4
ECE-Group II/III									
Booster cushion	16 (36.1)	5 (38.6)	16 (23.1)	2 (3.6)	2 (1.3)	45 (19.8)	12 (17.6)	25 (22.9)	123
Impact shield	56 (63.2)	19 (56.7)	78 (33.9)	3 (5.3)	0 (1.6)	48 (29.1)	16 (26.2)	53 (33.7)	271
Booster cushion + impact shield	23 (13.2)	9 (14.1)	3 (8.4)	0 (1.3)	2 (0.5)	15 (7.4)	7 (6.5)	8 (8.4)	67
Total	404	431	258	40	14	221	199	256	1,823
Cramer's V	0.23	0.39	0.39	0.29	0.09	0.32	0.27	0.24	
Significance	$p < 0.001$	$p < 0.001$	$p < 0.001$	$p < 0.001$	$p < 0.001$	$p < 0.001$	$p < 0.001$	$p < 0.001$	

Note: Figures of observed value and *(expectation value)*

Figure 19. Failure of Child to Accept the Restraint System Depending on the System (N = 1,823 responses)

- Narrowness is named with significant frequency for the impact shield systems in the ECE-Group I and the combination of booster cushion + impact shield in the ECE-Group II/III as a reason for the child's refusal to sit down in the CRS
- The children have to perspire very frequently in all the CRSs in the ECE-Group I.
- Children in impact shield systems in the ECE-Group I and II/III have an especially bad view from the car

windows, a problem that hardly exists for the users of 4-point-belt systems.

- In the impact shield systems the children can hardly bend their legs, while here again the users of the 4-point-belt systems seem to have almost no such problem.
- Children in the systems in the ECE-Group II/III have the problem of not being able to go to sleep in the system significantly more frequently, according to our figures.
- It is especially the children in the 4-point-belt systems that lack the chance to play.
- Finally the problem of "the child being too heavy or too large for the particular system" is statistically of only minor importance, at least according to the parents; it is most likely to occur with the rearward-facing systems in the ECE-Group 0.

Parents' Wishes and Suggestions for Improvements

Because of the specific way the questions were asked, it is understandable that only 17.2% of the respondents considered no improvements to the systems to be necessary, while the overwhelming majority made several suggestions.

The wishes and suggestions for improvements are of very varying quality. Some are quite general, but others are concrete. They also show up conflicting aims: on the one hand, the child itself should not be able to open the belt buckles, but, on the other hand, it should not be complicated for adults to open the buckles, either, so that installing and removing the seats and rescuing the child after an accident is made considerably more difficult. If an attempt is made to categorise the wishes and suggestions for improvements it can be seen that such subjects as comfort for the child, handling, safety and quality of the products is repeatedly mentioned; frequently the suggestions touch on several subjects at the same time.

A statistical analysis of the replies given in the questionnaires related to the systems (Figure 20) produces the following results:

System designation	Greater durability	Easier installation and removal	Belt buckles that child cannot open	Better instructions for use	Height and position of seat adjustable	Distribution of wishes for improvement
ECE-Group 0						
Rearward-facing	22 *(21.8)*	26 *(26.1)*	7 *(32.4)*	10 *(11.4)*	20 *(40.0)*	85
Car-bed	1 *(1.7)*	5 *(2.0)*	1 *(2.5)*	2 *(0.9)*	0 *(3.1)*	9
ECE-Group I						
4-point-belt	86 *(115.5)*	237 *(138.3)*	214 *(171.9)*	90 *(60.9)*	121 *(212.0)*	748
Impact shield	166 *(136.1)*	149 *(162.9)*	201 *(202.6)*	63 *(71.5)*	340 *(249.7)*	919
3-point-belt	34 *(23.0)*	4 *(27.5)*	37 *(34.2)*	7 *(21.1)*	48 *(42.2)*	130
Rearward-facing	1 *(0.7)*	2 *(0.9)*	2 *(1.1)*	1 *(0.4)*	3 *(1.3)*	9
ECE-Group II/III						
Booster cushion	42 *(41.4)*	6 *(49.6)*	39 *(61.6)*	8 *(21.7)*	74 *(76.0)*	169
Impact shield	25 *(31.7)*	23 *(38.0)*	53 *(47.2)*	12 *(16.7)*	74 *(58.2)*	187
Booster cushion + Impact shield	4 *(9.0)*	4 *(10.7)*	13 *(13.3)*	7 *(4.7)*	19 *(16.4)*	47
Total	381	456	567	200	699	2,303
Cramer's V	0.14	0.36	0.20	0.15	0.33	
Significance	$p < 0.001$	$p < 0.001$	$p < 0.001$	$p < 0.001$	$p < 0.001$	

Note: Figures of observed value and *(expectation value)*

Figure 20. Suggestions for Improvement Mentioned in the Questionnaire Related to the System (N = 2,303 responses)

- In particular the owners of impact shield and 3-point-belt systems in the ECE-Group I want the products to be more durable and hard wearing;
- Mainly the owners of 4-point-belt systems consider easier ways of installing and removing to be desirable;
- The wish for belt buckles which the child itself cannot open is also especially marked among the owners of the 4-point-belt systems;
- An improvement in the instructions for use and handling is called for above all for the 4-point-belt systems;
- Finally, the wish for ways of adjusting the height and position of the seat is expressed with great frequency for all impact shield systems.

Deductions from the Interviews

Many of the detailed findings from our survey speak for themselves and require no further comments. Thus the manufacturers of CRSs should eliminate the technical and design defects of the CRSs mentioned above; this would at the same time do away with some of the sources of misuse. To have a preventive effect here misuse diagnosis instruments should already be used in the development stage of CRSs.

To reduce the problems of installing the CRSs in the car the automobile manufacturers will also have to make their contribution by stepping up their cooperation with the CRS manufacturers. Over and beyond this, more integrated CRSs should be offered for sale in the course of further optimising the passive safety of cars; in the long term no less attention should be paid to the safety of children in cars than to the safety of adults.

As can be concluded from the large number of references to problems and the many wishes for improvements, parents have certainly been made aware of the subject of child safety. On the basis of the information they provided it can be assumed that CRSs are generally by no means perceived as unproblematical articles, the purchase of which results in obvious benefits. A greater awareness of the dangers for unrestrained children in cars alone will not have the necessary effect on the parents. The CRS must appear to them to be a comfortable, practicable and safe way of transporting children, which at the same time satisfies the needs of the latter.

Summary

In spite of intensified activity in the area of child safety, an increase in the number of children killed in cars was recorded in the last three years in West Germany; in 1990, 140 children aged from 0 to 14 years died as passengers in cars. The reasons for this are not known at present; *one* reason might be that the rate for restraining children has been stagnating for years, while the total mileage of all cars has gone up.

HUK-Verband's accident research has for many years been dealing with the subject of children in cars, and today it is part of the HUK philosophy that not only knowledge obtained from the analysis of real-life accidents but also the experience gained from crash tests and interviews are included in the research work. The analysis of car accidents with restrained and unrestrained children has confirmed the very positive protective effect of CRSs: thus unrestrained children are injured far more frequently than restrained ones and have a 7 times higher risk of sustaining serious to fatal injuries.

Although retrospective accident analysis results in clear indications of possible injury mechanisms for restrained children, it is very difficult to clearly demarcate certain factors. Trolley tests conducted with carry-cots and four different systems in the ECE-Group I made it possible to confirm conjectured loadings and movement sequences of restrained children and to detect weak points in certain CRSs. The results obtained also showed that the test conditions specified in ECE-R 44 are no longer adequate for assessing a CRS which is in keeping with real-life conditions.

Surveying 1,282 parents in writing on problems with CRSs yielded information on 1,903 products. The knowledge thus gained goes far beyond purely technical considerations. Indications of the parents' behaviour when purchasing, selecting and using CRSs was obtained; and not only system-specific problems in dealing with CRSs but also weak points as seen by the consumer emerged. Indications of misuse showed up indirectly.

The accident analysis, the trolley tests and the interviews produced the following conclusions and demands:

- Children should be restrained in rearward-facing systems up to an age of about 1.5 years.
- For safety reasons carry-cots should not be used for transporting babies in cars.
- To make it possible to design new CRSs (especially for infants) the ECE-Groups 0 and I should be expanded; a change of CRS from Group 0 to Group I at the child's age of about 9 months—being a critical age of injury risk could thus be avoided.
- The present ECE-Groups II and III could—by expanding Group I—be combined into *one* group.
- New dummies should be developed which allow not only the head and chest loadings to be measured but also the neck and abdominal loadings.
- CRSs should also be tested in cars.
- Oblique and side collisions should be taken into account in test regulations.
- Fastening CRSs in cars should—especially in the case of 4-point-belt and rearward-facing systems—be improved.
- The weak points of CRSs should be eliminated in both the technical area and with regard to comfort and handling.
- The manufacturers of CRSs should make any form of misuse impossible in the development stage of their products by using misuse diagnosis instruments.
- A safety assessment of CRSs should take into account not only the safety in tests but also easy handling and the safety against misuse respectively the effect of misuse.
- Each car manufacturer should give recommendations as to which CRSs are suitable for his car models.
- Possible problems in connection with the fastening of CRSs in the car should be avoided through further improvement in cooperation between the car and CRS manufacturers ; moreover, in future more integrated systems should be offered for sale.
- The legal provision for restraining children in cars in the Federal Republic of Germany should be fundamentally revised so that concrete and unequivocal regulations come into force.
- The existing international contacts in the area of child safety should be continued and further expanded to come even closer to the aim of increased safety for children in cars.

References

1. Bundesanstalt für Strassenwesen, "Anlegequoten von Sicherheitsgurten und Benutzung von Kinder-Rückhaltesystemen in Pkw—Ergebnisse der Erhebung in den alten Bundesländern vom September 1990," Bergisch Gladbach
2. K. Langwieder, Th. Hummel, "Children in Cars—Their Injury Risks and the Influence of Child Protection Systems," Twelfth International Technical Conference on Experimental Safety Vehicles, Goteborg, May/June 1989
3. ECE-R 44, "Einheitliche Bedingungen für die Genehmigung der Rückhalteeinrichtungen für Kinder in Kraftfahrzeugen," Economic Commission for Europe
4. K. Langwieder, Th. Hummel, B. Felsch, W. Klanner, "Injury Risks of Children in Cars—Epidemiology and Effect of Child Restraint Systems," XXIII FISITA Congress, Torini, May 1990
5. Statistisches Bundesamt Wiesbaden, "Strassenverkehrsunfälle," Fachserie 8, Reihe 3.3
6. K.-P. Glaeser, K. Langwieder, Th. Hummel, "Protection Effects of Child Restraints—Experiences from Accidents and Sled Tests with Carry-Cots," International Road Safety Conference, Göteborg, September 1990
7. K. Langwieder, Th. Hummel, F. Ruppert, "Kinderschutzsysteme im Auto—Eine Befragungsstudie über Probleme bei ihrer Verwendung," HUK-Verband, Munich, (will be published in January 1992)
8. Th. Turbell, "ISOFIX," ISO working group ISO/TC22/SC12/WG1, Paper N 220, July 1991

S3-O-13

Side Protection and Child Restraints—Accident Data and Laboratory Test Including New Test Methods

Kamrén B, Kullgren A, Lie A, Sköld B-Å, Tingvall C.
Folksam Research and
Chalmers University of Technology

Abstract

The use of child restraints, especially rearward facing, has proved to be very effective. This effectiveness is mainly addressed to frontal impacts and ejection. The protection in side impacts is however limited. Among restrained children 1/3 of the serious injuries occur in side impacts. The implication for better side protection is therefore clear. In this presentation, accident data is used to give the background for the main priorities in increasing child restraint protection. The injury mechanism is discussed in relation to fullscale laboratory tests and real life case studies. A test method is proposed, and results from using the method on child restraint in ECE mass group 1 is showed. It is concluded that the side protection can be increased by fairly simple methods.

Background

In frontal impacts, the protection afforded by rearward facing child restraints has been proved to be very high, in the region of 90% (1). In the regulations used to test child restraint systems (CRS), both frontal and rear end collisions are subject to dynamic tests and specified limits of dummy responses.

Side collisions offer an other situation than frontal and rear end collisions where instead of a movement of the CRS and the child relative to the vehicle and a limited interior contact, the injuries occur as a result of a direct contact with the car and the CRS. The injuries are therefore due to a different mechanism compared to other impact types.

Side protection for adults has been a matter of great interest during the last decade with several studies conducted and proposals for legislation (2). For this reason, it is important to study the situation also for children, in order to benefit from the work conducted for the adult population, but also to point out in what way the situation for children in CRS differs.

In this study, rearward facing CRS were studied in relation to lateral impacts. In this group of restraints, children are sitting in a restraint system that are only to a lesser degree dependent on the vehicle where they are used. Instead, the rear facing CRS has got its own seat belt system and energy absorbing areas. Older children, aged 3 and upwards, are sitting mainly in forward facing systems using the seat belts of the vehicle with a crash behaviour more close to adult occupants.

The objectives of this study were to:

- from accident materials assess the amount and severity of injuries occurring in lateral impacts,
- from in depth studies study possible injury mechanisms,
- from full scale crash tests create a model and a method for a more simple test method of CRS.

Accident Study

Material and Methods

All accidents with injured children during 1984 and 1990 and reported to the Statistics Sweden by the police were studied. Also, some accidents where children were occupants in cars were studied more in-depth.

The accident data was collected by using the police record and a questionnaire was sent out to the driver of the car. In case of more severe injuries, hospital records and doctor's certificates were collected for medical coding. All injuries were coded according to AIS.

Concerning the in-depth studies, the data was collected from different accident files available as well as an analysis of the car and the CRS of interest.

Results

In table 1, the number of injuries in different impact directions are given. It can be seen, that while among all injuries, 11% occurred in side collisions (struck side) and among moderate and severe injuries, one third were due to side impacts. The head was the most dominating part of the body injured in lateral impacts. Among moderate to severe injuries to the head, 11 out of 15 injuries were due to side impacts.

Table 1. Accident Type and Number of Injured Restrained Children

	ISS 1-3	ISS4-	All
Frontal	79	11	90
Struck side	11	10	21
Opp side	8	0	8
rear	43	2	45
misc	16	7	23
total	163	30	193*

*) incl 6 unknown accident type

A separate study of all fatalities among children sitting in rearward facing CRS that occurred in Sweden 1970-90 showed that only seven children were killed.

In table 2, the accident types are given for the seven fatalities that occurred during the period.

Table 2. Accident Types and Main Cause of Death in Accidents with Rearward Facing CRS During 1970-90 in Sweden

	No of cases
Frontal collision Catasprophic, ran over by truck, head injuries	1
Rear end collision (Burned to death)	1
Roll-over (drowned)	1
Side impacts, near side (neck and skull/brain injuries)	4

Two cases with severe injuries were studied in detail. One case resulted in fatality, while the other child survived with severe injuries.

Case 1

A SAAB 99, 2-door, lost control and skidded against an Opel Kadett D with the right side contacting towards the full front of the Opel. The right side door of the SAAB was deformed and the maximum deformation was approx. 600 mm. The barrier equivalent speed of the Opel was approx 40 kmh.

At the right side of the SAAB a 1.5 year old boy was sitting in a rearward facing child restraint of group 1 type leaning against the dashboard. The seat was not correctly mounted but this did not influence the outcome.

The child received a complete cord transection in the neck and some moderate injuries to the abdomen. Injuries due to contact with the left side of the face resulted in a facial fracture and teeth injuries. The child died at the spot of the accident.

The child restraint showed clears signs of contact with the intruding door and energy had been dissipated to a high degree between the child and the inside of the CRS at the struck side. This was seen in the energy absorbing material in the CRS. There were no signs of contact between the child's head and the CRS. Instead, the face of the child had contacted the intruding door when ejected out of the CRS.

Case 2

A SAAB 900, 5-door, lost control and skidded while braking into the oncoming traffic. The car was hit by a truck running in 70 kmh before impact. The truck ran over the right rear part of the SAAB and caused lateral deformation in the right rear seat of more than 600 mm.

In the right rear position a mother and her 6 month old child were sitting unbelted. They were both killed immediately. A 1.5 year old girl was sitting in the mid rear position in a rearward facing CRS of group 1 type with a supporting strut contacting the floor of the car. The CRS was not mounted correctly but this did not influence the outcome. The child was found outside the CRS after impact, but it was not known if this was due to the impact or if the child was unbelted before impact. This did not influence the outcome.

The child received a severe bleeding in the brain (AIS 4) but survived. The child had a facial injury due to contact at the left side of her face.

The CRS only had minor damages, but there were clear signs of contact between the child and the CRS inside the seat. There were no signs of contact in the head region.

The roof of the car had been deformed to such amount that it had contacted the ejected head of the child. There was sign of contact that can explain such a mechanism.

Full Scale Side Impact, Car to Car

Method

A full scale side impact was conducted to study the kinematics and loads acting at car, CRS and child dummies. A Volvo 244 was struck by a SAAB 99 at 50 kmh in the R point at the right side. In the front right and mid rear seat group 1 rearward facing CRS were mounted with 3-year TNO dummies. The cars, the CRS and the dummies were instrumented. In the CRS there were three accelerometers, two in the bottom base and one in the top. The dummies were instrumented in the chest and in the head.

Results

In the front seat, the intruding door contact with the CRS gives a high lateral acceleration of max. 110 g. The CRS is slightly deformed at this sequence. The padding of the interior of the CRS gives a max. acceleration of 50G in the dummy chest. The head rotates (ejects) out of the CRS and hits the intruding door of the car.

Component System Test for Side Impact

A component test was developed for a side collision with simulated impact speed of 50 kmh. The basis for the set up was the ECE 44 trolley that was rotated 90 degrees. An impactor was mounted on the barrier in a location where it would contact the child restraints. The trolley was decelerated in a distance of 350-400 mm. The simulated door contacted the child restraint with 42-43 kmh and intruded into the simulated compartment 200-300 mm. The test set-up is shown in figure 4a.

Both a 3-year TNO dummy and an American 3-y Part 572 type C dummy were used in the tests. Child restraints of type FOLKSAM MINI (group 1 rearward facing) were used throughout the whole study. Both production and modified seats were tested. The modified seats with a side impact system is shown in figure 1.

The system consists of four major parts:

A. Energy absorbing area on the outer surface of the seat to diminish the initial impulse that could affect the buckle area.

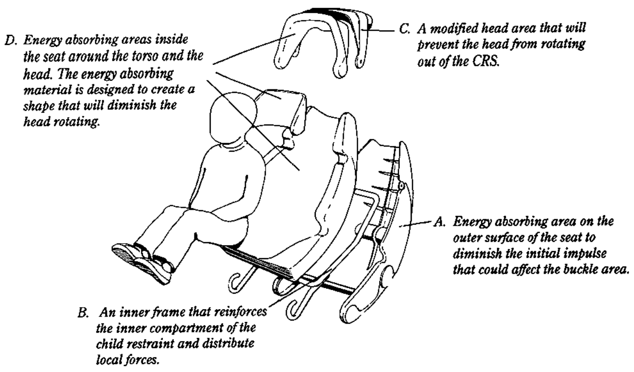


Figure 1. Schematic Drawing of Side Protection System for Child Restraints

B. An inner frame that reinforces the inner compartment of the child restraint and distribute local forces.
C. A modified head area that will prevent the head from rotating out of the CRS.
D. Energy absorbing areas inside the seat around the torso and the head. The energy absorbing material is designed to create a shape that will diminish the head rotating.

Analyzing the Dummy Movements

To be able to evaluate the dummy movements in the tests a special photogrammetrical technique was developed and used. The aim was to measure the movements in three dimensions with high accuracy. This goal could not be fulfilled using traditional highspeed filming.

Three Dimensional Photogrammetry with Flashing LEDs

To be able to locate the position of different parts in the test setup strong wideangle light emitting diodes was fasten. These LEDs was flashing with a predefined frequency of 1000 and 125 Hz. As the LEDs on the dummy and the child restraint was moving during the test their locations were registered with photogrammetrical cameras. The cameras were triggered by a photocell right before the collision with the impactor and they were standing open for 250 milliseconds, the full time for the test. In the photographs clear spots of every 1000 Hz flash is visible when the object is moving rapidly. When more slow movements occurs, and the 1000 Hz are so close to one another that clear distinction between them are difficult, the 125 Hz flashes are more convenient for measurements. To get a precise starting point for the measurements a flash with a electronic flash unit was triggered in an early stage of the test. From this takeoff point all continuing points can be identified. To make the traces on the photographs more distinct a dark background was used.

Analyzing the Photos

For the analysis of the photogrammetric stereopartners a self-developed software package C.A R.S. was used. In this system, originally build for documentation of deformations of cars involved in road traffic accidents (7), a digitizing tablet is used as a measuring device. This results in a fast and easy data acquisition. The measurements are processed in photogrammetrical and bundle adjustment software and this results in three dimensional coordinates for the LEDs.

Results

In figures 2-4 the impacts for an original and a modified seat is shown. It can be seen that while the head ejects out of the original seat, it is well kept into the seat in the modified CRS thus giving the desired protection. Independent of the dummy type, the same result was achieved.

Figure 2. Front View Original Seat

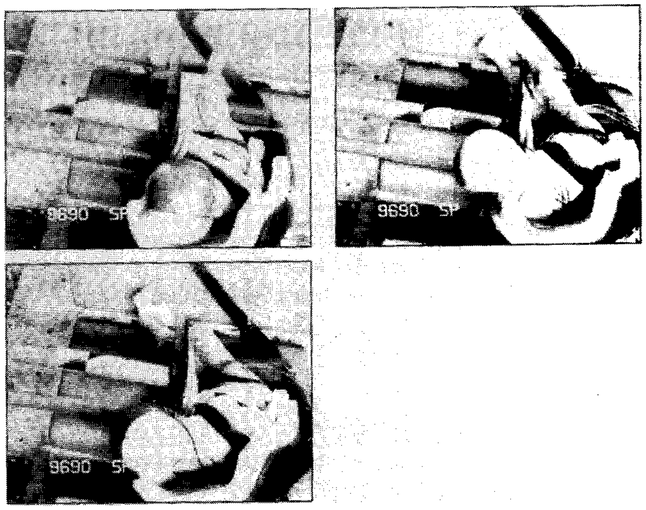


Figure 3. Top View Original Seat

In figure 5 the Y and Z displacement in time for the head are given. The time between every registration bar was 8 ms. The location immediately before impact is given as t_0. It can be seen that the head for the original CRS rotates with almost the impact speed until contact with the impacting surface. With the modified upper part, the head stayed within the seat and never rotated out and reached the vertical plane simulating the intruding door.

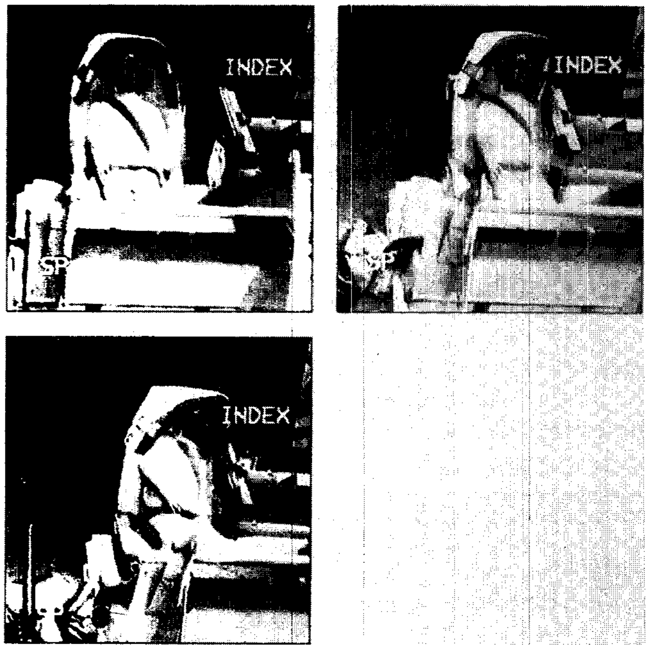


Figure 4. Front View Seat with Head Ejection Protection Device

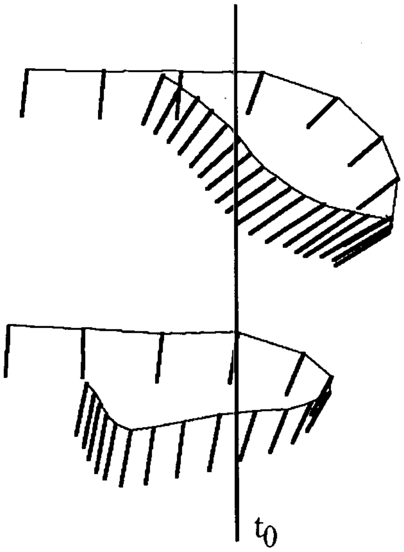


Figure 5. Movement of Two Point on Dummy Head with Original (Upper) and Seat with Head Ejection Protection Device (time between registrations, 8 ms; impact speed 43 kmh)

Discussion

The protection of car occupants should be based on the nature, number and severity of occurring injuries together with a knowledge of mechanisms and effectiveness of injury preventive measures. In this paper the protection of children in CRS in side impacts is studied.

In order to have a broad base for priorities in injury protection a large number of accidents was studied. It was found that the head was the leading body area in the number and severity of injuries; followed by the neck. This is contrary to what has been found for adults (2), though more recent studies has shown that the skull, brain and neck should be the main areas of interest in lateral impacts. In actions taken for legislation in the area, the main body areas has been the chest and the abdomen.

For children in CRS, the chest was not found to be injured frequently and with high severity, it was therefore not of major interest to prevent from such injuries but instead focus on head and neck injuries.

There could be many reasons for the lower risk of children receiving chest injuries, one of them being the lower weight of a child (1).

The full scale test could confirm a hypothesis of the ejecting head against the intruding door or bullit vehicle. Such a mechanism is not unknown among adults, but for children in CRS it seems to be the main mechanism (4).

A simplified test using the ECE 44 equipment is of importance as it makes it possible to include such testing fairly simply at least in the development work of CRS. If the design requirement only addresses to the head ejection, the inability for the simple dummies used to give a good possibility to make measurements of loading can be considered to be a minor problem. The use of two different dummies showed a similar behaviour. The impactor was designed as a flat wall. It has been showed that the design of the impacting structure will alter the outcome measurement of a dynamic test (6). In the present test set up where the main protection criteria was the head ejection, it seems to be a reasonable assumption that the design of the impactor will not dramatically influence the results.

The most important protection criteria was considered to be the head ejection during impact. If this ejection can be avoided, the risk of injury is diminished. What can limit the protective effect is if the head already before impact, or due to acceleration of the car, is positioned outside the head ejection protective device. This problem is though limited in a rearward facing device, where pre impact braking does not interfere with the function of the system, and where a possible early trajectory of the head mainly is directed towards the front of the vehicle into the protective system (3).

In this study a principle for protecting the child in side collisions was presented. By combining a reinforced side structure, energy absorbing materials and a head anti-ejection device, the performance in a component side impact test was dramatically increased. The design features such as the head area of the seat seems to be important. If the seat does not give to much lateral space before starting to decelerate the head, the protection seems to be even better. The characteristics of the energy absorption in the lateral head area must be chosen with the respect also to impacts to lorries/busses and pole/trees where there is a possible direct contact between the CRS and the object collided. Not only the door speed but, also the direct impact will be different from car to car impacts (5).

The seat belt system in the CRS seems to be of minor importance as long as the major protection system is based on the side structure of the CRS.

Also, the connection between the car and the CRS seems to be of importance. Normally, a rear facing CRS for children over 9 months (ECE 44 group 1) is anchored to the car not only by the car seat belt but also by straps connecting the base of the CRS with the car seat. Such a technique will increase the duration between the initial impact with the CRS and the lateral acceleration of the CRS and the child. This is considered to be an important drawback, and therefore a technique where such mounting of the CRS is used should be avoided in the future. The ISOFIX solution presented in the ISO work on CRS seems to be a positive way also to increase the protection in side impacts as the CRS is hold only in one region.

Conclusions

- For children in CRS in side impacts the head and neck are the main areas of concern.
- The dominating injury mechanism is a direct contact between the intruding structure and the head of the child.
- In a simplified test set-up a simulating a lateral impact, a modified CRS was compared to a standard CRS showing a possibility to increase the safety performance.

References

1. Tingvall C. Children in cars. Some aspects on the safety of children as car passengers in road traffic accidents. Acta Paediatrica Scand. Suppl 339 1987.
2. Håland Y, Lövsund P, Nygren Å. Estimation of fatalities and disabilities in car to car side impacts—an evaluation of different risk factors. In: Proc. 34th AAAM annual conf 1990:275-287.
3. Czernakowski W. The effects of pre-impact braking on dynamic test performance of child restraint systems/CRS) in frontal impacts. In: Proc 1991 IRCOBI Conf. 1991:145-156.
4. Shimoda N, Nishida Y, Akiyama A. Effects of belt restraint systems on occupant protection performance in side impact crashes. In: Proc 12th ESV conference 1989:89-5A-O-018.
5. Griswold C J . Side impact component test development. In: Proc 9th ESV Conference 1982: 503-510
6. Tsujimura H, Isobe H, Maeda K Dummy injury values obtained in side collision sled tests. In: Proc 9th ESV Conference 1982:494-503.
7. Lie A, Tingvall C, Johansson S, Johansson S-O. Photogrammetric measurements of damaged vehicles in road traffic accidents. In: 9th ESV Conference 1989.

S3-O-17

A Technical Evaluation of Motorcycle Leg Protectors

Nicholas M. Rogers
International Motorcycle Manufacturers
Association

Abstract

This paper summarizes the technical background, information and conclusions regarding proposed leg protection devices for motorcycles. Leg protector concepts researched over the last 20 years are reviewed, the general conclusion being that they tend to produce negative effects (ie, transfer of injuries to the upper body and upper legs). In 1987 the United Kingdom proposed a national Draft Specification (UKDS) for motorcycle leg protectors, currently a prospective topic of discussion in the EEC. Although the UKDS concept is similar to earlier concepts, the motorcycle industry undertook an extensive evaluation of it, culminating in full scale tests in 1989. This paper discusses the results of the full scale crash tests and computer simulations of the UKDS, as well as observations concerning the methodologies used to evaluate it. One overall conclusion reached is that, for motorcycles, any leg protector involving a robust knee restraint—with or without external energy absorption, knee pads, or leg retention—inherently results in negative effects, and therefore is not feasible.

Background

Early History

Since 1969, a number of industry and other organizations worldwide have studied motorcycle leg protection devices with the aim of minimizing leg injuries to motorcyclists during collisions.

Examples of leg protector (LP) devices examined up to 1987 are listed in Table 1. This work (Refs 1 to 11) has been carried out mainly by organizations in the United Kingdom, Japan, and the United States.

In the early phases of this research, it was found that maintaining leg protection "space" between a motorcycle and an impacting car was possible by using certain robust kinds of structures. However, it was also found that such devices can make overall rider injuries, including head injuries, worse. This was because of increased torso pitch and a lowering of the head (due to forces acting through the knee and femur); increased tendencies toward rider ejection (because of maintaining excessive "leg space"); and increased leg injuries (because of leg impact or interaction with the device

Table 1. Example Leg Protector Types Examined Through 1987

Time Period	Proposed Device	Reference
1971	Accessory bars	1
1973	Revised heavy duty crash bars	2
1975	Side protection devices	3
1973-76	Experimental Safety Motorcycle (ESM) structures	4, 5
1975	Crash bar with energy absorbing bucket seat	4
1975-81	Reinforced leg shield fairing device	6
1984	Hard leg protector	7, 8
1984-87	Soft leg protector	7, 8, 10 11
1985	Crushable leg protector	9

itself). Later research—involving the addition of energy absorption regions—has not solved these problems, and so far a viable solution has not been found.

Accessory Bars

Conventional crash bars. Initial leg protection research in the late 1960s and early 1970s, evaluated commercially available accessory bars (eg, Fig 1) to determine if these devices might prevent leg trapping between the motorcycle and opposing vehicles.

These structures were generally made of loop shaped steel tubes with a 25 mm (1") outer diameter and 1.6 to 2.3 mm (1/16 to 3/32") wall thickness. Such structures were tested by, for example, Bothwell, et al (1), under contract to the US National Highway Traffic Safety Administration (NHTSA). The results indicated that these structures were too weak to protect legs during collisions and capsize situations. It was also noted that leg impacts with the bars were a source of injuries. From this study it was recommended that the strength of such structures should be increased such that they could withstand a 48 km/h (30 mi/h) broadside collision.

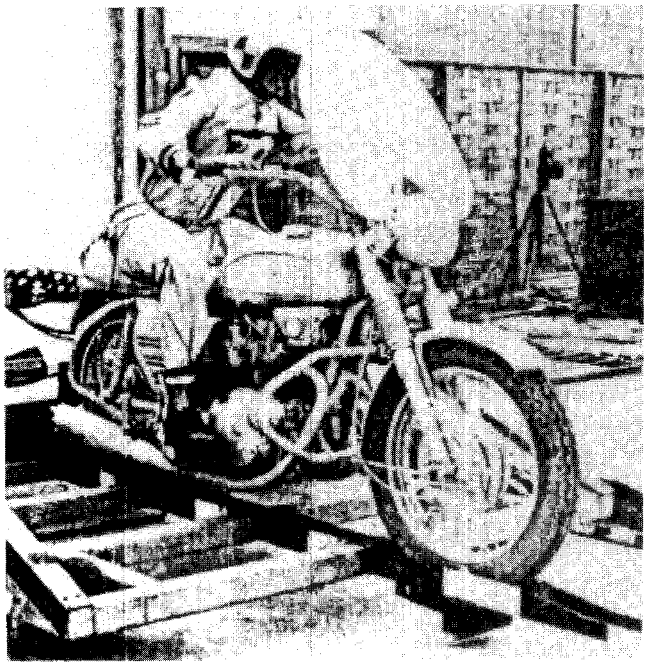


Figure 1. Test Motorcycle with Accessory Bars

Accessory bars were also examined via accident investigations, which indicated that these structures did not produce differences in leg injury occurrence.

Reinforced Bar Type Leg Protectors

Revised heavy duty crash bars. Based on the results of the previous study, structurally reinforced experimental leg protectors (Fig 2) were fabricated and tested by Bothwell, et al (2). The bars were made of loop shaped steel tube with a 50 mm (2 in) outer diameter and 2.3 mm (3/32 in) wall thickness.

The revised heavy duty crash bars were able to endure 48 km/h (30 mi/h) angled collisions. As a result, leg space was maintained and the leg was not trapped between the motorcycle and opposing vehicle. However, the knee and lower leg hit the LP's steel tube structure resulting in impacts which could potentially fracture the leg.

Side protection devices. These devices, shown in Fig 3a to d, were designed to preserve leg space during broadside collisions, eliminating leg trap between the motorcycle and opposing vehicle. Construction consisted of large diameter steel tubes with reinforcement braces.

A study by Uto (3) of the Japan Automobile Manufacturers Association (JAMA) using simulated breakable leg bones in the lower and upper leg showed that:

- Side protection devices reduced lower leg fractures by preserving leg space.
- In some cases, side protection changed the nature of upper leg fractures by changing fracture modes from simple bending fractures to twisting fractures.

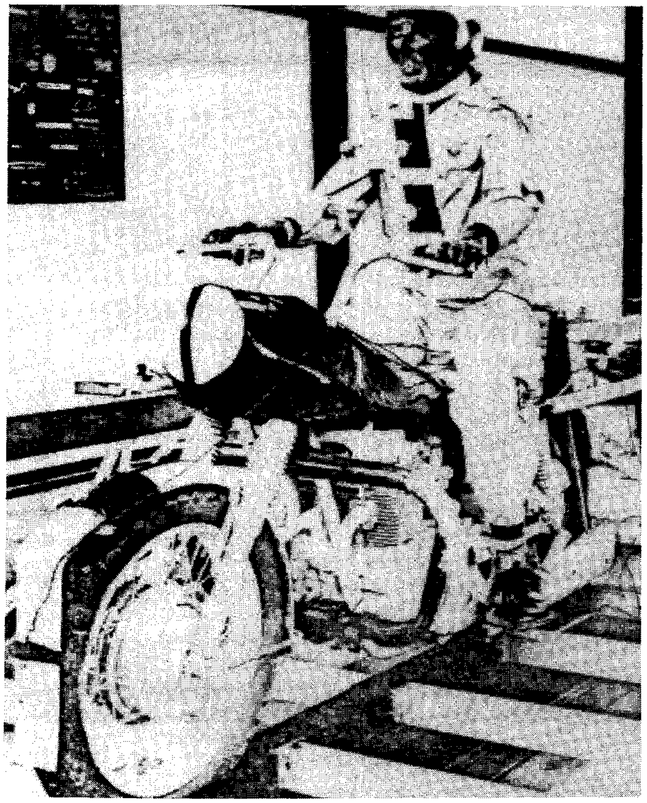
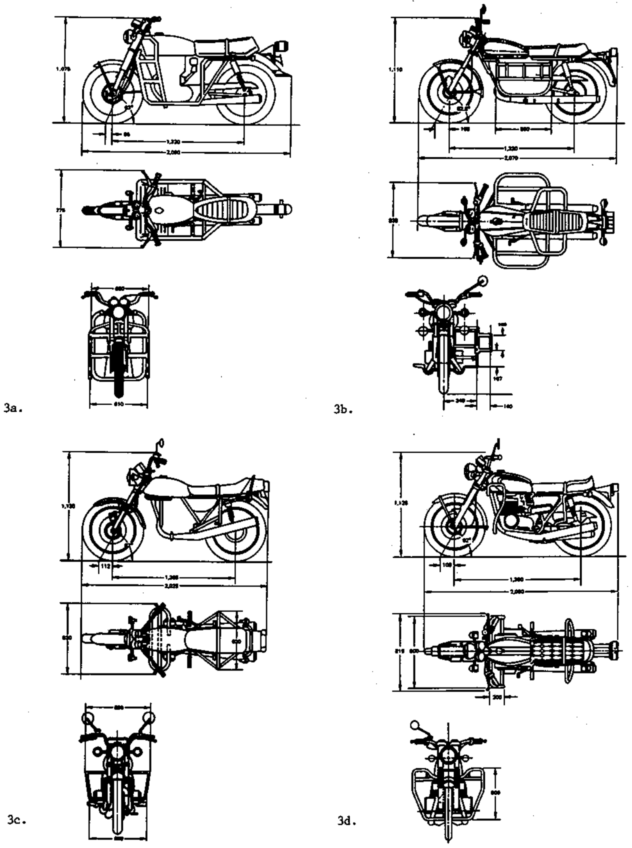


Figure 2. Test Motorcycle with Revised Heavy Duty Crash Bars



3a.

3b.

3c.

3d.

Figure 3. Drawings of Motorcycles with Side Protection Devices

- When looking at the dummy motion, the dummy on the motorcycle with side protection had a greater tendency to be ejected more violently towards the opposing vehicle in a head first manner, increasing the potential for serious head injury.

Experimental safety motorcycle (ESM) structure. This structure, shown in Fig 4, was similar in concept to the revised heavy duty crash bars and side protection designs. Findings by Livers (4) and Bartol, et al (5) indicated that:

- Leg loads in the tibia and femur were lower with the ESM structure.
- Chest and head accelerations were generally higher with the ESM structure, indicating an overall increase in potentially fatal injuries.

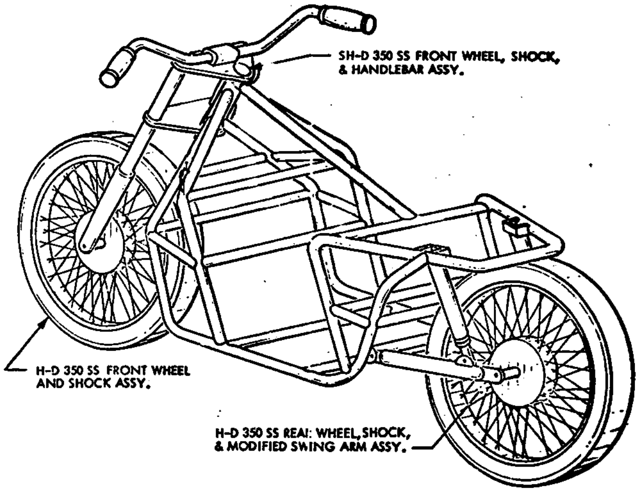


Figure 4. Drawing of Motorcycle with ESM Structure

Modified Reinforced Leg Protectors

Reinforced leg shield fairing device. This device, investigated by Bothwell (6) and shown in Fig 5, seemed to reduce force concentration due to leg impact with tubular structures, as it was equipped with relatively thick knee pads on the rear surfaces of the device.

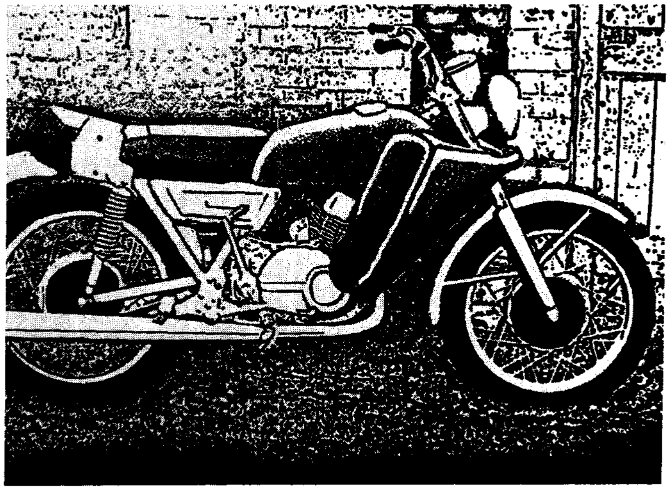


Figure 5. Motorcycle with Reinforced Leg Shield Fairing Device

When this device was tested in an angled collision the knee of the dummy hit the knee pad inducing a violent somersaulting motion. The neck of the dummy was markedly flexed and the head was pushed into the side of the car.

A lower head trajectory resulting from knee contact with the leg shield structure on the motorcycle was also observed. This lowering of the head was considered undesirable as it increased the chance of head impact with more rigid structures of the opposing vehicle.

Hard leg protector. This device, proposed by Chinn, et al (7) of the Transport and Road Research Laboratory (TRRL), shown in Fig 6, seems to be the same concept as the reinforced leg shield fairing device. Although few details were presented, it seems to have been one type of reinforced leg protector. The results showed that this device decreased motorcycle yaw motion during angled collisions with fixed barriers and maintained leg space in a manner similar to the heavy duty bars. However, considerable forward pitching of the dummy torso and a lowering of the dummy head was observed with this device, as in the case of the reinforced leg shield fairing device.

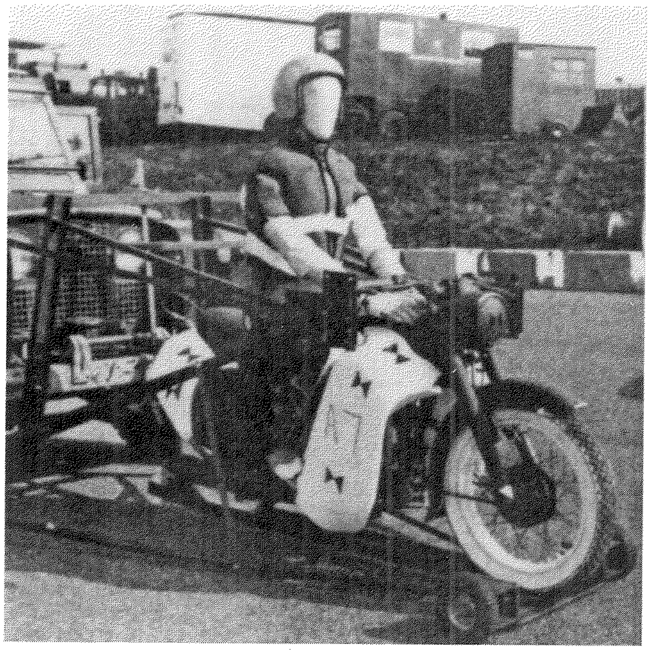


Figure 6. Test Motorcycle with Hard Leg Protector

Energy Absorbing Leg Protectors

Crash bar with energy absorbing bucket seat. This design, shown in Fig 7, was proposed by Bartol, et al (5) to reduce head acceleration by reducing the deceleration of the dummy. The device consisted of a reinforced type bar structure and an energy absorbing seat. Test results indicated that this device did not reduce rider injuries.

Soft leg protector. Chinn, et al (7) reported that this type of energy absorption element, shown in Fig 8, reduced the component of dummy head velocity along the initial direction of travel of the motorcycle.

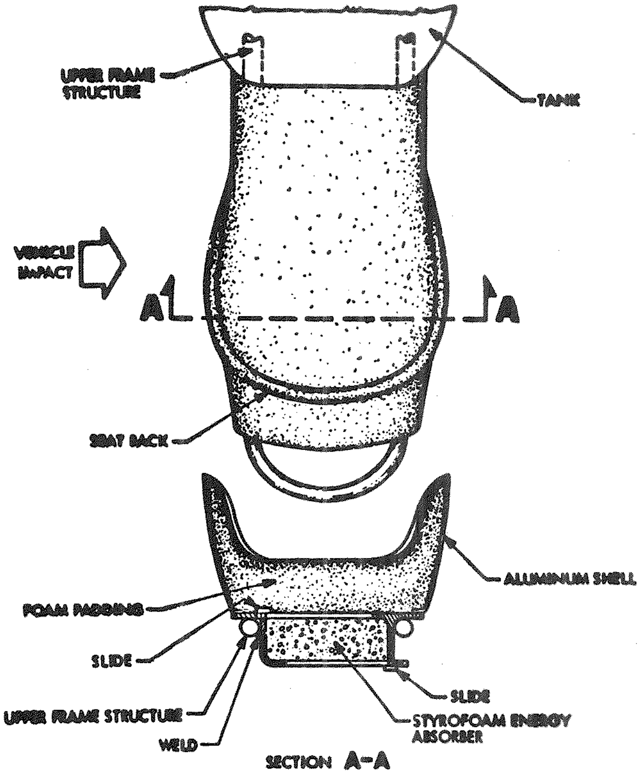


Figure 7. Top View and Cross Section Drawings of Energy Absorbing Bucket Seat

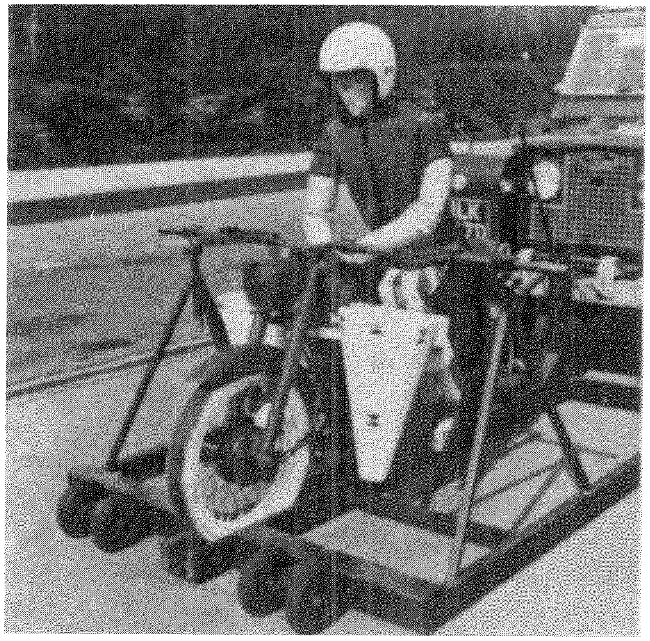


Figure 8. Test Motorcycle with Soft Leg Protector

Crushable leg protector (CLP). The CLP, shown in Fig 9, was proposed by Tadokoro, et al (9) and was intended to prevent violent ejection towards the opposing vehicle while maintaining leg space. The CLP involved 2 concepts. One was to reduce dummy ejection caused by motorcycle impact acceleration. To achieve this, energy absorbing materials were installed. The second concept was to reduce the available leg space as much as possible since excessive leg space was considered a cause of ejection. To control leg space the width of the reinforced structure of the CLP was reduced to match the width of the dummy legs while the dummy was straddling the motorcycle.

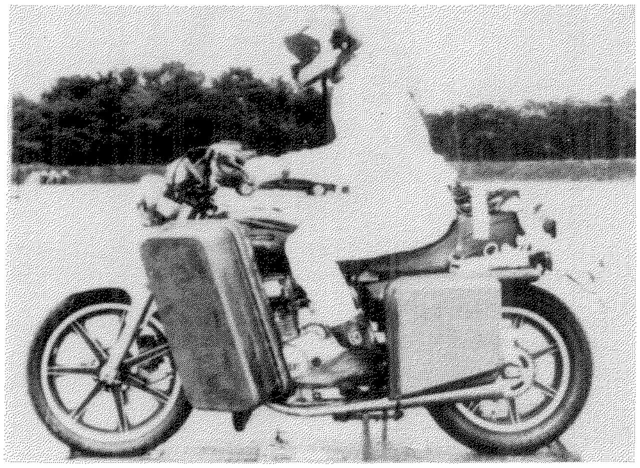


Figure 9. Test Motorcycle with Crushable Leg Protector

The motorcycle acceleration was decreased by about 10 percent by the CLP. Leg fractures were also reduced by maintaining the necessary minimum leg space. However, the problem of dummy ejection and increased head velocity was not solved by the CLP.

TRRL Research on Leg Retention LPs

The one exception in the research cited above has been the leg protector research carried out by the Transport and Road Research Laboratory (TRRL) in the UK since 1982. The work initially investigated the hard and soft leg protectors noted above as the subject of a doctoral dissertation (Ref 16) prepared by the technical leader of TRRL's leg protector research.

The subsequent TRRL leg protector concept closely resembles a 1980 UK patent by Bothwell (Ref 14), involving: external and internal (knee) energy absorbing regions, a structure supporting these two regions, and a fairing enclosure. Although TRRL has continued to work on this concept, it is no longer considered technically valid by its inventor.

In recent years, the concepts of leg lateral retention and leg protector breakaway to prevent leg trap were added to the TRRL research.

The TRRL research, differs from other research in that, at every stage of its development, the evolving concept has shown promise (eg, 8, 10, 11), and none of the negative effects reported by other researchers have been encountered. The industry considers that the most likely explanation for this is the test methodology used by TRRL, which is summarized later.

In 1986, in view of the major divergence in results between TRRL and other researchers, the motorcycle industry proposed to ECE/WP29/GRSG that improvement of test methodologies was the next logical step for finding clearer answers to rider leg protection.

UK Draft Specification (UKDS)

In July, 1987, despite the continuing differences in research results, the United Kingdom Department of Transport unexpectedly published a national Draft Specification for motorcycle leg protectors for comment. The UKDS was based on the TRRL work and applied to motorcycles and mopeds. The UKDS involves:

- A primary impact element
- A rigid support element
- A knee protector element
- Leg lateral retention
- Detachment of the rigid support at high impact energies (optional in the original draft; mandatory in the revised drafts)
- Smooth outer contour (during and after impact)

These elements have specific geometric and mechanical requirements to be verified by laboratory testing.

Industry Response to UKDS

The motorcycle industry responded to the publication of the UKDS in various ways, including:

- two commissioned reports from independent experts (Refs 12, 13), which discussed in detail the ways in which TRRL's research was extremely limited and based on faulty, distorted methodology (ie, a non-breakable "honeycomb" dummy leg which could not accurately predict leg fractures)
- Preliminary full scale tests of a UKDS prototype device (Ref 14), which indicated that the device resulted in lower leg fracture and increased upper leg damage in all 3 impact configurations tested; as well as other negative effects, including increased rider ejection, torso pitch and head impact with the car and road
- A meeting with the UK Parliamentary Under Secretary of State for Roads and Traffic in April 1988, at which it was agreed that: the UK Department of Transport would not proceed further without consulting the industry; industry would perform a major accelerated refinement of its evaluation methodology (including accident analysis (Ref 15), an improved dummy and dummy leg (Refs 16, 17), injury criteria (Ref 18), self contained instrumentation (Ref 19), and refined test procedures) with a view to a fuller evaluation of the UKDS tests during 1989; and TRRL and industry experts would hold technical meetings to discuss their differing results
- A presentation and discussion at ECE/WP29/GRSG in May 1988, at which the delegates agreed to postpone discussion of a Draft Recommendation (based on the UKDS), until industry had completed further research
- A large, in-depth series of crash tests of UKDS leg protectors in 1989 by the industry (Ref 20). These

tests were the most comprehensive to date in terms of: the types of motorcycles and cars used; the leg protector designs and UKDS categories; the type of impact configurations considered; and the use of state-of the-art test methodologies, including a new motorcycle impact dummy and performance indices. Test results showed that UKDS type of leg protection devices could increase both leg and head injuries, as well as the overall injury severity (further described below)

- A series of detailed technical meetings and discussions between TRRL, UK Department of Transport and the industry. The 9 main points of technical agreement between TRRL and the industry are summarized in Ref 21.

Results of 1989 Industry Tests

Test Description

The 1989 motorcycle industry tests of UKDS type leg protectors (Ref 23) involved:

- 16 motorcycle/car impact tests (8 pairs, where the conditions were some of the more frequently occurring in the accident databases)
- Small, medium and large motorcycles (Piaggio COSA CL 125 scooter, Yamaha XS 400, BMW K 75 S)
- 3 independent design teams (who designed and verified the leg protectors to meet the UKDS)
- Improved test methodology, including: breakable, instrumented dummy legs having 8 human injury modes; self contained dummy instrumentation system; and an injury cost model, so that the resulting head and leg measurements could be compared on a common bio-economic basis

Regarding the improved methodology, Fig 10 shows some of the technical features of the Motorcycle Anthropomorphic Test Device, Version 1 (MATD-l). Figure 11 is a photograph showing the instrumented breakable composite material tibia and femur, and the 3 degree of freedom knee, which simulates knee ligament failure in the lateral bending and torsional modes. Figure 12 from Ref 22 compares the dynamic fracture force of 2 composite tibias to 9 human cadaver tibias. This example data confirms that the 2 composite tibias:

- Have fracture responses similar to those of human specimens in the upper percentile range
- Have nearly identical responses, indicating good reproducibility

Specifications of the test motorcycles and UKDS leg protector prototypes are summarized in Tables 2 and 3. A summary of the test conditions is given in Tables 4 and 5.

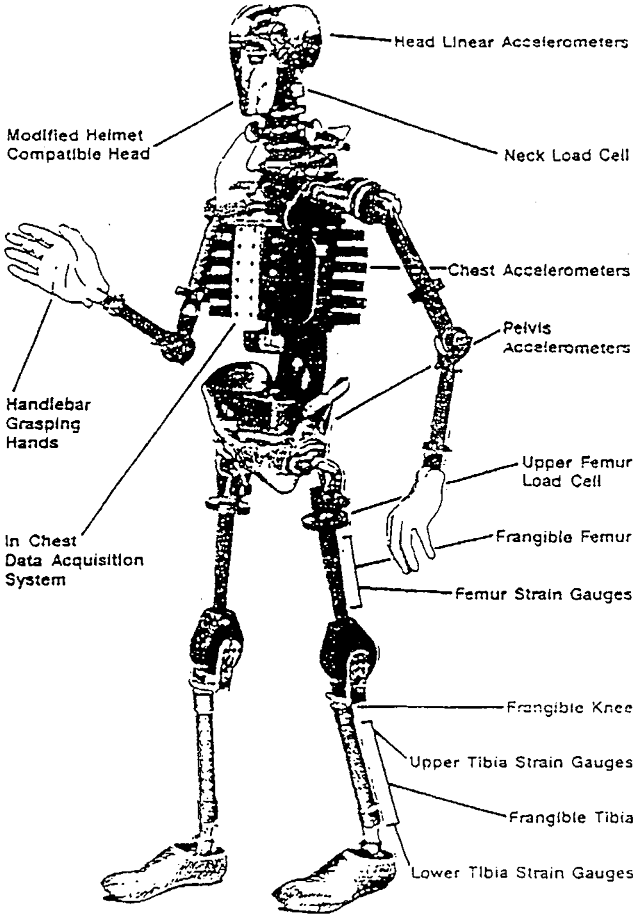


Figure 10. Motorcycle Dummy and Sensors

Table 2. Specifications of Test Motorcycles

Specification	Motorcycle		
Size:	Small	Medium	Large
UKDS Category:	2	3a	3b
Manufacturer:	Piaggio	Yamaha	BMW
Model:	COSA CL 125	XS400 SP	K 75 S
Overall Length:	1,810 mm	2,070 mm	2,230 mm
Overall Width:	565 mm	870 mm	675 mm
Overall Height:	1,080 mm	1,140 mm	1,230 mm
Weight: Standard	110 kg	170 kg	237 kg
with LP	123 kg	194 kg	255 kg

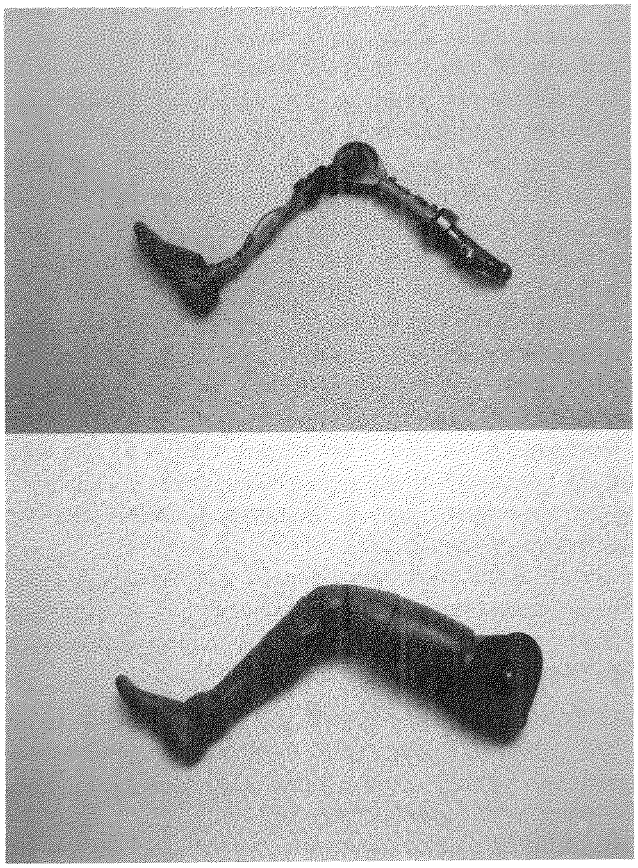


Figure 11. Photo of Instrumented Breakable Dummy Leg

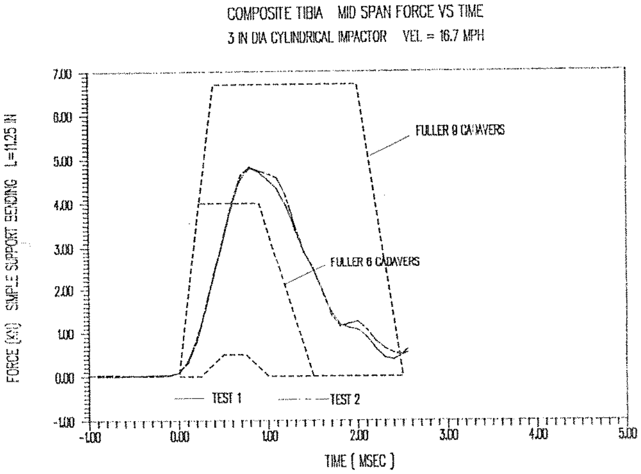


Figure 12. Composite Tibia Mid-Span Force vs Time 76 mm Dia Cylindrical Impact Vel 7.47 m/s

Table 3. Leg Protector Descriptions

Element		Motorcycle		
		Piaggio	Yamaha	BMW
PIE	External	Sheet Metal	FRP	Sheet Metal, FRP
	Internal	Partially filled with polyurethane	Polyurethane/ Aluminum Honey-comb on sheet metal	Polyurethane
RSE		Sheet metal, internally reinforced with 4 metal sheets	Steel tubes	Steel tubes
RSE		Polyurethane foam d = 0.100*	Polyurethane foam d = 0.078	Polyurethane foam d = 0.112

*d: density, gm/cm^3

Table 4. Summary of Test Configurations

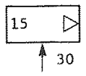
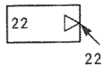
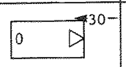
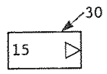
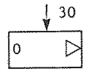
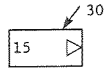
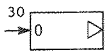
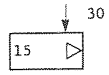
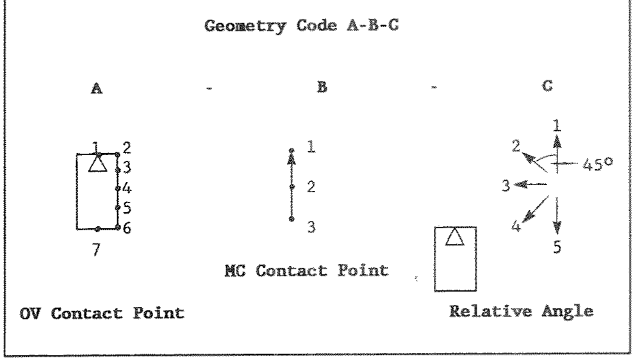
Name	Configuration (Speed in mi/h)	Geometry (see Tbl 5)	OV	MC	Facility
A1	 15 30	4-1-3	Sedan	Medium	JARI
A2	 22 22	1-1-4	Sedan	Medium	JARI
A3	 30 0	2-2-5	Sedan	Medium	JARI
A4	 30 15	3.5-1-4	Coupe	Medium	FAA
A5	 30 0	4-1-3	Coupe	Medium	FAA
B1	 30 15	3.5-1-4	Coupe	Large	FAA
B2	 30 0	7-1-1	Coupe	Large	FAA
P1	 30 15	3.3-1-3	Coupe	Small	FAA

Table 5. Geometry Code Used for Test Configurations



Test Results

The results of the tests are described in more detail in Ref 20 and showed that with leg protectors:

- In 4 out of 8 cases, there was an increase in the number of leg fractures per crash (in 2 cases, there was a reduction in the number of leg fractures)
- In 5 out of 8 cases, leg injury resulted from leg contact with the leg protector, and 4 of these were "combined load" fractures
- In 8 out of 8 cases the dummy head followed a lower trajectory, increasing the likelihood of head-to-car impact
- In 7 out of 8 cases the head-to-car impact velocity was increased
- In 7 out of 8 cases the maximum peak resultant head acceleration was increased
- In 6 out of 8 cases, the total Abbreviated Injury Scale (AIS) per crash increased
- In 4 out of 8 cases, the maximum AIS increased
- In 5 out of 8 cases, the injury cost per crash increased

In all crash configurations, the lower head trajectory was ascribed to the restraining action of the leg protector as the upper body moved forward, diagonally to the side, or laterally during impact. Figure 13 compares the dummy head trajectory for the standard and LP motorcycle tests for the 8 different impact configurations. The amount by which the head trajectory is lowered varies from about 30 mm to as much as 270 mm.

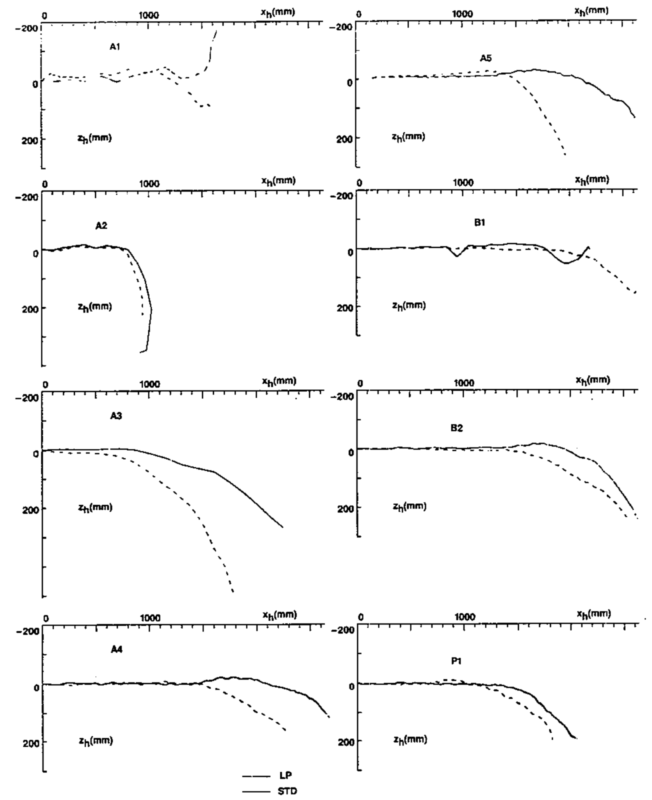


Figure 13. Summary of Head Trajectory Data

This torso pitch behavior is a fundamental result of this concept of leg protection, which restrains the knee and applies large loads to the lower part of the torso below the dummy's center of gravity.

In addition, in some of the tests, the leg protectors themselves fractured the legs, due to combined loading of the femurs. Figures 14 to 17 show time histories of femur loads in 4 of the tests with leg protectors. During knee contact with the energy absorbing knee protector, the compression loads (Fz) are seen to remain well below the compression fracture level (of about 770 kgf). However, during the contact sequence, lateral and fore-aft bending moments rise sharply, as the upper leg moves relative to the knee protector, resulting in combined load fracture of the femur.

Analysis shows that both the penetration by the knee and the concavity of the knee protector itself contribute to the subsequent rise in bending moments and the occurrence of leg fracture.

For all of the above reasons it was concluded that the UKDS "robust knee restraint" concept of leg protection is injury producing and does not contribute to improved rider protection.

Extension to All Motorcycle/Car Impacts

The 1989 full scale tests examined 8 impact configurations which were among the more frequently occurring in the accident data.

In order to extend the evaluation of UKDS-type leg protectors to cover the wide range of other impact configurations known to occur, extensive in-depth computer simulations were conducted (Ref 23). The analyses involved:

- A 3 dimensional multibody computer simulation of motorcycle, helmeted rider, leg protectors and passenger car, based on an enhanced version of the US Air Force "Articulated Total Body" simulation
- Validation against detailed test data from the 16 full scale crash tests, using a single consistent set of input parameters
- Extension to 163 impact configurations, representing 508 motorcycle/car accidents from the Los Angeles and Hannover databases
- Use of the same biomechanics and bioeconomics based injury cost model used in the full scale tests
- Modelling of the same motorcycles, leg protectors, cars and MATD-1 dummy as were used in the full scale tests, based on laboratory and full scale measurements

Figure 18 shows 3 views of the simulation model of the large sport motorcycle with UKDS leg protectors and dummy. Figure 19 and Table 6 show the correlation between simulation and full scale test data, in terms of peak resultant head acceleration and occurrence of leg fractures, respectively. In general, a correlation level of 80 to 90 percent was achieved, using a single consistent set of input parameters.

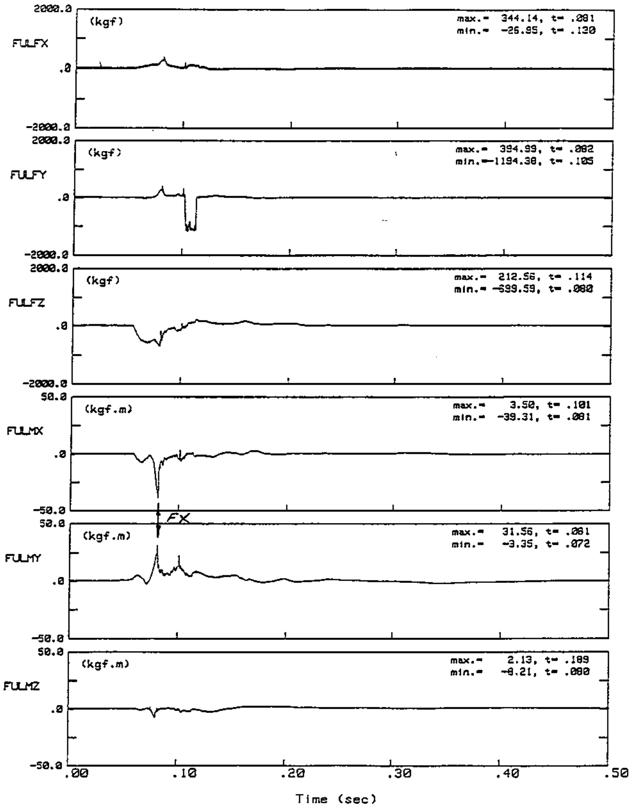


Figure 14. Left Upper Leg Force Time Histories, Configuration A2 LP

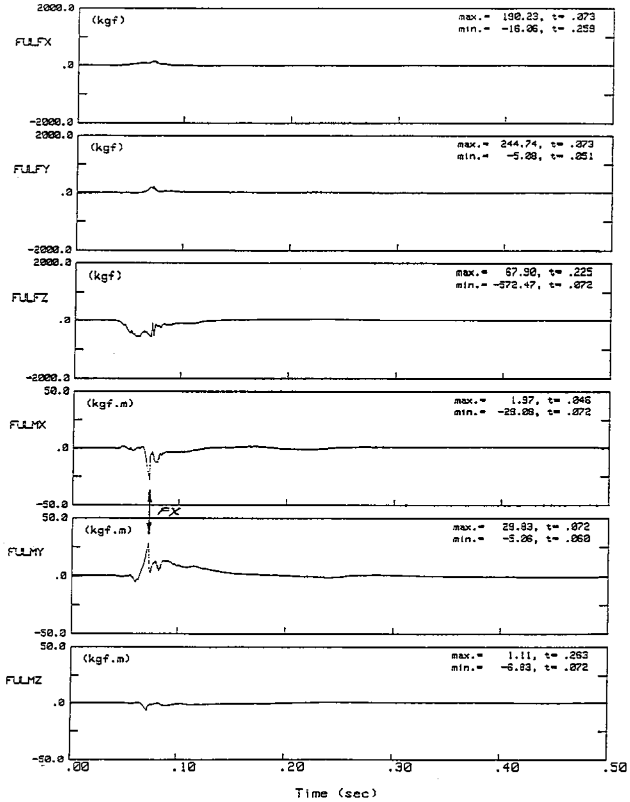


Figure 15. Left Upper Leg Force Time Histories, Configuration A3 LP

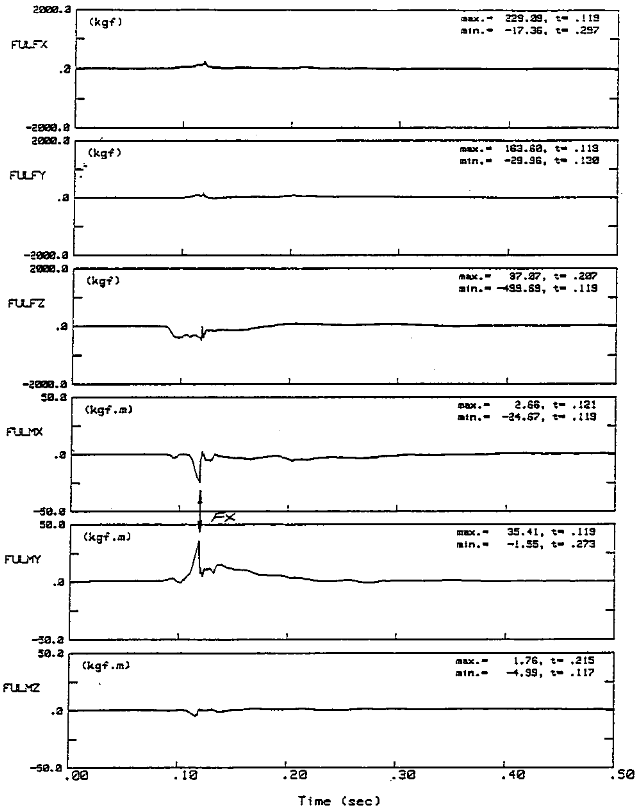


Figure 16. Left Upper Leg Force Time Histories, Configuration A4 LP

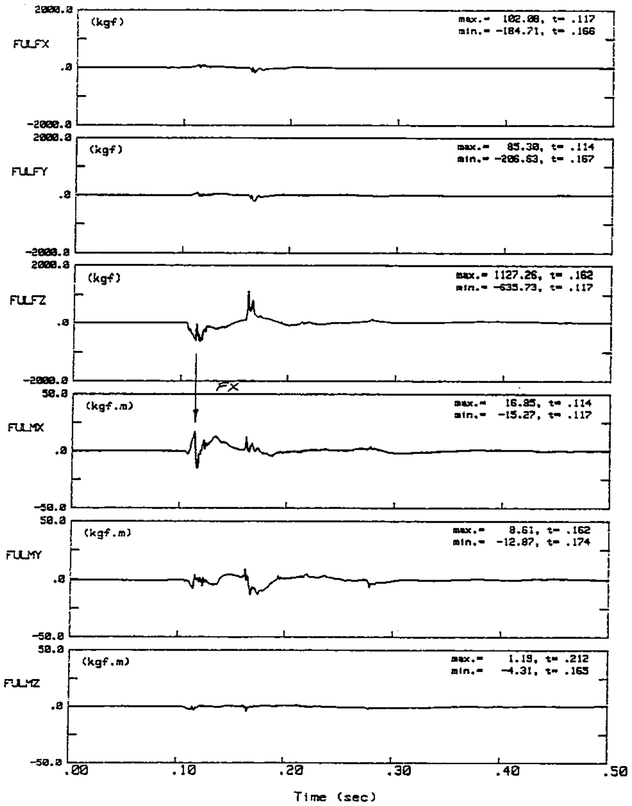


Figure 17. Left Upper Leg Force Time Histories, Configuration P1 LP

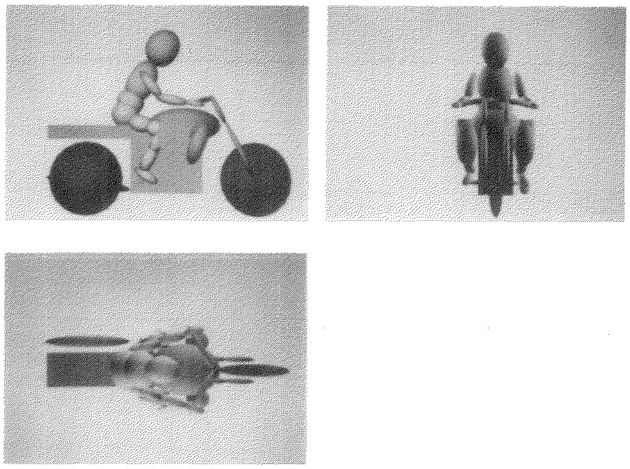


Figure 18. Three Views of Large Sport Motorcycle Simulation Model Including UKDS Leg Protectors

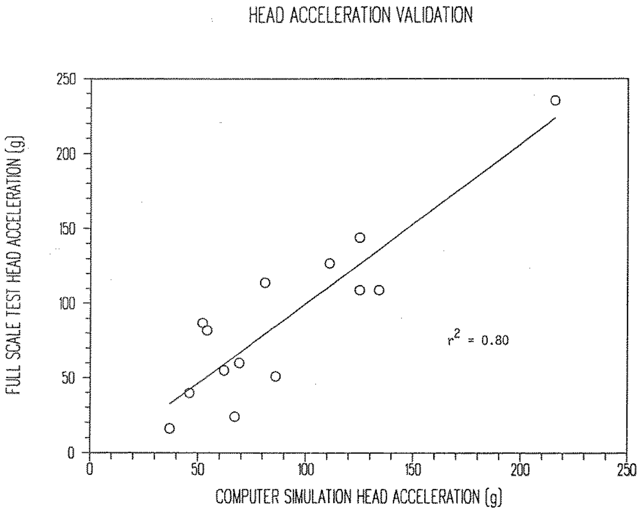


Figure 19. Comparison of Full Scale and Computer Simulation Peak Head Accelerations Leg Fractures

The results of the computer simulation are statistical distributions of the changes in injury severity, due to the addition of leg protectors, across the 163 impact configurations. Examples of results for the large sport motorcycle are shown in Figs 20 to 24, for the head, upper and lower legs, knee and overall injury cost.

The conclusions from the simulation results are that leg protectors:

- Decreased injuries to the legs or head in some accidents
- Increased injuries to the legs or head in a larger number of accidents
- Resulted in a significant net increase in total injury costs across all accidents

Table 6. Comparison of Full Scale and Computer Simulation Leg Fractures

a) **Femur:**

		Computer Simulation	
		No Fx	Fx
Full Scale	No Fx	21	3
	Fx	2	6

= 84% agreement

b) **Knee:**

		Computer Simulation	
		No Fx	Fx
Full Scale	No Fx	28	2
	Fx	2	0

= 88% agreement

c) **Tibia:**

		Computer Simulation	
		No Fx	Fx
Full Scale	No Fx	27	0
	Fx	4	1

= 88% agreement

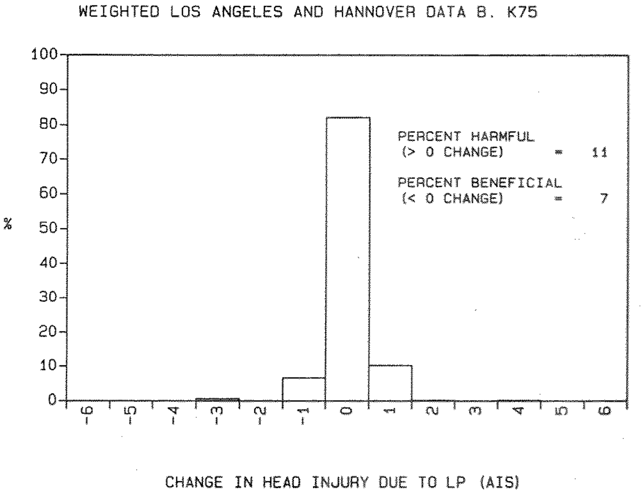


Figure 20. Distribution of Change in Head Injury Severity Due to Leg Protectors, Large Sport Motorcycles

The percentage of motorcycle/car accidents in which injuries increased was high, compared to, for example, passenger car belt restraints, eg:

- Head injury severity was increased in 19% of accidents (reduced in 9% of accidents)
- Upper leg injury severity was increased in 16% of accidents (reduced in 6% of accidents)
- Lower leg injury severity was increased in 8% of accidents (reduced in 4% of accidents)
- Total injury costs were increased in 34% of accidents (reduced in 17% of accidents)

The increased injuries were mainly related to:

- Angular momentum imparted to the rider by the leg protectors
- Combined load fracture of the upper leg

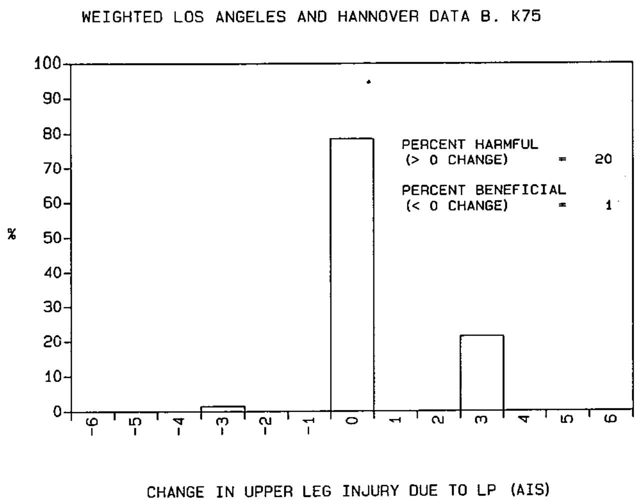


Figure 21. Distribution of Change in Upper Leg Injury Severity Due to Leg Protectors, Large Sport Motorcycle

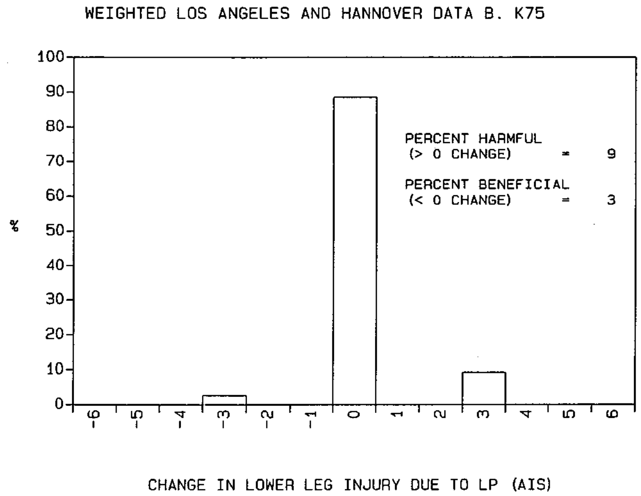


Figure 22. Distribution of Change in Lower Leg Injury Severity Due to Leg Protectors, Large Sport Motorcycle

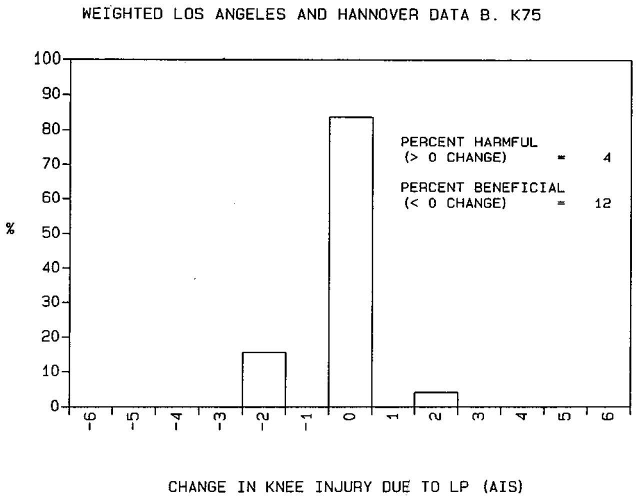


Figure 23. Distribution of Change in Knee Injury Severity Due to Leg Protectors, Large Sport Motorcycle

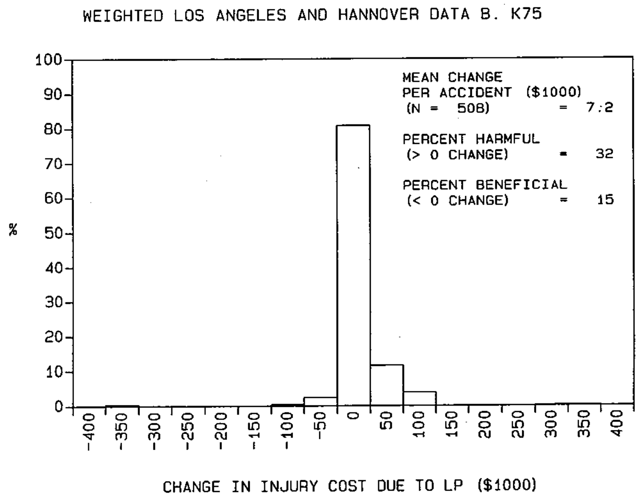


Figure 24. Distribution of Change in Injury Cost Due to Leg Protectors, Large Sport Motorcycle

For these reasons, it was concluded that overall this type of device would worsen rider injuries. Sensitivity analyses have also shown that changes in various LP mechanical properties have little influence on the overall results.

Reasons for TRRL Discrepancies

The reasons for TRRL's contrary results have been extensively documented (eg, Refs 12, 13), and involve a large number of factors. These centre on:

- The use of an inappropriate dummy leg
- A limited choice of test conditions
- Inaccuracies in test condition
- A lack of supporting data

There is little question that the first three of these have greatly influenced the results, and led to erroneous conclusions regarding leg protection effectiveness.

Use of an Inappropriate Dummy Leg

The dummy leg used by TRRL to support the leg protector research consists of two, 20 mm thick, alloy plates, hinged with a screw joint at the knee. The edges of the plates are oriented toward the front and rear of the dummy. To the lateral faces of the plates are glued 50 mm thick blocks of aluminum honeycomb (Fig 25). During crash tests, the honeycomb material is crushed and deformed.

TRRL has developed equations (Ref 24, pp 108-109) which relate the change in honeycomb volume (in various "directions") to absorbed energy. The absorbed energy is then compared to the energy required for a mid-span fracture of a tibia or femur. If the honeycomb material becomes separated from the plate during a crash test, then an additional adjustment is made for "glue shear energy." In addition, the upper leg is strain gauged to sense compression force and torsional moment.

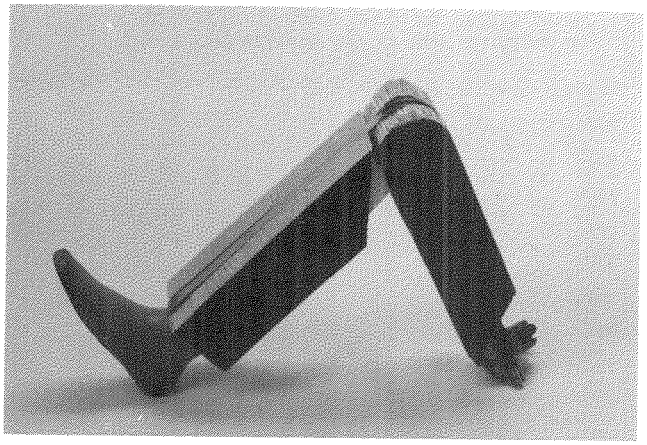


Figure 25. Photo of TRRL Honeycomb Leg

Some of the main problems with the honeycomb leg in the TRRL test configurations include:

- The edges of the alloy plates are exposed on the front surface of the leg. Therefore, during impacts to the front or front quarter of the lower leg, the plates prevent or limit honeycomb deformation. Such impact directions are quite typical during motorcycle/car angled collisions (Fig 26)
- The most sensitive axis of the honeycomb (ie, the side with the highest energy per unit volume) faces to the rear quarter of the motorcycle (Fig 26), away from the main impact direction. Consequently, impacts to the forward facing portions of the honeycomb require 37 times more volume change to indicate a "fracture," than do impacts to the lateral (rear quarter) faces. Again, the alloy plates tend to prevent such large deformations.
- The very large directional sensitivity in the energy absorption rate means that the analyst must decide from which direction the volume changes "came." For a massively deformed piece of honeycomb, this involves a highly subjective process
- The honeycomb damage is cumulative, increasing during all phases of contact and subsequent dummy tumbling motions. However, human leg fractures are known to be due to exceeding peak force, not cumulative surface deformation
- TRRL reports that, in angled car side impacts, the exposed edge of the alloy plate at the knee "penetrates through and is held in" the car door structure; causing massive honeycomb damage and effects on dummy motion (Ref 25). TRRL further reports that UKDS leg protectors have been designed to prevent such "door penetration" effects. However, in general, human legs are not strong enough or sharp enough to penetrate such structures in angled impacts. For example, in the 1989 industry tests with standard motorcycles (Tests A4 and B1), the leg was deflected without fracture in angled car side impacts
- The honeycomb leg, though instrumented, does not measure the most important and fundamental variables, namely leg bending moments, which are the principal cause of leg fracture. These are crucial in the leg fracture criteria for combined loads proposed by Mertz (Ref 26), shown in Fig 27. Fundamentally, the honeycomb leg cannot account for or predict such basic fracture phenomena.

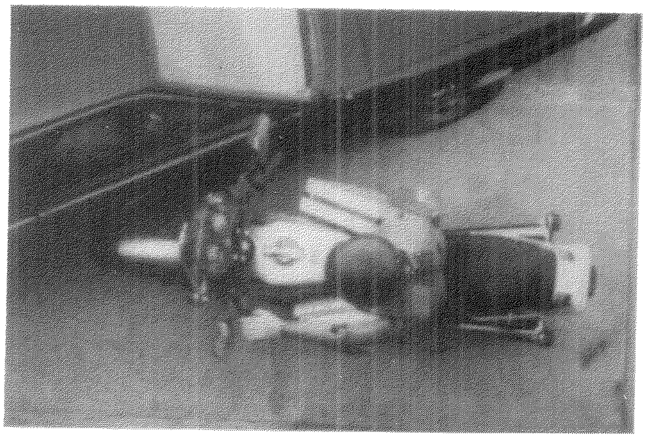


Figure 26. Top View of Honeycomb Leg in Relation to Motorcycle/Car Side Impact

$$\left(\frac{F_Z}{F_{Z_C}}\right) + \sqrt{\left(\frac{M_X}{M_{X_C}}\right)^2 + \left(\frac{M_Y}{M_{Y_C}}\right)^2} = 1$$

F_{Z_C} = Ultimate compression force for long bone

M_{X_C} = Ultimate lateral bending moment for long bone

M_{Y_C} = Ultimate antero-posterior bending moment for long bone

Figure 27. Combined Force Leg Fracture Criteria, as Proposed by Mertz

Results of recent laboratory tests on the honeycomb leg, whole cadaver legs, and the MATD-l composite leg are presented in Table 7 and Fig 28. The tests comprised high energy (1450 J) impacts with a 70 mm cylindrical anvil (more than 25 times the energy level used by TRRL to denote a lower leg fracture). The lower leg specimens were supported at and free to pivot about a bearing clamped to the knee. Initially, the specimens were held in an horizontal attitude by a l g friction plate, and impacted mid-tibia. The specimens were impacted in 3 directions: antero-posterior, 45° oblique, and latero-medial. Published data (Fuller, 1990) indicated that 26 out of 27 cadaver specimens tested with this kind of procedure experienced bending fractures.

Table 7 shows that the cadaver and MATD legs fractured, as would be expected. On the other hand, when applying the formulae used by TRRL, the honeycomb leg did not indicate a "fracture" in the antero-posterior or oblique impacts, which are the most common impacts in accidents, due to obstruction by the leg's alloy center plate. The honeycomb leg did record a 5 mm deep dent for the latero-medial impact, indicating a "fracture" for that case.

Table 7. Comparison of Fracture Occurrence in Dummy and Human Legs, for High Energy (1200 Joules) Impact Tests, 70 mm Cylindrical Impactor

Impactor Direction	Cadaver Leg	Composite Leg	Honeycomb Leg
Antero-posterior	Fracture	Fracture	No Fracture
45°	Fracture	Fracture	No Fracture
Latero-medial	Fracture	Fracture	"Fracture"

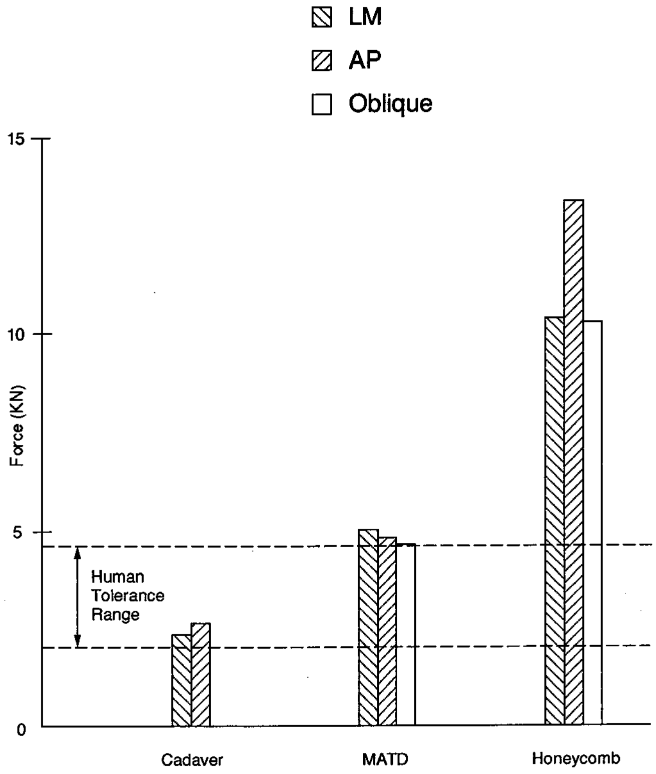


Figure 28. Comparison of Peak Forces for Mid Lower Leg Impacts (1450, cylindrical impactor; all cadaver and MATD legs fractured)

Figure 28 compares the peak force levels for the three legs. The cadaver and MATD legs lie near the lower and upper boundaries of human leg fracture forces, respectively, as expected. In contrast, the honeycomb leg forces (and accelerations) were 3 to 4 times higher than the mid range of human leg fracture forces.

In summary, these data confirm that the honeycomb leg is not able to predict leg fracture (in 2 of 3 cases tested); and that its impact force levels and resulting effects on leg motions are non human-like.

Limited Choice of Test Conditions

Figures 29 and 30 compare the distribution of motorcycle/car relative heading angles for car front and car side impacts used in published TRRL leg protector tests to the distribution of angles occurring in the Los Angeles and Hannover accident data. As can be seen, most of TRRL's tests have been done at 30 degree ("glancing") angles to the car front and car side. These angles are seen to be relatively infrequent in the accident data. In contrast, industry tests have been conducted at the indicated 45 degree increments, which correspond to some of the more frequent modes in the accident distribution.

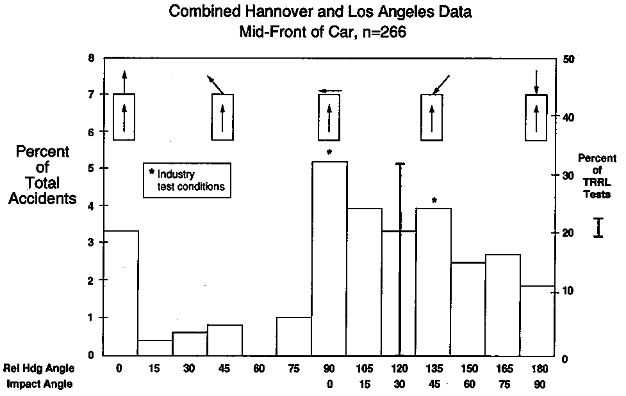


Figure 29. Distribution of Accident Impact Angles, Front of Car, Los Angeles and Hannover Accidents, and TRRL Tests

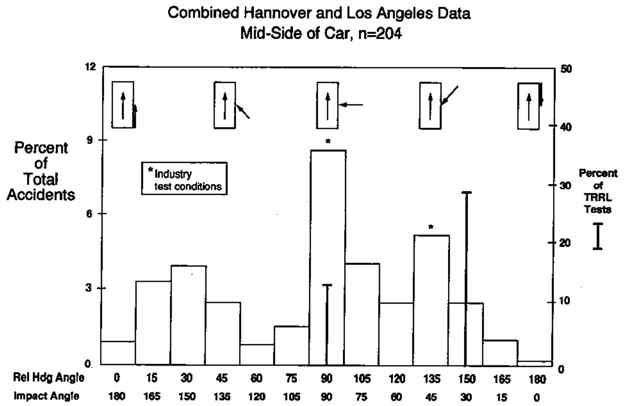


Figure 30. Distribution of Accident Impact Angles, Side of Car, Los Angeles and Hannover Accidents, and TRRL Tests

TRRL's stated reason for selecting 30 degrees is that this corresponds to the condition where leg injuries occur most frequently (Ref 27, p 25), based mainly on statements by Fuller, et al (Ref 28) and Hight, et al (Ref 29). However:

- Supporting reconstruction or statistical data are not given in or available for the Fuller or Hight papers, and
- The Fuller statement and study was based on a small, non-random sample of accidents; the Fuller statement is not quantitative or statistical in nature.
- The Hight, et al paper discusses angles in terms of "relative approach [path] angles," which include the vectorial sum of the motorcycle and car speeds.

> Although this is an unusual definition, it is clearly and unequivocally not the same as TRRL's "impact angle" definition. For a given "relative approach angle" there are an infinite number of possible "impact angles," depending on the motorcycle and car speeds. Also, the Hight statement is qualitative, and no statistical or reconstruction basis is given. TRRL has misquoted Hight.

More importantly, even if there was an epidemiological basis for a 30 degree impact angle, it is clearly not sufficient to test predominantly at one condition, since motorcycles are subjected to a very wide range of impacts in the real world. Industry tests have addressed this by using the more frequently occurring modes of accidents, as shown in Figs 29 and 30, and by use of validated computer simulations, described above, which extend the evaluation to all impacts known to occur.

Inaccuracies in Test Conditions

TRRL has reported tests where leg protector and standard motorcycles were tested under very different impact conditions, and the results were then compared. In the test films corresponding to Ref 30, Fig 9, the standard motorcycle fork contacts the *side* of the car (as it moves parallel to and in the opposite direction from the car); the leg protector motorcycle passes by the car with the fork approximately 10 inches (25 cm) away from the side of the car. TRRL ascribed the difference in dummy injuries between these cases to the action of leg protectors. Despite agreeing in 1990 technical discussions (Ref 25) that this was a fallacious test and that they would retest it, TRRL has continued in 1991 to publish these results for a Kawasaki GPZ as an example of leg protector effectiveness (Ref 27).

Such impact inaccuracies have occurred throughout the TRRL research, and are most probably related to limitations of the motorcycle delivery system. Other cases are known (for example, Ref 30, Fig 14; Ref 11, p 4; Ref 10, p 277, Fig 2) and are embedded in TRRL's overall data and conclusions.

In contrast, the average impact point accuracy in the 1989 industry tests was within ± 30 mm.

Lack of Supporting Data

Following 10 years of leg protector research, TRRL reports that it has done "over 120 full scale leg protector tests" and that "All of the evidence to date, and there is much of it covering a very wide range of conditions, shows the TRRL leg protectors to be successful . . ." (Ref 27). However:

- The published literature contains information on only 51 motorcycle/car/leg protector test
- No data has ever been published or released showing:
- Measurements of the damaged honeycomb
- Calculations of the damaged honeycomb "energy"
- Mainly summary (reduced and converted) data have been published
- Results of technical discussions (Ref 25) have indicated that no TRRL data exist which show the independent effects on injuries of the UKDS:
  - Detachment requirement
  - Leg retention geometry requirements
  - Knee protector location requirements
  - First-point-of-external-contact requirements
  - Primary impact element force and deformation requirements
  - Rigid support element force and deformation requirements

  and in this sense, the specific requirements and tolerances cited in the UKDS lack a scientific basis.
- When comparing the raw data which is available to the final published data, there are numerous and large discrepancies, as have been documented elsewhere.

Summary

For all of the reasons mentioned above, the TRRL leg protector data cannot be relied upon or used as a basis for evaluations of leg protector effectiveness.

Conclusions

Research by the motorcycle industry and others into rider leg protection concepts over the past 20 years has indicated that, in restraining the knees and lower legs during impact, the injury potential to the head and upper body (as well as the upper legs) increases. This can be viewed as a result of basic physics, and as having an adverse effect on rider safety.

A Draft Specification (UKDS) for leg protectors has been proposed by the United Kingdom Transport and Road Research Laboratory (TRRL) which is in many ways similar to earlier concepts.

UKDS leg protectors have been evaluated in full scale crash tests by TRRL and by the motorcycle industry. The two test programmes have produced opposite results, and this is attributable to differences in test conditions, test accuracy and test methodology.

Industry's extensive full scale test programme (Ref 20) has shown that UKDS leg protectors lead to an increased number of leg fractures per crash; leg fractures resulting from leg protector contact; a lower head trajectory; and increased head impact velocity and acceleration. Expressed in terms of injury severity and costs, the test results have shown that leg protectors lead to increased total Abbreviated Injury Scale (AIS) scores and increased injury costs, in the majority of cases tested.

These results have been extended to address a wide range of motorcycle/car impacts by means of extensive, in-depth computer simulations, involving 163 impact configurations known to occur in real world accidents.

The simulations, validated against data for 16 full scale crash tests, have shown that UKDS leg protectors: result in a significant net increase in total injury costs across all accidents; result in increased injuries in a relatively large percentage of all accidents; cause injuries by imparting angular momentum to the rider, and combined loads-to the upper legs.

Close examination of the TRRL research shows that it cannot be relied upon or used to evaluate leg protectors. This is due to: use of an inappropriate dummy leg which is unable to predict common types of leg fracture; limited choice of test conditions (emphasizing glancing 30° impacts); large inaccuracies in test conditions, affecting the conclusions; and lack of supporting data. In contrast, the Ref 20 industry research has involved high accuracy tests, a wider range of test conditions, fully published raw data, and an instrumented, breakable dummy leg which has been designed and verified to duplicate the fracture characteristics of human legs.

Based on all of the above considerations, as well as the previous research, it is concluded, regrettably, that the UKDS concept of leg protection is inherently harmful, liable to cause injury as a result of transfer of injuries to the head and upper legs, and lacking a scientific basis. Further testing or refinement of the UKDS is not warranted and would not be fruitful, in the opinion of industry experts, due to its fundamentally defective and harmful nature.

Moreover, based on a review of past research, it is the view of the motorcycle industry that any leg protector concept involving a robust knee restraint—with or without external energy absorption, knee pads, or leg retention—inherently results in negative effects, and therefore is not feasible.

From the in-depth study of this complex topic, improved methodologies and investigative tools have emerged. These tools, which are continuing to be improved, should be useful for the investigation of other more hopeful rider safety concepts.

References

1. Bothwell, P. W., R. E. Knight, H. C. Peterson, *Dynamics of Motorcycle Impact. Volume II, Motorcycle Crash Test Program,* DOT-HS-5-01160, 1971.
2. Bothwell, P. W., H. C. Peterson, *Dynamics of Motorcycle Impact. Volume II. Motorcycle Crash Test Program,* DOT-HS-800-907, 1973.
3. Uto, T., *Side Collision Test of Motorcycle Equipped with Side Protection Devices,* Japan Automobile Manufacturers Association, 1975.
4. Livers, G. D., *An Analysis of Motorcycle Side Impact,* DOT-HS-801-840, Final Report, 1976.
5. Bartol, J. A., G. D. Livers, R. Miennert, *Near Term Safety Improvements for Motorcycles. Phase II,* DOT-HS-801-653, 1975.
6. Bothwell, P. W., Dynamics of Motorcycle Impact. Volume I. Motorcycle Crash Test Program. Interim Report, DOT-HS-126-3-632, 1975.
7. Chinn, B. P., M. A. Macaulay, "Leg Protection for Motorcycles," IRCOBI Conference on the Biomechanics of Impacts, 1984.
8. Chinn, B. P., P. D. Hopes, M. A. Macaulay, "Leg Protection for Riders of Motorcycles," The Tenth International Technical Conference on Experimental Safety Vehicles, Oxford, 1985.
9. Tadokoro, H., S. Fukuda, K. Miyazaki, "A Study of Motorcycle Leg Protection," The Tenth International Technical Conference on Experimental Safety Vehicles, Oxford, 1985.
10. Chinn, B. P., M. A. Macaulay, "Leg Protection for Motorcyclists," IRCOBI Conference on the Biomechanics of Impacts, 1986.
11. Chinn, B. P., P. D. Hopes, "Protecting Motorcyclists Legs," The Eleventh International Technical Conference on Experimental Safety Vehicles, Washington, 1987.
12. *Comments on the UK Draft Specification for Leg Protection for Riders of Motorcycles,* Dynamic Research, Inc., Technical Memorandum No. 88-2, Torrance, CA, Jan 1988.
13. Bothwell, P. W., and R. Bothwell, *Motorcycle Leg Protectors—Response of Motorcycle Association of G. B. Ltd. to D.Tp. Legislative Proposals,* Motor Cycle Association of Great Britain, Jan 1988.
14. Sakamoto, Shinichi, *Preliminary Evaluation of a Motorcycle Leg Protector Design as Proposed by the United Kingdom Department of Transport,* Japan Automobile Manufacturers Association, Jun 1988.
15. Pedder, J., H. Hurt, D. Otte, "Motorcycle Accident Impact Conditions as a Basis for Motorcycle Crash Tests," The Twelfth International Technical Conference on Experimental Safety Vehicles, Goteborg, 1989.
16. St. Laurent, Andre, Tom Szabo, Nick Shewchenko, and Jim Newman, "Design of a Motorcyclist Anthropometric Test Device," The Twelfth International Conference on Experimental Safety Vehicles, Goteborg, Sweden, May 1989.
17. Development of Frangible Upper and Lower Leg Elements for Motorcycle ATD, Dynamic Research, Inc., Technical Memorandum No. 89-2, Torrance, CA, Jan 1989.
18. Newman, J. A., B. M. Gallup, and A. M. St-Laurent, *Development of a Preliminary Crash Test Injury Cost Model,* Biokinetics and Associates, Ltd. Report R89-ID, Ottawa, Canada, Apr 1989.
19. White, Richard P., Jr., and Thomas W. Gustin, "The Application of a New Data Recovery System for Automotive/Motorcycle Dynamic Testing," The Twelfth International Conference on Experimental Safety Vehicles, Goteborg, Sweden, May 1989.

20. Rogers, N. M., "Further Crash Tests of Motorcycle Leg Protectors as Proposed in the UK Draft Specification," The Thirteenth International Technical Conference on Experimental Safety Vehicles, Paris, Paper Number 91-S3-W-04, Nov 1991.
21. *Summary of Industry Position on Motorcycle Leg Protectors,* International Motorcycle Manufacturers Association, Paris, 1990.
22. Newman, J. A., J. W. Zellner, K. D. Wiley, "A Motorcyclist Anthropometric Test Device MATD," IRCOBI Conference on the Biomechanics of Impacts, 1991 .
23. Zellner, J. W., S. A. Kebschull, K. D. Wiley, "Motorcycle Leg Protectors: An Analysis of Overall Effectiveness Via Computer Simulation," Proceedings of the 1991 International Motorcycle Conference, Bochum, 1991 .
24. Chinn, B. P., *Injuries to Motorcyclists' Legs: Testing Procedures and Protection,* PhD Thesis, Brunel University, 1985.
25. *Minutes of Leg Protector Data Review Meeting at TRRL on 13/14 June 1990,* Leg Protector Coordinated Research LPCR-SEC-6, 1990.
26. Mertz, H., *Hybrid III Injury Assessment Values Used to Evaluate Response Measurements,* USG 2284 Part III, Attachment I, Enclosure 2, Submission to NHTSA, by Safety and Crashworthiness Systems, Current Product Engineering, General Motors Corporation, 1984.
27. *TRRL Review of Research on Motorcycle Leg Protection—1991,* Transport and Road Research Laboratory, Crowthorne, 1991.
28. Fuller, P. M., J. N. Snider, "Injury Mechanisms in Motorcycle Accidents," IRCOBI Conference on the Biomechanics of Impacts, 1987.
29. Hight, P. V., P. E. Newhall, K. Langweider, G. M. Mackay, "An International Review of Motorcycle Crashworthiness," IRCOBI Conference on the Biomechanics of Impacts, 1986.
30. Chinn, B. P., and H. Karimi, "Leg Protection for a Sports Motorcycle," SAE 900748, Feb 1990.

S3-W-04

Further Crash Tests of Motorcycle Leg Protectors as Proposed in the UK Draft Specification

Nicholas M. Rogers
International Motorcycle Manufacturers Association

Abstract

This paper describes results of a series of tests conducted during 1989 to evaluate further the UK Draft Specification for Motorcycle Leg Protectors (UKDS). Proposed in 1987, the UKDS involves leg protector elements which have specific geometric and mechanical properties to be verified by laboratory measurements. The full scale leg protector crash tests described are the most comprehensive to date in terms of: the types of motorcycles and cars used; the leg protector designs and UKDS categories; the type of impact configurations considered; and the use of state-of-the-art test methodologies, including a new motorcycle impact dummy and performance indices. Test results showed that UKDS type leg protectors lead to: increased numbers of leg fractures per crash; leg fractures resulting from leg protector contact; a lower head trajectory; and increased head impact velocity and acceleration. The lower head trajectory was ascribed to the restraining action of the leg protector as the upper body moves forward, diagonally to the side, or laterally during impact. In addition, the leg protector itself was seen to cause direct injury to the legs, due to upper leg combined load failure. Expressed in terms of injury severity and costs, the test results showed that UKDS leg protectors lead to increased total Abbreviated Injury Scale (AIS) scores and increased injury costs, in the majority of cases tested. For these reasons it was concluded that this general concept of leg protection is injury producing and does not contribute to improved rider protection.

Introduction

This paper describes results of a series of tests conducted during the Summer of 1989 by the International Motorcycle Manufacturers Association to evaluate further the UK Draft Specification for Motorcycle Leg Protectors (Ref 1). These tests were a follow to a 1988 preliminary evaluation described in Ref 2. The current tests were more comprehensive in terms of: the types of motorcycles and cars used; the leg protector designs and categories; and the types of impact configurations considered. Improved test methodologies, including new motorcycle dummy and performance measures, were also used.

Background

Research into devices which potentially might protect the legs of motorcycle occupants, without increasing injuries to other parts of the body, has continued over the last 2 decades. To date, this research has not found a viable solution. This is partly due to the basic nature and properties of motorcycles as vehicles; and also due to the very wide range of crash conditions under which such devices should not be injurious. The research also has been technologically limited with regard to test methodologies for the assessment of rider injuries, especially in the area of the leg, and with regard to providing realistic dummy motions in motorcycle/car impacts.

Notwithstanding this situation, the UK Draft Specification for Leg Protectors (UKDS) was published in July 1987. The proposal was based on the exploratory work of the Transport and Road Research Laboratory (TRRL) over the previous several years. At the time the UKDS was published, there was no published information or data for devices which actually complied with the UKDS. Also the exploratory work of TRRL had been limited by methodology problems, as have been documented elsewhere (eg, Ref 3).

For these reasons and in order to understand and comment on the UKDS, the Japan Automobile Manufacturers Association (JAMA) conducted a preliminary full scale evaluation of an example UKDS type leg protector (LP) which is reported in Ref 2. Although preliminary, the results showed that the example UKDS device did not reduce leg injuries in the 3 collision configurations tested. Also, in some cases it induced upper leg fractures, suggesting that the proposed device could increase leg injuries. In addition, in some cases the LP equipped motorcycles produced increased torso pitch, increased head velocities at impact, and increased motorcycle tumbling tendencies following impact.

Following these tests, the motorcycle industry increased efforts to improve test methodologies, a long term goal which had been announced in ECE subcommittee meetings in Geneva several years earlier. The goal was to assemble an "Interim Methodology" which would enable a more complete evaluation of the UKDS during 1989, the latter being the subject of the current paper.

The improved methodologies include six items:

- Detailed accident data analyses, to assist in selection of test conditions.
- Development of a motorcycle impact dummy.
- Development of an injury indicating dummy leg. Development of overall injury criteria applicable to motorcycle riders.
- Development of instrumentation to be self contained within the dummy (no external cables), which records measurements related to the injury criteria.
- Test procedures and plans including conditions, measurement methods, and criteria.

Technical descriptions of the improved methodologies are given in Refs 4 to 9, which are referred to later in this report.

Three UKDS LPs were designed, developed, and lab tested by the industry, to provide examples for study. These comprise Lps for small, medium and large motorcycles, representing different categories in the UKDS. Full scale crash test results for these Lps are presented in this report.

Objectives

This current study was carried out within the industry's long term objectives for leg protection research, namely:

- Assess the feasibility and effects on predicted injury costs of motorcycle design alternatives which are intended to:
  - Reduce injuries to the lower extremities of motorcycle riders in collisions, and
  - Not increase the overall costs of injuries resulting from collisions, and
  - Not increase the likelihood of various types of motorcycle accidents.

The specific goals of the study were to evaluate UKDS type leg protectors using:

- A wider range of vehicles
  - Motorcycles
    Small
    Medium
    Large
  - Opposing vehicles
    Saloon Car
    Coupe
- A wider range of leg protector designs
  - UKDS category
    2
    3A
    3B
- A wider range of test configurations and conditions (8)
  - 1 angled car front configuration
  - 1 offset car front configuration
  - 2 angled car side configurations
  - 3 car side configurations
  - 1 car rear configuration
- Improved test methodology including:
  - A new motorcycle impact dummy, MATD with:
    A new injury indicating leg with instrumented frangible tibias, femurs, and knee ligaments
    A digital recording system contained in the dummy
  - Injury criteria including dummy motion and fracture criteria and injury severity indices

Dummy Development Tests

Following assembly of the new motorcycle impact dummy, MATD a series of tests were performed which involved dummy operational checks and initial refinement. These included: free drop tests; impact fracture of the legs; a stationary motorcycle/moving car impact; and 8 moving motorcycle/moving car impacts. During the course of these tests a large number of dummy functional problems were identified and solutions developed and implemented. Among the more significant of these (which resulted in its specifications being different from those described in Refs 4 and 8) were:

- A reduced amount of chest deflection, because of the current design for the recorder housing and instrumentation cabling. This meant the deletion of chest deflection from the test measurements and injury criteria.
- Increased frequency of hip dislocation, because of unintended failure modes in the new hip joint design. This meant the deletion of hip dislocation from the test measurements and injury criteria, and physical replacement with a standard Hybrid III standing kit hip joint.

These changes led to a dummy design which had improved biofidelity and injury indication, compared to past dummies, and a reasonable level of durability and reliability with proper technical support. However, there remained considerable room for further improvements in maintainability, biofidelity, and injury indication.

Paper Organization

The next section of this paper describes the experimental procedures used in the full scale crash tests. This includes test vehicles, leg protectors, test facilities, dummy, performance measurements, and impact configurations. The third section summarizes the test results. This includes descriptions of individual tests and a summary of the effect of leg protectors on performance measurements. The final section presents the summary and conclusions based on the test results. Further details of the tests are given in Ref 10, including: leg protector lab tests and specifications; supporting crash test data; and description of the revised injury cost model.

Experimental Procedures

Test Vehicles

Motorcycles. The motorcycles used in the current full scale crash tests were:

- Small: Piaggio COSA CL 125 Scooter (110 kg)
- Medium: Yamaha XS 400 SP (170 kg)
- Large: BMW K 75 5 (237 kg)

These were selected to be in the upper three of the four UKDS size categories. The specifications of the test motorcycles are given in Table 1. The physical appearance of the standard motorcycles is shown in Figs 1 to 6.

Opposing Vehicles. The opposing vehicles were:

- Toyota Crown Saloon Car
- Toyota Celica GT Coupe

The specifications of the opposing vehicles are given in Table 2. The Toyota Crown Saloon Car was used in previous JAMA research, for example, Ref 2, and was selected to provide a connection with that data. The Toyota Celica Coupe was chosen to represent a medium

Table 1. Specifications of Test Motorcycles

Specification	Motorcycle		
Size:	Small	Medium	Large
UKDS Category:	2	3a	3b
Manufacturer:	Piaggio	Yamaha	BMW
Model:	COSA CL 125	XS400 SP	K 75 S
Overall Length:	1,810 mm	2,070 mm	2,230 mm
Overall Width:	565 mm	870 mm	675 mm
Overall Height:	1,080 mm	1,140 mm	1,230 mm
Weight: Standard	110 kg	170 kg	237 kg
with LP	123 kg	194 kg	255 kg

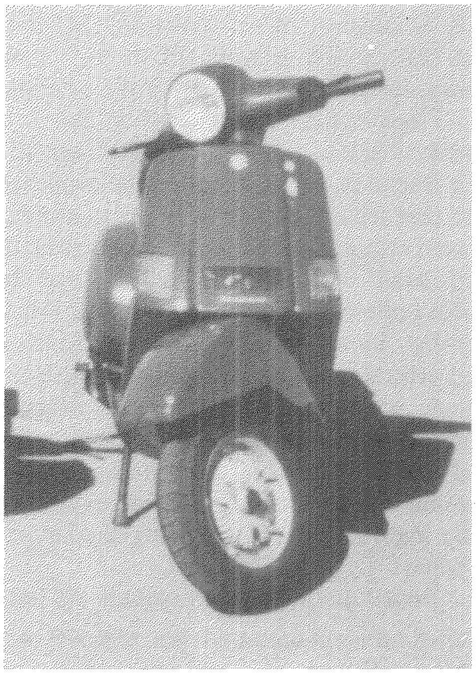


Figure 1. Front View of Small Motorcycle, Standard

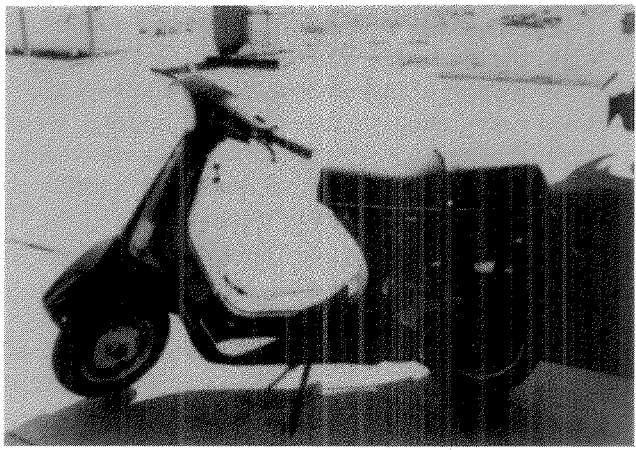


Figure 2. Side View of Small Motorcycle, Standard

Figure 3. Front View of Medium Motorcycle, Standard

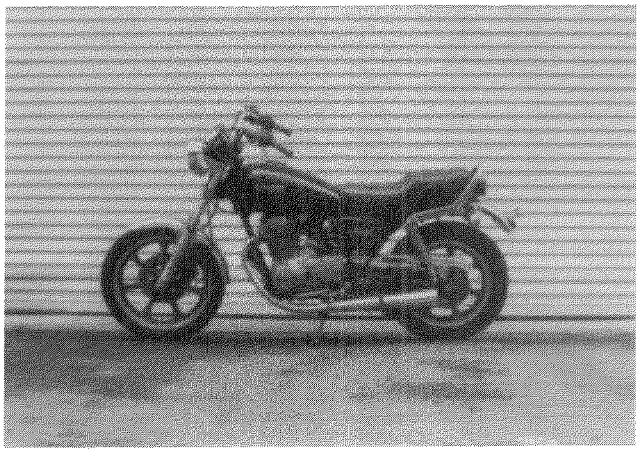


Figure 4. Side View of Medium Motorcycle, Standard

sized body style, which was available and popular worldwide. Photographs of the opposing vehicles are given in Figs 7 to 10.

UKDS Leg Protectors

Leg protectors for each of the three test motorcycle models were designed, developed, and lab tested to meet the UKDS. A summary of the specifications for the three different leg protectors is presented in Table 3. Photographs showing the appearance of the leg protector prototypes on the respective motorcycles are shown in Figs 11 to 16.

In general, an iterative design and lab test procedure was used to develop each of the three LP designs. Reference 10 describes the series of lab tests and results used in the development process, for the Primary Impact Element (PIE), Rigid Support Element (RSE), and Knee

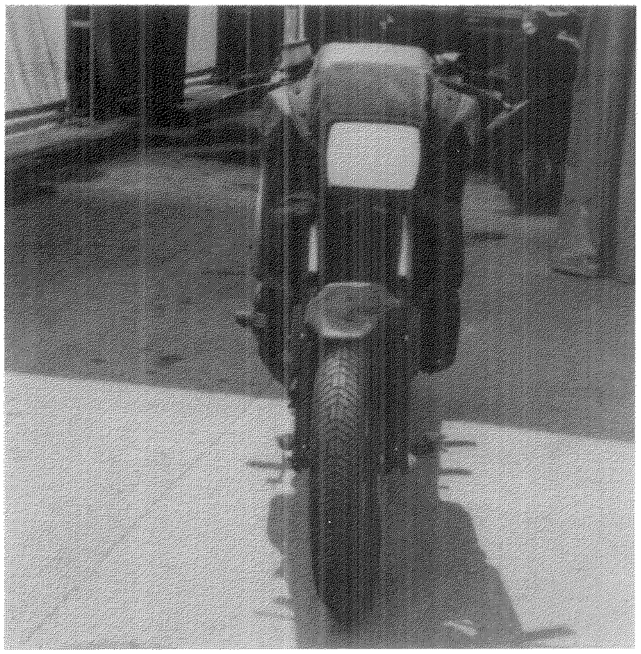


Figure 5. Front View of Large Motorcycle, Standard

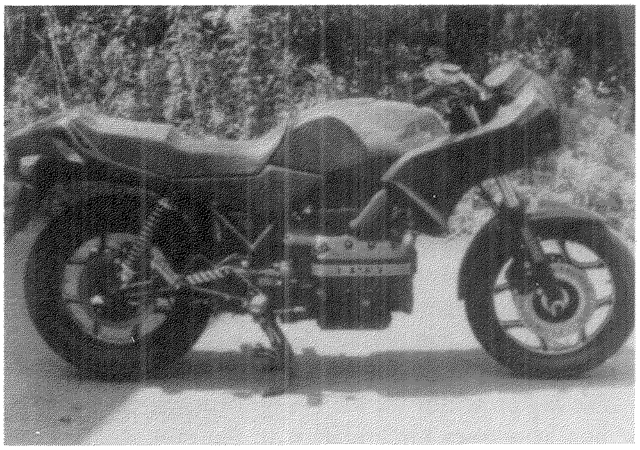


Figure 6. Side View of Large Motorcycle, Standard

Table 2. Specifications of Opposing Vehicles

Specification	Opposing Vehicle	
Type:	Saloon Car	Coupe
Manufacturer:	Toyota	Toyota
Model:	Crown	GT Celica
Overall Length:	4,690 mm	4,390 mm
Overall Width:	1,690 mm	1,640 mm
Overall Height:	1,440 mm	1,290 mm
Weight:	1,380 kg	1,120 kg

Figure 7. Front View of Saloon Car

Figure 8. Side View of Saloon Car

Figure 9. Front View of Coupe Car

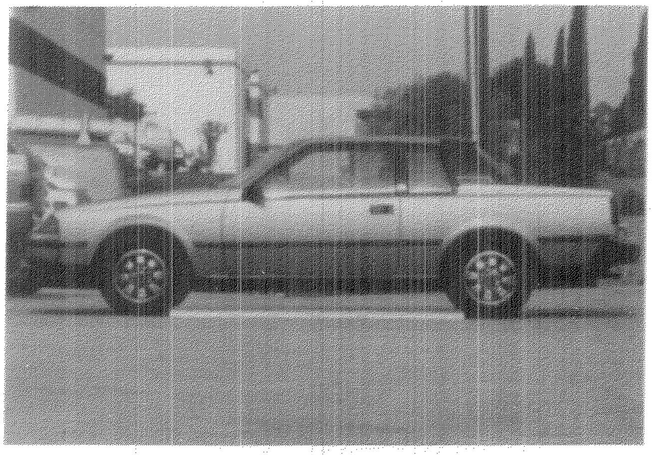


Figure 10. Side View of Coupe Car

Table 3. Leg Protector Description

Element		Motorcycle		
		Piaggio	Yamaha	BMW
Pie	External	Sheet metal	FRP	Sheet metal, FRP
	Internal	Partially filled with polyurethane	Polyurethane aluminum honeycomb on sheet metal	Polyurethane
RSE		Sheet metal, internally reinforced with 4 metal sheets	Steel tubes	Steel tubes
KPE		Polyurethane foam d = 0.100*	Polyurethane foam d = 0.078	Polyurethane foam d = 0.112

*d: density, gm/cm^3

Protection Element (KPE) as well as the final specifications of the complying devices. All three devices complied with the UKDS.

The leg protector for the Piaggio consisted of a series of box structures integrated with the monocoque front frame of the scooter. The PIE consisted of an outer metallic steel with polyurethane foam inside. The RSE was integrated with the front main assembly framework and the original framework was reinforced to support the leg protector. The KPE was made of polyurethane foam.

The LP for the Yamaha was similar to the design used in Ref 2. Two refinements were made in response to comments made by TRRL. The first of these was to extend the energy absorbing portion of the KPE downward. The other addition was a "smooth outer contour" in the form of a fibreglass fairing covering the PIE, RSE, and KPE.

The BMW LP was similar to the TRRL design for the Norton police motorcycle, tests of which were reported in Ref 11. The PIE was a steel box, rounded on the outer surface, and filled with polyurethane foam. The RSE consisted of steel tubes. During development the tube size was progressively reduced to a level of where the LP "just barely passed" the UKDS, in response to a TRRL concern that past LPs might have been "too rigid." The KPE was made of polyurethane foam.

Figure 11. Front View of Small Motorcycle, with Leg Protectors

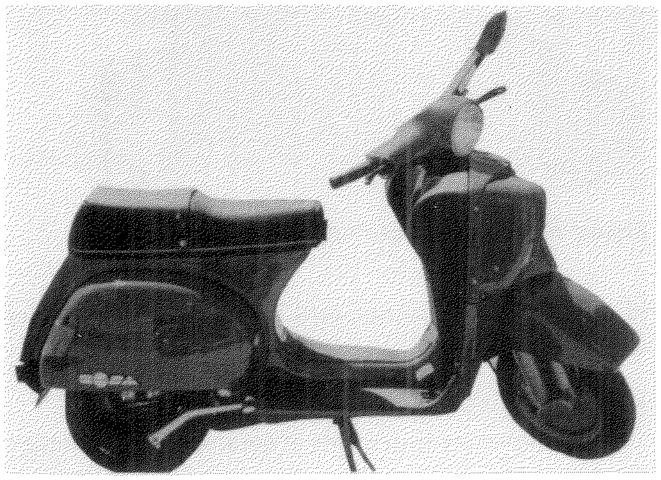


Figure 12. Side View of Small Motorcycle, with Leg Protectors

Test Facilities

Two crash test facilities were used for the full scale impact tests: the Japan Automobile' Research Institute (JARI), Japan; and those of Failure Analysis Associates (FAA), USA.

Both facilities consist of a main rail, along which the motorcycle trolley is drawn by cable; and a series of side runways at various angles to the main rail, along which the opposing vehicle is also drawn by cable. Vehicle speeds are determined by a system of pulleys in the JARI facility, and by a gear train in the F M facility. In both cases the motorcycles are propelled to the point of impact by a four-wheeled trolley, in which the motorcycle is held by braces at the handlebar, wheel supports, and main frame, until its release just prior to impact. Figures 17 and 18 show side views of the respective trolleys with example motorcycles.

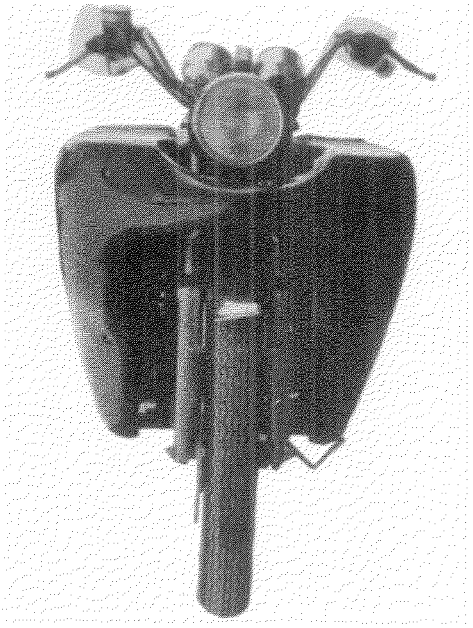


Figure 13. Front View of Medium Motorcycle, with Leg Protectors

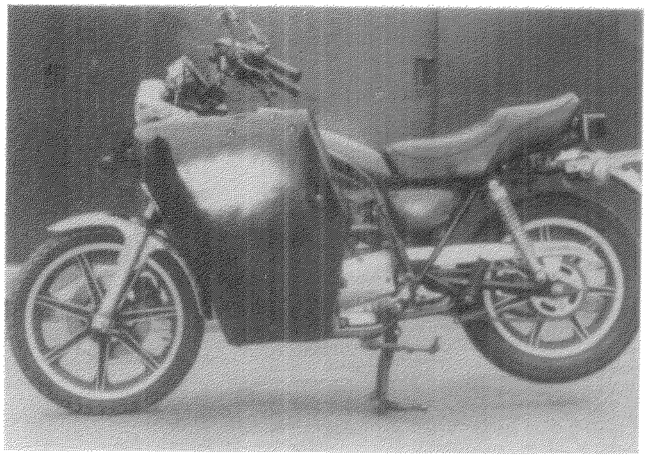


Figure 14. Side View of Medium Motorcycle, with Leg Protectors

Impact Dummy

A newly developed Motorcycle Anthropomorphic Test Device (MATD-1) was used in all the full scale impact tests. The requirements and design for this dummy are summarized in Refs 4 to 7. MATD-1 was developed for improved biofidelity with respect to motion and injury indication. The dummy comprises a highly modified Hybrid III pedestrian impact dummy (standing kit) with:

- Instrumented, frangible, composite material femurs and tibias, with bending, torsional and compression strengths and stiffnesses corresponding to human bone.
- Frangible knee ligaments in two axes (torsion and lateral bending with respect to the tibia).
- Internal 64 channel digital recording system (10,000 samples per channel per second).

Figure 15. Front View of Large Motorcycle, with Leg Protectors

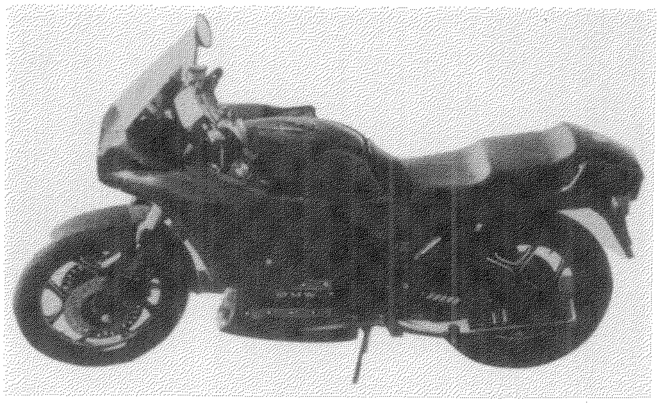


Figure 16. Side View of Large Motorcycle, with Leg Protectors

- Modified head form (chin and neck areas) to accommodate a motorcycle helmet.
- Modified hands which allow grasping of the handlebars.
- No external cables.

Typically, approximately 50 channels of motion data consisting of component accelerations, forces, and moments were recorded. However, only a subset of these was used in injury evaluation (as described in the next subsection), the remainder being used to provide further insight into motions and sources of injury.

Of course, the current state of crash dummy technology limits the ability to predict and quantify human injuries, especially for the complex motions of motorcycle crashes. While MATD-1 is the most advanced dummy used to date in motorcycle impact testing, many modes of potential injury and motion remain unconsidered. Continued research concerning the mechanisms of injury and body motion may help to identify areas for improvement.

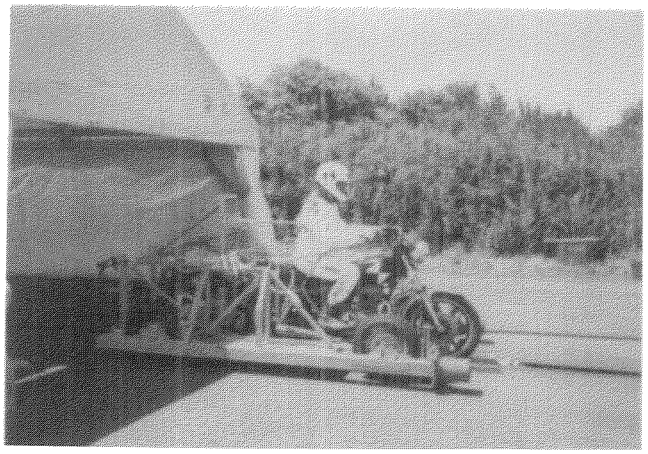


Figure 17. Side View of JARI Motorcycle Trolley

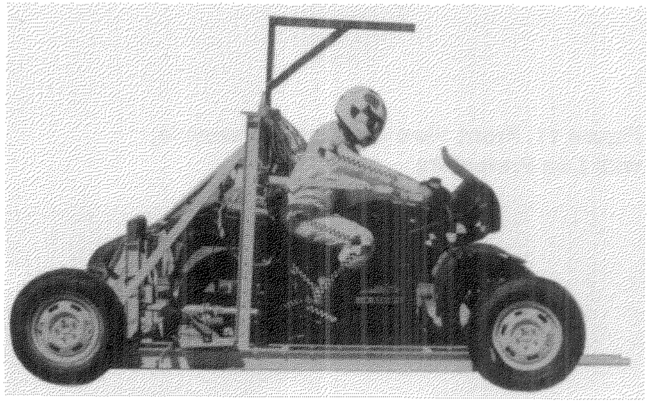


Figure 18. Side View of FAA Motorcycle Trolley

Performance Measurements

A number of measurements of dummy motions, forces, moments, and injury modes were collected, in order to assess the relative performance of the LP prototypes. In addition, using these measurements, a number of performance indices were computed. The basic raw data upon which all the measurements were based include:

- High speed film coverage of dummy, motorcycle, and opposing vehicle motions during and following impact.
- Digitally recorded time histories of approximately 50 electronically sensed dummy motion, force, and moment variables.
- Post-crash examination and photos of frangible elements.

Some of the derived performance measurements were computed at or over a certain time interval. Generally speaking the time intervals are related to 3 events, namely:

- Initial impact (motorcycle to car).
- Primary impact (of the dummy or of certain dummy parts with some large object).

- Secondary impact (of the dummy with some larger object).

The primary and secondary impacts refer to a variety of objects depending on the circumstances. For example, the primary head impact in many cases refers to head/car contact, although head/ground first contact occurred in one case. For leg impacts, the primary impact was with motorcycle, LP, car, or in some cases even the ground. In general, therefore, primary and secondary refer respectively to the first and second impacts between a dummy part and some larger object, irrespective of the object.

Also, for purposes of calculating injury severity, injuries during the entire crash sequence were combined, including primary, secondary, and any other impact. This was done because there is no obvious rationale that would limit the effects of leg protectors to, for example, primary impact. In other words, the injury severity estimates presented herein include all the consequences, primary, secondary and additional, of a particular crash sequence.

The following is a discussion of the central performance measurements used in the current tests.

Leg Injury Indication. Frangible leg elements inspected after each impact test were:

- Tibias (for simple or multiple fracture)
- Femurs (for simple or multiple fracture)
- Knee ligaments (for torsional or lateral bending failure).

As discussed elsewhere, these elements were designed to have force and moment versus deflection characteristics which were similar to human properties. For the tibia and femur composite material tubes, the fractures are categorized as being simple or multiple fractures. Simple was taken to mean one fracture zone. Multiple was taken to mean either more than one fracture zone or one fracture zone with an axial extent of more than 4 mm. The latter distinction was somewhat arbitrary; however the overall results do not appear to be sensitive to this particular criterion.

In the case of the knee, the torsion and lateral bending shear pins were examined. The criterion for ligament tear was whether the shear pin had been fractured into two or more pieces.

In addition, multiple load cells and strain gauges attached to the leg components provided information on modes and axes of failures. This information did not enter into the calculations of injury severity, but was used to examine cause/effect relationships.

Head Motion

Head Trajectory (x_h vs z_h projectory). High speed film (1000 fps) footage was used to measure the longitudinal (x_h) ant vertical (z_h) helmet target trajectory. These were analyzed from the time of motorcycle initial impact up through head primary impact. The longitudinal axis is parallel to the initial trajectory of the motorcycle, positive forward; and the vertical axis was perpendicular to this, positive downward, in standard SAE convention. Cross plots of x_h vs z_h show the head trajectory from the initial motorcycle impact to the head primary impact.

Head trajectory was used as a coarse indicator of potential head injury, in the sense that lower head trajectories can tend to lead to more direct impacts with stiff vehicle structures, as has been noted by other researchers (Ref 12). Of all head measures, head trajectory is the least affected by the details of the particular car structures impacted by the head and can be considered to show the most basic trends in motion.

Resultant Head Velocity at Primary Impact. The head trajectory data (x_h, y_h, z_h) were used to calculate a resultant head velocity time history. Then, using initial motorcycle impact as a datum for both film footage and time history, the time of primary head impact was identified in the time history.

Resultant head velocity at head primary impact was used as an indicator of momentum or energy with which the head struck the primary object. An alternative might be velocity perpendicular to the surface; however, this is difficult to define for the many compound curved surfaces found on typical cars (eg, the roof edge).

Peak Resultant Head Acceleration. Signals from duplicate sets of triaxial accelerometers (ie, 6 accelerometers) located in the dummy head were used to calculate peak resultant head acceleration at primary and at secondary head impact. The signals were antialias filtered, sampled at 10,000 samples per second, and SAE band filtered. The resultant acceleration from each of the triax sets was calculated digitally and the average of the peak resultants from the two triax sets was computed, for the primary and for the secondary impacts.

As discussed in Ref 8 peak resultant head acceleration is currently considered to be the most appropriate head injury indicator for helmeted head subjected to multi axis impact. Criterion values are discussed below.

Estimated AIS Levels. Dummy injuries were assessed using peak resultant head acceleration and frangible element failures based on the dummy injury criteria presented in Ref 8 and summarized in Table 4. This provides integer levels of injury severity corresponding to the traditional scales, namely:

AIS	Injury Severity
0	None
1	Slight
2	Moderate
3	Severe
4	Serious
5	Critical
6	Fatal

Based on the AIS score for each body part, aggregate measures of injury severity were assessed for each impact. These were: maximum AIS for a given impact;

and total AIS for a given impact. The former assumes that the worst injury is an indicator of injury severity; and the latter assumes that a linear summation of the injuries indicates overall severity.

Table 4. Summary of MATD-1 Dummy Interim Injury Criteria (from Ref 8)

Body Region	Severity AIS	Injury Assess Value	AIS 85 Human Injury
		Peak resultant head acceleration (g)	
Head (concussive injuries) Anatomic lesions can only be presumed	0	0-50	None
	1	50-100	Headache, dizziness
	2	100-150	Unconscious < 1 hr
	3	150-200	Unconscious 1-6 hrs
	4	200-250	Unconscious 6-24 hrs
	5	250-300	Unconscious > 24 hrs
	6	over 300	Dead
Lower Leg	0	No fracture	None
	2	Simple fracture	Tibia/fibula fracture
	3	Complex fracture	Multiple fracture
Upper Leg	0	No fracture	None
	3	Simple fracture	Femur fracture
	4	Complex fracture	Multiple fracture
Knee	0	No damage	None
	2	Shear pins failed	Ligament tear
	3	Pivot bolt failed	Dislocation

Estimated Injury Costs. Another aggregate indication of overall injury severity was based on the initial economic Injury Cost Model (ICM-1) presented in Ref 8. This uses the dummy measures to predict injury severity and then, based on economic data correlating the costs of medical treatment, disability, lost work, and ancillary expenses for various injury severities to the head and several parts of the leg, predicts an estimated overall injury cost.

Note that the Ref 8 injury cost model contains discontinuities in the cost function. These result in oversensitivity to small differences in dummy measurements in certain regions. To reduce this oversensitivity a linear interpolation method was used as described in Ref 10.

As mentioned elsewhere, such injury severity estimates are preliminary and incomplete but do provide a means to compare overall injury potential during the entire impact sequence.

Other Measures. Other measures of dummy motions, forces, and moments were recorded during the current tests. These variables (eg, chest and pelvis accelerations; leg forces and moments) provide additional insight into the mechanics of impact and injury. At the same time they are not considered to be either biofidelic or injury indicating; and for these reasons are not included in this report.

Impact Configurations

Selection. As with any product, test conditions can be selected on the basis of: conditions of typical use; conditions which fully exercise the capabilities of the device; and conditions which might indicate potential failure modes.

In the case of leg protectors, typical use includes conditions for their primary intended function, namely impacts with opposing vehicles. The Hannover and Los Angeles databases, analyzed and catalogued in Ref 9, were used to determine which impact configuration are known to occur. This reveals approximately 170 configurations which did occur and which can be simulated in existing motorcycle/car crash test facilities (note that this is only about 10% of the theoretically possible number of configurations, given the parameters used in Ref 9.). From this set of 170 candidate configurations a subset was selected based on an analysis of device capabilities, and this permitted exploration of a wider range of impact geometries and phenomena than heretofore. Also some of the configurations are among the most frequent occurring in the accident databases.

Summary of Configurations. Table 5 summarizes the 8 test configurations used in the current study. The first 5 of these were for the medium motorcycle. In addition, there were 2 test configurations for the large motorcycle; and 1 test configuration for the small motorcycle. The first 3 configurations were tested at JARI and involved the Toyota Crown opposing vehicle; and the last 5 configurations were tested at F M and involved the Toyota Celica coupe. Overall there was:

- 1 angled car front configuration.
- 1 offset car front configuration.
- 2 angled car side configurations.
- 3 car side configurations.
- 1 car rear configuration.

Table 5 also lists the impact geometry codes which further describe the impact condition. As shown in Table 5, "fractional" car impact points were sometimes used, which were a consequence of differences in vehicle geometry and delivery dynamics.

For each configuration a pair of impacts was conducted: one with the standard motorcycle, and one with the leg protector motorcycle.

Test Results

This section describes the resulting measurements for each impact test, first on a test by test basis and then focusing on the effects of leg protectors on the performance measures.

Test by Test Results

Configuration A1 (Car Side, Medium Motorcycle, 15/30) (numbers refer to car and motorcycle speeds in mi/h). Table 6 presents the summary of the physical measurements for test configuration A1, with the standard and LP motorcycles. Figure 19 presents the head trajectory data for standard and LP motorcycles.

For the standard motorcycle, the motorcycle front wheel turned to the right on impact with the moving saloon car. As the dummy slid forward, the right lower leg impacted the motorcycle front wheel, fracturing the tibia; and the chin of the full face helmet impacted the

Table 5a. Summary of Test Configurations

Name	Configuration (Speed in mi/h)	Geometry (see Tbl 5b)	OV	MC	Facility
A1	15 ▷ ↑30	4-1-3	Saloon car	Medium	JARI
A2	22 ▷ ↖ 22	1-1-4	Saloon car	Medium	JARI
A3	0 ▷ ← 30	2-2-5	Saloon car	Medium	JARI
A4	15 ▷ ↙ 30	3.5-1-4	Coupe	Medium	FAA
A5	0 ▷ ↓30	4-1-3	Coupe	Medium	FAA
B1	15 ▷ ↙ 30	3.5-1-4	Coupe	Large	FAA
B2	30 → 0 ▷	7-1-1	Coupe	Large	FAA
P1	15 ▷ ↓ 30	3.3-1-3	Coupe	Small	FAA

Table 5b. Geometry Code Used for Test Configurations

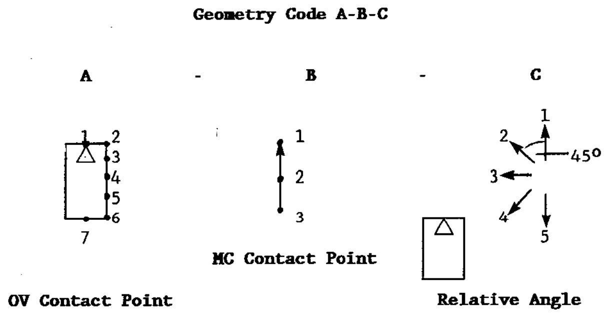


Table 6. Summary of Physical Measures for Configuration A1

Measure	Standard		LP	
Head Trajectory	Fig 19			
Resultant Head Velocity at Head Primary Impact (m/s)	14.2		9.2	
Peak Resultant Head Acceleration (g) - Primary Impact - Secondary Impact	144 59		235 65	
	L	R	L	R
Femur Fracture/Source	-	-	S*/Road	-
Tibia Fracture/Source	-	S/MC Front Wheel	-	S/Road
Knee Ligament Break - Torsion - Bending	- -	- -	- -	- -

* M - denotes multiple fracture
S - denotes simple fracture

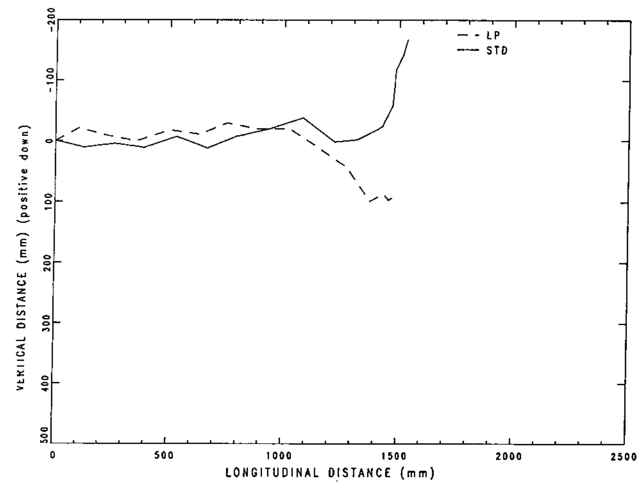


Figure 19. Comparison of Head Trajectories for Standard and LP Motorcycles, Configuration A1

roof edge, deflecting the head upward. Secondary impact was with the ground, the dummy landing on its left leg with no fracture, then on its back, impacting the back of the helmet.

With the LP motorcycle, on initial impact the knees were restrained by the KPE. The upper legs and torso rotated about the knees and the head was lowered, the helmet striking the roof edge at about helmet eye level. This resulted in a significantly higher head acceleration than for the standard case. Although the head velocity was lower for the LP, the head acceleration was higher due to the lower trajectory and more direct impact with the car roof structure. The helmet and head were deflected downward and on secondary impact with the road the left upper leg and right lower leg bones were fractured.

Configuration A2 (Angled Car Front, Medium Motorcycle, 22/22). Table 7 presents the summary of the physical measurements and Fig 20 presents the head trajectory data for configuration A2.

With the standard motorcycle, the motorcycle front wheel turned to the right on initial impact and the car front impacted the left front of the motorcycle. The left lower leg was fractured by the bumper and the left upper leg by the bonnet edge. As the dummy torso and hips continued to move forward, the right upper leg was

Table 7. Summary of Physical Measures for Configuration A2

Measure	Standard		LP	
Head Trajectory	Fig 20			
Resultant Head Velocity at Head Primary Impact (m/s)	6.5		7.1	
Peak Resultant Head Acceleration (g)				
- Primary Impact	60		55	
- Secondary Impact	71		103	
	L	R	L	R
Femur Fracture/Source	M/Bonnet	M/MC Fuel Tank	S/KPE, OV Head-light	-
Tibia Fracture/Source	M/Bumper	-	-	-
Knee Ligament Break				
- Torsion	-	-	-	-
- Bending	-	-	-	-

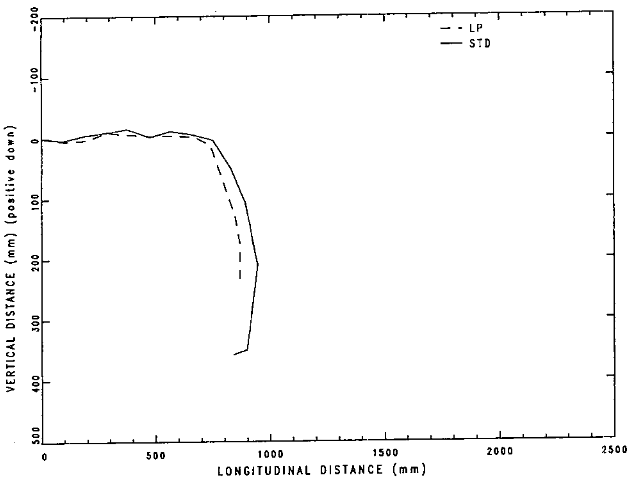


Figure 20. Comparison of Head Trajectories for Standard and LP Motorcycles, Configuration A2

fractured on contact with the motorcycle fuel tank. The helmet face impacted the hood with low acceleration. The dummy continued diagonally across the hood and landed on its back on the ground with low head acceleration.

For the LP motorcycle the front wheel turned right on impact and the car front impacted the PIE. The lower leg and knee were restrained within the KPE and the torso pitched forward. The left upper leg was fractured by simultaneous contact with the KPE edge and the right headlight of the saloon car. The trajectory of the head was somewhat lower than with the standard motorcycle and impacted with slightly higher velocity, closer to the front edge of the bonnet. In this test, the bonnet was deformed upward more than in the standard case. As the torso continued forward, the left leg came out of the KPE. The dummy remained over the bonnet and then fell to the ground on its back with somewhat higher head acceleration than the standard case.

Configuration A3 (Offset Car Front, Medium Motorcycle, 0/30). Table 8 presents the summary of physical measurements and Fig 21 presents the head trajectory data for configuration A3.

Table 8. Summary of Physical Measures for Configuration A3

Measure	Standard		LP	
Head Trajectory	Fig 21			
Resultant Head Velocity at Head Primary Impact (m/s)	No Head Impact		17.0	
Peak Resultant Head Acceleration (g)				
- Primary Impact	16		24	
- Secondary Impact	None		63	
	L	R	L	R
Femur Fracture/Source	M/OV Head-light	-	M/KPE	-
Tibia Fracture/Source	M/Bumper	-	-	-
Knee Ligament Break				
- Torsion	-	-	-	-
- Bending	-	X	-	-

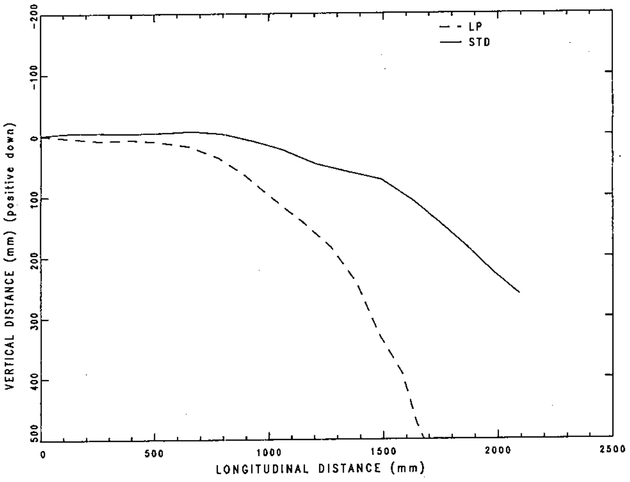


Figure 21. Comparison of Head Trajectories for Standard and LP Motorcycles, Configuration A3

For the standard motorcycle, the initial contact was between the motorcycle fork and the front side of the saloon car. The dummy left knee impacted the left headlight, fracturing the left upper leg. The left lower leg was fractured on impact with the bumper. The torso pitched forward and the motorcycle leaned to the right. However, the dummy stayed on the motorcycle and there was no secondary impact.

With the LP motorcycle the initial contact was between the PIE and the car front corner. As the dummy moved forward, the upper left leg was fractured during impact with the KPE. The front of the motorcycle decelerated and the rear of the motorcycle yawed to the right. The dummy torso pitched forward and downward and the motorcycle leaned and capsized to the right. As the head continued downward it glanced off the LP fairing. The rider was ejected over the front of the capsized motorcycle impacting its head against the ground with low acceleration.

Configuration A4 (Angled Car Side, Medium Motorcycle, 15/30). Table 9 presents the summary of physical measurements and Fig 22 presents the head trajectory data for configuration A4.

Table 9. Summary of Physical Measures for Configuration A4

Measure	Standard		LP	
Head Trajectory	Fig 22			
Resultant Head Velocity at Head Primary Impact (m/s)	13.4		13.7	
Peak Resultant Head Acceleration (g) - Primary Impact - Secondary Impact	51 54		109 52	
	L	R	L	R
Femur Fracture/Source	-	-	M/KPE (leg trap)	-
Tibia Fracture/Source	-	-	-	-
Knee Ligament Break - Torsion - Bending	- -	- -	- -	- -

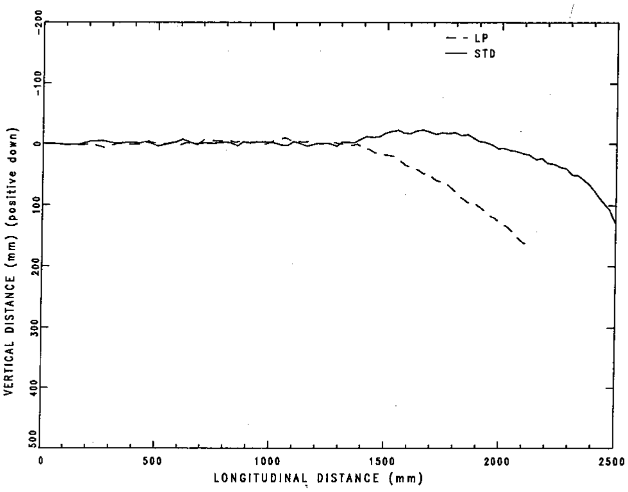


Figure 22. Comparison of Head Trajectories for Standard and LP Motorcycles, Configuration A4

With the standard motorcycle, the motorcycle front wheel turned to the right on impact with the moving coupe. The motorcycle yawed rapidly to the right, the dummy's left knee glancing along the coupe left door. There were no leg fractures. As the motorcycle turned away from the car the dummy torso continued toward the car, the head remaining above and traveling over the roof. The helmet chin glanced off the top rear of the roof with low acceleration and the torso glanced off the C pillar. The dummy landed behind the car on its back with low head acceleration.

For the LP motorcycle, the front wheel turned to the right on impact and the PIE impacted the left door of the coupe. The dummy left lower leg and knee slid forward inside the KPE. The motorcycle experienced a large roll to the right and less yawing motion compared to the standard case. However, the left lower leg was restrained in the KPE. The torso pitched rapidly forward and downward, as the motorcycle moved away to the right with the lower leg still restrained. The left upper leg fractured due to the restraint of the lower leg and the lateral, forward and downward pitching of the torso. The trajectory of the head was considerably lower than in the standard case and the helmet impacted the side of the car at the C pillar with about twice the acceleration level as in the standard case. The head continued to move downward glancing off the rear edge of the boot. The legs left the motorcycle in an upward direction and the dummy impacted the ground head first behind the car with slightly lower acceleration than in the standard case.

Configuration A5 (Car Side, Medium Motorcycle, 0/30). Table 10 represents the summary of physical measurements and Fig 23 presents the head trajectory data for configuration A5.

Table 10. Summary of Physical Measures for Configuration A5

Measure	Standard		LP	
Head Trajectory	Fig 23			
Resultant Head Velocity at Head Primary Impact (m/s)	13.1		14.1	
Peak Resultant Head Acceleration (g) - Primary Impact - Secondary Impact	82 79		109 None	
	L	R	L	R
Femur Fracture/Source	-	-	-	-
Tibia Fracture/Source	-	-	-	-
Knee Ligament Break - Torsion - Bending	- -	- -	- -	- -

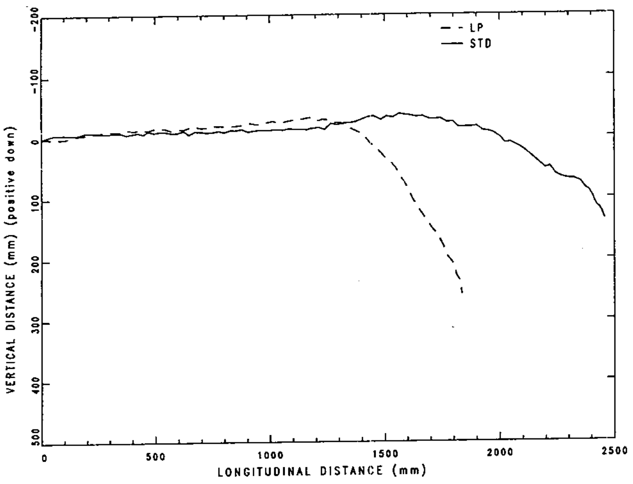


Figure 23. Comparison of Head Trajectories for Standard and LP Motorcycles, Configuration A5

With the standard motorcycle, the motorcycle front wheel impacted the right door of the coupe and impacted the engine case of the motorcycle, as the motorcycle continued to move forward. The dummy slid forward over the fuel tank, as the motorcycle front end continued to collapse. The knees contacted the side of the car with no leg fracture, as the head continued forward, considerably above the edge of the roof. The dummy contacted the edge of the roof with its chest, and the helmet face then contacted the center area of the top of the roof. The dummy somersaulted over the roof, landing on the far side of the car on its back with low head acceleration.

With the LP motorcycle, the front wheel impacts the right door of the coupe and impacted the engine case, as the motorcycle continued to move forward. The dummy knees contacted the KPE and the hips remained near the seat as the torso pitched rapidly forward and downward. As the head continued to move downward, the hips moved upward, pivoting about the knee contact with the KPE. The helmet struck the car below the roof line at the right front window near the A pillar. Acceleration of the head as it impacted the window was higher than for the standard case. The head continued through the window and into the car as the hip continued upward and forward. The dummy impacted and pivoted about the roof edge at the back of the neck and upper shoulders. The dummy continued to somersault and came to rest on the roof on its back.

Configuration B1 (Angled Car Side, Large Motorcycle, 15/30). Table 11 presents the summary of physical measurements and Fig 24 presents the head trajectory data for configuration B1.

With the standard motorcycle, the motorcycle front wheel turned to the right on impact with the left door of the coupe. The front of the motorcycle yawed away from the car, the left knee glancing along the door of the coupe, with no leg fractures. The torso continued toward the car, the helmet chin impacting on the roof edge with high acceleration. The motorcycle was deflected away from the car, the rider continuing to straddle it until it capsized behind the car. The rider came to rest on top of the bike, face down, with low head acceleration and no leg fractures.

Table 11. Summary of Physical Measures for Configuration B1

Measure	Standard		LP	
Head Trajectory	Fig 24			
Resultant Head Velocity at Head Primary Impact (m/s)	10.3		11.3	
Peak Resultant Head Acceleration (g)				
- Primary Impact	200		144	
- Secondary Impact	24		108	
	L	R	L	R
Femur Fracture/Source	-	-	S/Road	-
Tibia Fracture/Source	-	-	-	-
Knee Ligament Break				
- Torsion	-	-	-	-
- Bending	-	-	-	X

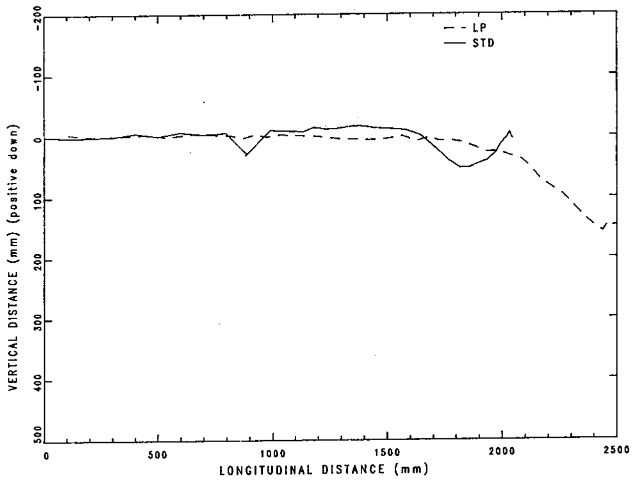


Figure 24. Comparison of Head Trajectories for Standard and LP Motorcycles, Configuration B1

For the LP motorcycle, the motorcycle wheel turned right on impact and the PIE impacted the left door of the coupe. The rider's left knee and lower leg moved into the KPE. The motorcycle yawed and rolled to the right. The dummy's torso continued toward the coupe, pitching forward and downward. As the motorcycle continued to yaw away from the car with legs restrained, the head moved downward and made a glancing impact to the left rear window and C pillar. The velocity of the head was somewhat higher than in the standard case, although the impact was glancing and penetrated the window, resulting in lower head acceleration than in the standard case. As the motorcycle continued to roll to the right with legs restrained, the right knee ligament broke (in lateral bending). The head continued downward to impact the ground at higher acceleration than in the standard case. In addition, the left upper leg was fractured on ground impact.

Configuration B2 (Car Rear, Large Motorcycle, 0/30). Table 12 presents the summary of physical measurements and Fig 25 presents the head trajectory data for configuration B2.

Table 12. Summary of Physical Measures for Configuration B2

Measure	Standard		LP	
Head Trajectory	Fig 25			
Resultant Head Velocity at Head Primary Impact (m/s)	5.9		12.2	
Peak Resultant Head Acceleration (g)				
- Primary Impact	40		43	
- Secondary Impact	87		102	
	L	R	L	R
Femur Fracture/Source	-	-	-	-
Tibia Fracture/Source	-	-	-	M/Road
Knee Ligament Break				
- Torsion	-	-	-	-
- Bending	-	-	-	-

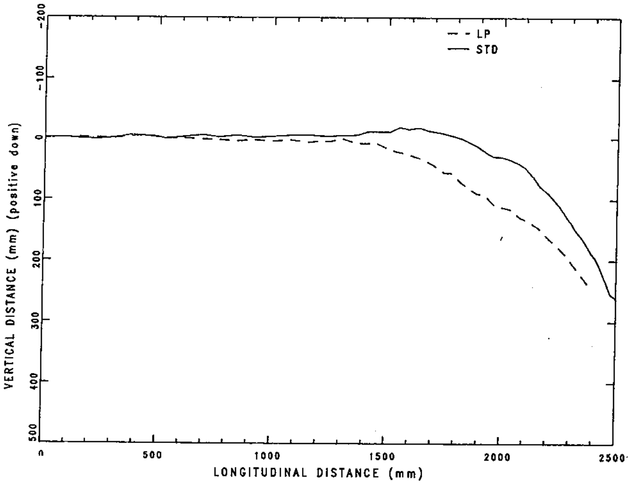


Figure 25. Comparison of Head Trajectories for Standard and LP Motorcycles, Configuration B2

For the standard motorcycle, the motorcycle front wheel impacted the rear bumper and then the motorcycle engine case as the motorcycle continued forward. The motorcycle headlight impacted the rear of the coupe boot and the dummy slid forward over the fuel tank. As the head moved forward, the legs remained near the handlebars and the head impacted the boot near the rear window at low velocity and acceleration. The dummy continued forward and somersaulted over the front of the car, landing on the ground on its feet and then on its right shoulder, with low head acceleration and no leg fractures.

For the LP motorcycle, the front wheel impacted the bumper and the engine case and the headlight impacted the rear of the boot. The dummy knees contacted the KPE and the hips pivoted upward about this point. The trajectory of the head was somewhat lower than in the standard case. The helmet face impacted the top of the boot near the rear boot edge, at about twice the velocity as for the standard case. The head acceleration, however, was about the same as in the standard case. The dummy legs moved upward and the head forward along the boot and the dummy somersaulted over the right side of the car, landing on its feet and then its back, with somewhat higher head acceleration than the standard case. In addition, the right lower leg was fractured on impact with the ground.

Configuration P1 (Car Side, Scooter, 15/30). Table 13 presents the summary of physical measurements and Fig 26 presents the head trajectory data for configuration P1.

Table 13. Summary of Physical Measures for Configuration P1

Measure	Standard		LP	
Head Trajectory	Fig 26			
Resultant Head Velocity at Head Primary Impact (m/s)	13.4		14.1	
Peak Resultant Head Acceleration (g)				
- Primary Impact	127		114	
- Secondary Impact	34		154	
	L	R	L	R
Femur Fracture/Source	M/ Fairing	-	M/KPE	-
Tibia Fracture/Source	M/ Fairing	-	-	M/OV Rocker Panel
Knee Ligament Break				
- Torsion	-	-	-	-
- Bending	-	-	-	-

With the standard scooter, the scooter front wheel turned to the left on impact just aft of the left front wheel arch of the coupe. The scooter yawed to the left. The dummy slid forward on the seat, the left upper and lower leg bones fracturing on impact with the left fairing. The right knee continued forward, missing the fairing and contacting the side of the car with no leg fractures. The head continued forward above the level of the roof and impacted the roof about a third of the way across, just aft of the front of the roof, with moderate head acceleration and velocity. The scooter continued to yaw to the left and the dummy remained on the left side of the car, falling to the ground on its back, with low head acceleration.

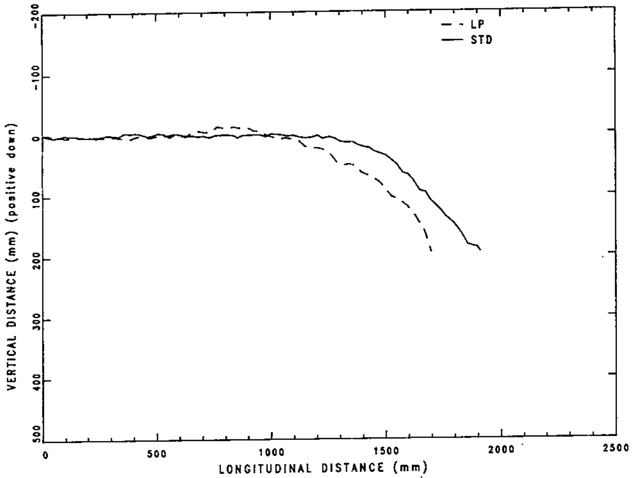


Figure 26. Comparison of Head Trajectories for Standard and LP Motorcycles, Configuration P1

For the LP scooter, the scooter front wheel turned to the left on impact just aft of the left front wheel arch of the coupe. The PIEs impacted the side of the coupe and the scooter yawed to the left. The dummy slid forward on the seat and the left knee impacted the KPE, fracturing the left upper leg. The right knee impacted and broke through the outer edge of the right KPE.

This straightened the right leg, and deflected the right foot downward beneath the car. The lower leg was fractured on impact with the lower edge of the car. The trajectory of the head was somewhat lower than with the standard scooter and the helmet chin impacted the top of the roof near the A pillar. The head velocity at impact was somewhat higher and the head acceleration was somewhat lower than for the standard case. The scooter continued to yaw to the left and the rider remained on the left side of the car, landing on its back with much higher head acceleration than for the standard case.

Effect of Leg Protectors on Performance

Effect of LPs on the Number of Leg Fractures Per Crash. Figure 27 compares the number of leg injuries per crash with the standard and LP motorcycles. In two of the configurations (A2, A3) there was a reduction in the number of leg injuries with LPs. In two of the configurations (AS and P1) there was no change in the number of leg injuries. In four of the configurations (A1, A4, B1, B2) there was an increase in the number of leg injuries with LPs.

Number and Cause of KPE Related Leg Injuries. In five of the configurations (A2, A3, A4, B1, P1) leg injury resulted from leg contact with the knee protection element. In one of these (P1), there were KPE related injuries to both legs. In three cases (A2, A3, P1) the injury was an upper leg fracture during leg to KPE impact, and in two of the cases (A4, B1), upper leg and knee injuries occurred due to restraint of the lower leg. In one case (P1), knee impact to the KPE deflected the foot downward the car, resulting in a lower leg fracture.

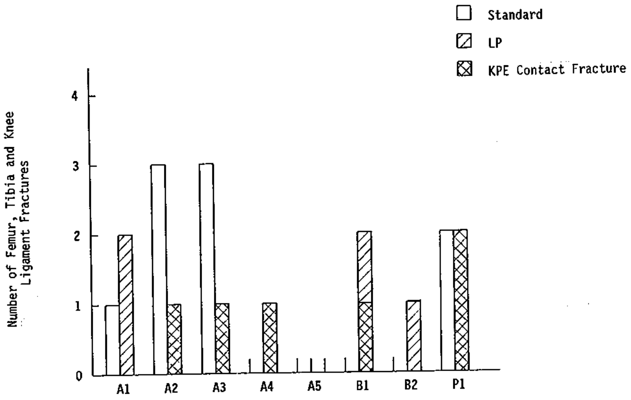


Figure 27. Summary of Leg Fracture Data

KPE Injury Mechanisms. Table 14 summarizes data related to the first four of the six KPE related leg injuries (the fifth and sixth injuries were associated with the bending failure of the right knee ligament in B1 and the downward deflection of the right leg in P1, previously discussed).

Table 14. Summary of KPE Injury Data

Test Configuration	KPE Fractured Bone	Time[1] of Fracture (ms)	Dominant Axes of Fracture (in order of force magnitude)
A2	Left Femur	81	Lateral Bending, Forward Bending, Compression
A3	Left Femur	72	Forward Bending, Lateral Bending, Compression
A4	Left Femur	119	Forward Bending, Lateral Bending, Compression
P1	Left Femur	114	Compression, Lateral Bending, Forward Bending

[1] Time refers to time history coordinate shown in the leg force time histories of App B. Time is referenced to an arbitrary datum, prior to initial motorcycle impact.

As shown in Table 14, in all four of these cases, the fracture was to the left femur (the left side being the more collision involved side of the motorcycle). Also, in all four cases the femur was fractured by a combination of lateral bending, forward bending and compression forces.

This is further described in Table 15, which shows the fraction of the bone strength reached during fracture, in each axis, based on the recorded leg force data of Ref 10. In all four cases, the compression loading was considerably below failure levels. However, substantial amounts of lateral and forward bending were present in each case, and were the dominant forces leading to fracture in cases A2, A3 and A4.

Table 15. Fraction of Single Axis Bone Strength Reached During Fracture

Test Configuration	Fraction of Single Axis Strength Reached		
	Lateral Bending	Forward Bending	Compression
A2	1.19	0.96	0.77
A3	0.85	0.87	0.63
A4	0.75	1.07	0.55
P1	0.51	0.39	0.70

Examination of the high speed film suggests that the large bending loads are associated with the concave shape of the KPE, as well as upper leg angular motions and orientation.

Overall, these data indicate that upper leg bending fractures occur with the KPE; the RPE design does not prevent such fractures; and in some cases, the URDS KPE design causes or increases the likelihood of such fractures.

Effect of LPs on Head Trajectory. Figure 28 compares the dummy head trajectory with the standard and LP motorcycles for the 8 different impact configurations. In all 8 configurations the head followed a lower trajectory when LPs were fitted.

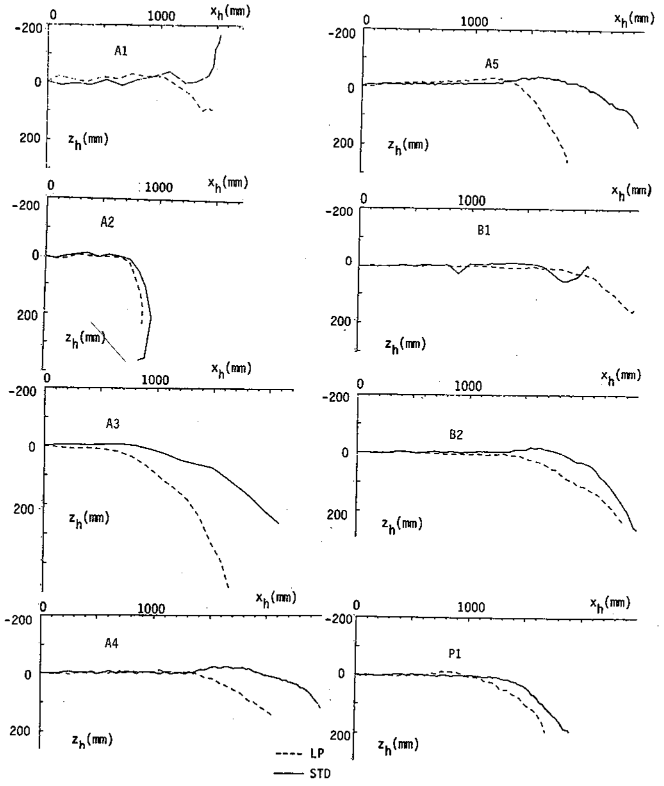


Figure 28. Summary of Head Trajectory Data

The amount by which the head trajectory is lowered varies from about 30 mm with configurations Al and B2 to as much as 270 mm with configuration A5.

Effect of LPs on Resultant Head Velocity at Primary Impact. Figure 29 compares resultant head velocity at primary impact with standard and LP motorcycles. In configuration Al the head velocity was reduced by about one third with LPs. In all other configurations, the head velocity at impact was increased, typically by around 5 percent, except in configuration B2 where the head velocity was nearly doubled with LPs.

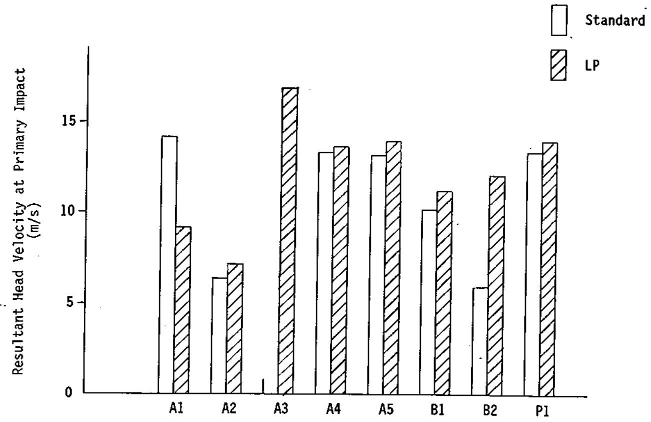


Figure 29. Summary of Head Velocity Data

Effect of Lps on Peak Resultant Head Acceleration on Impact. Figure 30 compares the peak resultant head acceleration on impact with standard and LP motorcycles. The maximum peak accelerations occurring during each crash sequence are shown. Configuration B1 shows a reduction in peak head acceleration. All of the other configurations (7 of 8) show an increase in head acceleration, ranging between 15 g for configuration B2 to 90 g for configuration A1.

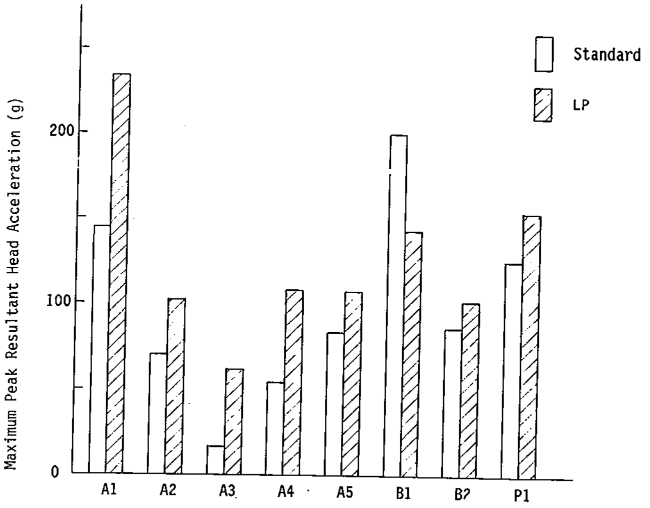


Figure 30. Summary of Head Acceleration Data

Effects of LPs on Estimates of Injury Severity. Table 16 summarizes various estimates of injury severity for the 16 crash tests. These include: the individual body part AIS per Ref 8; the total AIS for each crash; the maximum AIS for each crash as discussed in Ref 9 and elsewhere; and the estimated injury cost per Ref 8, with linear interpolation as described in App C.

Table 16. Summary of Injury Severity

Config		AIS										Injury Cost[2]
		Head	Leg						Total	Max		
			Left			Right						
			F	T	K	F	T	K				
A1	S	2	0	0	0	0	2	0	4	2		52,566
	L	4	3	0	0	0	2	0	9	4		420,100
A2	S	1	4	3	0	4	0	0	12	4		201,473
	L	2	3	0	0	0	0	0	5	3		69,448
A3	S	0	4	3	0	0	0	2	9	4		175,771
	L	1	4	0	0	0	0	0	5	4		116,923
A4	S	1	0	0	0	0	0	0	1	1		2,001
	L	2	4	0	0	0	0	0	6	4		127,535
A5	S	1	0	0	0	0	0	0	1	1		4,363
	L	2	0	0	0	0	0	0	2	2		11,213
B1	S	4[1]	0	0	0	0	0	0	4	4		169,993
	L	2	3	0	0	0	0	2	7	3		75,150
B2	S	1	0	0	0	0	0	0	1	1		6,190
	L	2	0	0	0	0	3	0	5	3		69,336
P1	S	2	4	3	0	0	0	0	9	4		174,773
	L	3	4	0	0	0	3	0	10	4		178,474

[1] Maximum peak resultant head acceleration of 200.2 g, was near an AIS boundary (200 g = AIS 3-4). However, this does not affect calculated injury cost, per Appendix C.

[2] 1981 US Dollars.

As an injury severity indicator, total AIS assumes linear weighing of the individual injuries: the more injuries which occur and the more severe the injuries, the greater the overall severity. The total AIS data show that LPs are beneficial in 2 of the 8 configurations; and LPs are harmful in 6 of the 8 configurations.

Maximum AIS as a coarse indicator of injury severity has been discussed in Ref 9 and elsewhere. The maximum AIS data show that: LPs are beneficial in 2 out of 8 configurations; LPs have no effect in 2 out of 8 configurations; and LPs are harmful in the remaining 4 configurations.

The injury cost model data describe the estimated economic costs of medical treatment, disability, lost work, and ancillary expenses as functions of body part, severity, and interactions among injuries. For example, moderate severity leg injuries can tend to be more costly than moderate level head injuries due to a relatively higher disability cost. Serious heat injuries, on the other hand, have higher costs than serious leg injuries because of higher costs of medical treatment as well as disability. The injury cost data show that LPs are beneficial in 3 of 8 cases; and harmful in 5 of 8 cases.

Overall, configuration A2 is the only case in which LPs are shown to be beneficial by all 3 injury severity measures.

Summary and Conclusion

Summary

Tests Performed. Sixteen full scale crash tests of UKDS leg protectors were conducted, using the following equipment and conditions:

- 3 motorcycles
  - Small
  - Medium
  - Large
- 2 opposing vehicles
  - Saloon car
  - Coupe
- 8 impact configurations
  - 1 angled car front configuration
  - 1 offset car front configuration
  - 2 angled car site configurations
  - 3 car side configurations
  - 1 car rear configuration
- New test methodology
  - MATD motorcycle tummy with internal recorder and frangible leg parts
  - Injury criteria ant injury cost motel

Findings. Results of the 8 pairs of tests (1 standard and 1 LP motorcycle in each pair), discussed in the previous section, showed the following:

Leg Injury Potential

- In 2 out of 8 cases there was a decrease in the number of leg injuries per crash with leg protectors; in 2 configurations there was no change in the number of leg injuries; and in 4 configurations there was an increase in the number of leg injuries with LPs.
- In 5 out of 8 configurations there were leg injuries resulting from leg contact with the leg protector Knee Protection Element (KPE). In the 5 configurations there were 6 injuries (2 in P1) involving fractures due to: motion of the upper leg relative to the KPE; restraint of the lower leg on the motorcycle, while the upper body moved in a different direction; and downward deflection of the lower leg, beneath the opposing vehicle.
- Four of the KPE contact injuries were combined force fractures of the femur (involving lateral bending, forward bending, and compression). These seem to be related to the concave shape of the KPEs, and also the angular motion and orientation of the upper leg.

Head Injury Potential

- In 8 out of 8 cases, the trajectory of the dummy's head was lower with leg protectors. This lowered head trajectory was between the time of initial motorcycle impact and primary head impact.

- In 7 out of 8 cases, there was an increase in the resultant head velocity at head primary impact, with leg protectors.
- In 7 out of 8 cases, there was an increase in the peak resultant head acceleration during each crash, with leg protectors.

Overall Injury Severity

- In terms of Total Abbreviated Injury Scale (AIS) scores, leg protectors were found to be beneficial in 2 out of 8 cases; and harmful in 6 out of 8 cases.
- In terms of Maximum AIS, leg protectors were found to be beneficial in 2 out of 8 cases; to have no effect in 2 out of 8 cases; and to be harmful in 4 out of 8 cases.
- In terms of estimated injury costs, leg protectors were found to be beneficial in 3 out of 8 cases; and harmful in 5 out of 8 cases.

Conclusions

The conclusion from these test results is that in various kinds of realistic accident configurations, leg protectors:

- Reduce the number of leg injuries in only certain cases,
- Can lead to increased leg injuries,
- Can lead to increased head injuries,
- Can increase overall injury severity.

In all crash configurations tested, the head trajectory was lowered with LPs. In general, this is ascribed to the restraining action of the Knee Protection Element (RPE) as the upper body moves forward, diagonally to the side, or laterally during impact.

This torso and head pitch behavior appears to be fundamental with this concept of leg protection, and it is not clear how this could be reduced within this general concept.

In addition, the KPE itself was seen to cause direct injury to the leg, due to: upper leg motions and forces occurring during and after impact; lower leg trap causing upper leg and knee bending failure; and downward leg deflection.

For these reasons it is concluded that this general concept of leg protection does not contribute to improved rider protection.

References

1. "Draft Specification: Leg Protection for Riders of Motorcycles," United Kingdom Department of Transport, July 1987, (Amended Jun 1988, Feb 1989).
2. Sakamoto, Shinichi, *Preliminary Evaluation of a Motorcycle Leg Protector Design as Proposed by the United Kingdom Department of Transport*, Japan Automobile Manufacturers Association, Jun 1988.
3. *Comments on the UK Draft Specification for Leg Protection for Riders of Motorcycles*, Dynamic Research, Inc., DRI-TM-88-2, Jan 1988.
4. *Requirements for an ATD for Motorcycle Crash Testing*, Biokinetics and Associates, Ltd., Contract Report R88-11d, Jan 1989.
5. *Development of Frangible Knee and Hip Elements for a Motorcycle ATD (Summary)*, Biokinetics and Associates, Ltd., Contract Report R89-b4, Jan 1989.
6. *Development of Frangible Upper and Lower Leg Elements for Motorcycle ATD*, Dynamic Research, Inc., Technical Memorandum 89-2, Jan 1989.
7. *Summary of Data Acquisition System for Motorcycle ATD*, Dynamic Research, Inc., Technical Memorandum 89-2, Jan 1989.
8. *Development of a Preliminary Crash Test Injury Cost Model*, Biokinetics and Associates, Ltd., Contract Report R89-1C, Mar 1989.
9. *Interim Analysis of Motorcycle/Car Accident Data Bases*, Biokinetics and Associates, Ltd., Contract Report R89 May 1989.
10. *Further Evaluation of Motorcycle Leg Protectors as Proposed in the UK Draft Specification*, International Motorcycle Manufacturers Association, Oct 1989.
11. Chinn, B. P., P. D. Hopes, and Melanie P. Finnis, "Leg Protection and Its Effect on Motorcycle Rider Trajectory," The Twelfth International Conference on Experimental Safety Vehicles, Goteborg, Sweden, May 1989.
12. Danner, M., R. Langwieder, and A. Sporner, "Accidents of Motorcyclists Increase of Safety by Technical Measures on the Basis of Knowledge Derived from Real Accidents," The Tenth International Conference on Experimental Safety Vehicles, Oxford, England, Jul 1985.

S3-W-16

APR Proposals for Child Protection in Cars

Y. Pincemaille, F. Brun-Cassan, P. Caillibot, J-Y. Le Coz
Laboratory of Accidentology and Biomechanics
Associated with Peugeot S.A. and Renault
(APR)
G. Brutel
P.S.A.-Peugeot-Citroen
Laboratory of Automotive Safety

Abstract

Taking into account its knowledge of accidentology and biomechanics, and further to many real and simulated vehicle crashes in different configurations with dummies of different sizes, the APR has been able to combine a certain number of specifications to define the highest performance in child restraint systems.

The objective is to offer the best possible protection as a function of the age of occupant, combined with easy mounting in vehicles.

Introduction

Up until now, FRANCE has had a rather unique position in terms of child safety for a number of reasons:

- on one hand, Child Restraint Systems (CRS) have had to pass specific certification standards since 1975 (which is prior to the ECE regulation)[1] (1);
- on the other hand, there has been no law requiring the use of CRS.

Due to these two facts, actual accident statistics in France indicate that the number of children killed or seriously injured in car accidents is much higher than in other countries. It has been estimated, using data from fatal accidents, that CRS use in France is not more than 14% (2). This situation should change in 1992 when the use of CRS will become mandatory.

Three years ago, French automobile manufacturers asked the Laboratory of Accidentology and Biomechanics to carry out a comparative study of the different existing CRS in order to choose the "best" among them in terms of safety and offer them for sale in their aftersales services.

This study looked at the following:

- dynamic CRS test performance (behavior during crashes);
- how to guarantee good CRS-vehicle compatibility.

Problems encountered made it possible to set the ground work for specifications for each type of CRS based on experimental results, observations made on the scene of accidents, and results from the study of real-world accidents (2). It became apparent during this study that current certification procedures, French as well as European, are insufficient in certain areas.

Dynamic Test Procedures and Results

In order to compare the different CRS, test procedure was developed using a simulated passenger car compartment (Renault 19 mainly as this car is considered representative of mid-range cars used by customers with children). The car body was equipped to copy the standard car interior with its usual seats, safety belts, anchorage points. The body was also set up and cut out to allow the maximum number of camera angles.

To date, 130 tests have been carried out. Figure 1 gives their distribution by CRS type.

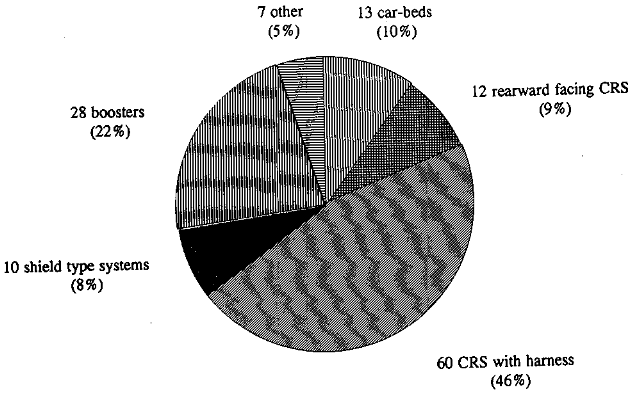


Figure 1. Types of CRS Tested

The CRS tested were for the most part French makes (60%); the remaining tested CRS being of European make.

Test set-up was as follows:

- car body equipped with a back bench seat,
- production safety belts (except in the case of CRS having their own webbing),
- front seats 50 mm forwards of the rearmost position,
- speed of 50 km/h,
- deceleration impulse in accordance with the French Regulation (identical to that set forth in ECE 44),
- FTSS, TNO test dummies (newborn, 9-month old, 3-year old and 6-year old),
- ten cameras (high speed and normal speed filming), several of them in-board in order to give more precise analysis during impact.

Test results will be looked at in this paper, by child weight, based on the child weight categories defined in certification procedures.

---

[1] France is currently in the process of signing the European regulation.

Infants from 0 to 9 kg (ages 0 to 9 months approximately)

Currently only car-beds in which babies lie flat can be sold in France. As soon as the signing of ECE 44 is finalized, rear-facing CRS in which the infant is in a semi-reclining position will be allowed to be sold in France.

Performance during dynamic testing for these two types of CRS was compared using either the TNO newborn size dummy (3.5 kg) or the TNO P-3 /4 dummy (9 kg) which has instrumentation in the chest and at the head's center of gravity. Because the newborn size dummy has no instrumentation in the head, only the kinematics of the dummy in the CRS were analyzed in this case.

According to French legislation a car-bed can be installed in two ways; longitudinally, in line with the direction of vehicle travel, only if it received certification before 1985 or transversally, perpendicular to the direction of vehicle travel. ECE 44 only allows transversal installation. This regulation also allows certification of devices which can be added to a baby carriage or a baby basket in order to anchor them in a vehicle.

Study of the kinematics of a dummy in a longitudinally installed car-bed shows projection against the car-bed extremity, resulting in high loads for head and neck, often head first; the protective netting keeps the infant from being ejected. In the case of a transversally installed car-bed, the infant's entire body moves and the impact loads are distributed over the car-bed side, usually made of fabric.

Of the various problems observed, the following should be noted:

- in the case of a longitudinally installed car-bed, the dummy is thrown in a heap towards the front of the car-bed. In a simulation of possible incorrect use (netting only partially closed), the dummy was partially ejected.
- in the case of a transversally installed car-bed, car-bed collapse was observed. This is due to its attachment points which were designed for anchorage points placed very far back. Because the door side anchorage in the tested vehicle was comparatively forward, slack occurred which resulted in a tendency of the car-bed to leave the seat.

Rearward facing systems generally consist of a plastic shell having supporting sides and inside padding, varying in softness depending on the model. The infant is restrained by a Y-shaped belt (two shoulder straps and one strap between the legs).

During impact, the infant's back is pushed against the CRS back which bends under the force of the seat belt holding it, and upon rebound the CRS turns back to the front seat back.

In Table 1 results allowing a comparison of thoracic accelerations between the two CRS types are given. When the car-bed was correctly used and it remained in place (cases indicated with an *), it was as effective as a rearward facing system. All results for rearward facing CRS were very close and were below the regulation tolerance criteria ($\gamma_v = 30$ g, $\gamma_{r3ms} = 55$ g).

Table 1. Comparison of Results for Test with Cars Beds and Rearward Facing Systems

TEST NUMBER	CONFIGURATION	P 3/4 TNO DUMMY		COMMENTS
		V3ms(g)	R3ms(g)	
CAR BEDS				
2263*	Transverse netting closed	5	57	Car bed certified before 1985
2260	Transverse netting closed	10	80	car bed collapse
2350*	Transverse netting closed	12,5	32	
2358	Transverse 3 point belt	7	80	Additional device for a baby swing - The dummy is partially thrown out of the bed
REARWARD FACING SYSTEMS (Group 0)				
2350	Right front seat	16	45	CRS turns back to the seat
2351	Right front seat	13	45	" "
2352	Right front seat	14	48	" "
2355	Right front seat	17	45	" "
2508	Right front seat	16	43	" "
2356	Right front seat	33	45	CRS does'nt turn back to the seat
2357	Right front seat	31	51	" "

A number of remarks can be made about the characteristics of these two types of CRS. First of all, the majority of car-beds are attached to anchorage points in the vehicles by their own webbing, and mounting is not always easy to do correctly. As well, when a car-bed is installed laterally, which is the only recommended installation position (FRANCE is the only country which allows longitudinal installation), it takes up 2 seats. Lastly, as seen in current literature (4), the risk of injury due to excessive head loading and neck compressive loads is quite high in the case of oblique and side impact.

When there are no space or mounting problems, the car-bed can be very effective with correct usage, in particular, netting correctly closed. This CRS is favoured by the public for long distance trips as it allows the infant to sleep comfortably.

In Europe, rearward facing systems are most often anchored by using the three-point seat belt. However, certain rearward facing systems can be installed using only a 2-point lap belt. Although designed to be installed rearwards, parents do not seem to like to place this CRS facing rearward in the back seat as this means they cannot see their children. Therefore, some parents make the worst possible mistake of installing this CRS facing forwards (4).

These small rearward facing seats, which are attractive and often have diverse uses (i.e. as a baby reclining chair, swing, adapted to a stroller) are not well known to the French public. A lot more information needs to be put out to the public in order to result in generalized use. The quality of this type of CRS is of course dependant on correct usage, in particular correct mounting in the rearward facing position and correct placement of the restraint harness.

Infants from 9 to 1 8 kg (ages 9 months to 3 years approximately)

In France, group B CRS (known as group 1 CRS in Europe) are designed for use by children approximately 9 months to 3 years old and represent the largest part of the CRS market, as well as offering the largest number of different models. In EUROPE, 121 different CRS in this category were counted, 102 of them being forward facing systems, and 19 being rearward facing systems.

Currently only forward facing systems can be found for sale in FRANCE. All these CRS are very similar in design. They consist of a plastic shell equipped with a 4-point harness either assembled into a tubular steel frame or joined to a blown plastic base with a position adjuster mechanism.

These CRS are generally anchored to the vehicle using the vehicle's production seat belt. However, certain models are equipped with their own webbing straps which must be attached to the vehicle's anchorage points. Models using the vehicle's own seat belt are always preferable to those requiring use of vehicle anchorage points as they are the easiest for parents to use.

Approximately 50 tests were carried out on this type of CRS under the same test conditions as described earlier.

In front impact tests, two important observations were made:

- there was frequent impact, with varying degrees of severity, between the head of the dummy and the front seat back or other parts of the vehicle;
- sub-marining occurred in varying degrees.

Head impact resulted from the cumulative effect of the displacements described below:

- The CRS being restrained by the vehicle's 3-point seat belt, in most cases of the inertia-reel type, the webbing strap is released approximately 100 mm during impact before blocking.
- The safety belt holds the CRS frame:
  - when the diagonal strap is used to hold the CRS, either by going through a webbing lock and/or slot designed to keep the diagonal strap at the correct height, it is observed that the CRS moves in the direction of vehicle travel. This forward movement stops when the slack in the webbing is taken up;
  - when the CRS is only held by a lap-belt, observations have shown that in addition to the abovementioned forward movement, there is also a rotation around the horizontal axis formed by the lap-belt.
- As well, the dummy restrained by a harness, usually of the 4-point type, moves head first within the CRS.

In tests carried out, all these cumulative displacements caused head excursion going far beyond the front seat and resulted in head impact with the front seat back, in particular with the stiff part of the front seat back.

The best improvements in safety with this type of CRS would be obtained by improving the way in which the CRS is anchored in the vehicle.

In fact, optimizing restraint with this type of CRS involves certain problems. All the different sources of slack, found in the attachment to the vehicle as well as in the CRS harness, can of course be reduced. However, this results in the only possible movement being that of the child's head and the neck. As the mass of an infant's head is relatively high in comparison to the mass of the rest of his body, the child would be severely, even perhaps fatally, injured due to excessively high loads being applied to the neck vertebrae. More extensive research needs to be carried out on harnesses in order to improve their energy absorbing capabilities and their ability to limit head and neck displacement in comparison to the displacement of the rest of the body.

Harnesses used in this type of CRS usually have 4 webbing straps, but certain CRS have 5 webbing straps (the extra strap going between the legs). There is no doubt that the 5-strap harness is an excellent solution to the problem of submarining. Dummy submarining is often observed when, during impact, the CRS sinks into the bench cushion which then rebounds and causes the CRS to be lifted. When the CRS goes up the dummy slides under the buckle, and the buckle often digs into the abdomen. Many CRS are equipped with an anti-submarining hump which, at the end of impact, is often crushed, indicating that it was involved in restraining the dummy.

Another argument in favor of a 5th strap is the fact that it can help avoid the infant sliding under the harness in normal conditions not involving a collision (when driving or stopped). Cases have been reported of infants being choked in this manner while the vehicle was stopped and the parents were absent for a very short period of time.

Another type of CRS is just beginning to be seen in France[2] although it has been in relatively widespread use for a number of years in other countries such as Germany. This type of CRS consists of a shield type restraint. The infant is restrained by means of a shield which is made of an energy absorbing material. The child and shield restraint device are held by the vehicle's seat belt, either of the 3-point or lap belt type, which goes across the lap at the angle formed by the thighs and body.

The principal behind this type of CRS is that it distributes the loads applied during frontal impact over the thorax, the abdomen, the pelvis and the thighs and it absorbs the energy released during impact. Therefore the advantage is that the infant is restrained uniformly across the thorax and abdomen.

In Table 2 results considered representative of these two types of CRS, harness and shield restraint, are given. In these tests, CRS were anchored using a production seat belt. The dummy used was a French regulation 3-year old size dummy (FTSS).

Table 2. Some Results with Forward Facing CRS: Harness Type and Shield Type

FORWARD FACING CRS (with 3 years F dummy)	HEAD Rmax	THORAX V3ms	THORAX R3ms	HEAD DISPLACEMENT (mm)
4 POINT HARNESS				
2136	119	15	-	672
2430	87	31	49	656
2503	53	21	52	708
2355	133	24	60	548
SHIELD TYPE SYSTEMS				
2502	50,8	14	40	548
2434	85	21	47	464
2433	62	24	43	516

During all of the tests carried out, there was no front seat. A study of the kinematics showed that less head excursion occurred when using shield restraints than forward facing harness systems. Figure 2, which gives results from some of the tests carried out on these two CRS types, illustrates this difference in head excursion. Of the three shield restraints tested, we can see that head excursion is well within the acceptable certification procedure limits (3) for two of them. These two models do not have a seat back meaning the child has his head as far back as possible against the bench seat back. For the third model, head excursion is just within the acceptable limits; this is due to the fact that this third model does not allow the child's head to be as far back as the other two. Only one CRS using a harness had head excursion measurements within the acceptable limit. For this reason we have chosen this model as having the best performance for this type of CRS.

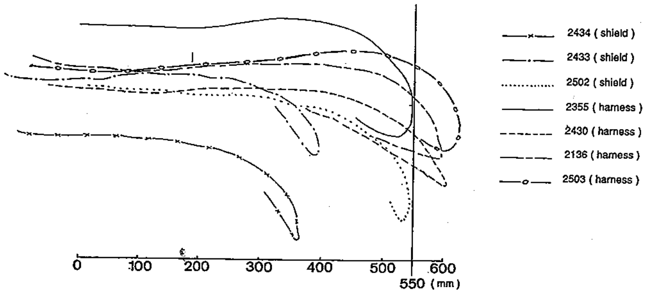


Figure 2. Head Trajectories for Harness and Shield Type CRS

The three other CRS of this type (with harness) for which the results are given correspond to models frequently used in France. Head trajectories measured for these models were far outside the head excursion limits required for certification (550 mm). In all cases the measured head excursions for these models would have resulted, had there been a front seat, in head impact with the seat back.

From acceleration measurements observed in test 2355, where the CRS was well anchored to the car (as per its design), we can note that the resultant acceleration at the head's center of gravity is much higher than in other tests, even though head impact did not occur. This lack of head impact can also be observed in the other tests shown in this table.

In general, the use of shield restraint type CRS results in the lowest head accelerations. As well, they seem to offer better protection than harness CRS even though the risk of neck hyperextension (whiplash) is not completely eliminated.

The first results published indicated that the neck load measurements obtained with the shield restraint CRS are 25% lower than with the harness CRS. As well, thorax acceleration measurements are around 30% lower with the shield restraint CRS (5), a figure confirmed by our study of this CRS type in sled tests using a reproduction of a car interior.

Analysis of harness CRS kinematics indicates a potential risk of very severe injury to the head and neck due to direct impact. As for shield restraint CRS, even if the probability of impact appears reduced, the risk of neck hyperextension still exists. These risks are confirmed by accident survey data looking at such cases (6).

It is also probable that hyperextension is the cause, in certain cases, of instant death. However it is currently impossible to check this hypothesis as it is not possible in France to carry out autopsies on children who die in accidents. Only in a few cases is accident data available and these are not systematically recorded (2).

---

[2] This type of CRS existed approximately 15 years ago in France.

We can therefore conclude that, given the current design of forward facing CRS, optimal protection cannot be guaranteed in the case of frontal impact. The only alternative would be to use backward facing CRS for this age group. This type of CRS for children 9 months old to 3 years old exists mainly in Sweden and to a lesser extent in the rest of EUROPE where it has not yet been fully accepted.

This type of backward facing CRS can be mounted in the front passenger seat with the back of the CRS supported by the dashboard. They are anchored using the vehicle's seat belt as well as additional webbing. However, this additional webbing can often be complicated to mount. Therefore a current study of possible vehicle adaptations is being carried out to find faster and easier ways to mount this webbing correctly.

Another problem found with this sort of CRS is the fact that, due to its dimensions, it is very close to the windshield when in place. A possible solution to this would be to design a backward facing CRS for children 9 months to 2 years old (minimum), as this is the age group which seems the most in danger, which could be mounted in the front passenger seat as well as in the back seat.

For children over 2 years old, we would choose shield type systems given the results earlier discussed.

Children 18 kg and over (approximately 3 years old)

For larger children, from 3 to 10 years old approximately, booster seats are the best solution. They can adapt the child's body structure to the seat belt. However *they must always be used with a 3-point seat belt.*

The boosters are designed to do the following:

- make the seated child higher to ensure that the seat belt crosses the child's body at the appropriate place, in particular the diagonal strap across the shoulder. Certain boosters have a seat back, which increases the level of comfort as well as having two additional functions: the first being to protect taller children's heads and necks in the rebound phase during frontal (or rear) impact and the second being to make it possible to correctly guide the diagonal shoulder belt strap across the thorax using slots designed for this purpose;
- avoid submarining. To do this it is imperative that the booster have side brackets or slots which ensure correct routing of the lap belt. These must ensure that the lap belt crosses at the upper thigh and remains flat. It should not be possible for the lap belt to move up from the pelvis region to the abdomen as this results, in the majority of cases, in submarining which is responsible for very serious abdominal injuries. Certain boosters have armrests which can carry out this function at the same time as they improve the child's comfort.

On a practical level, boosters are not bulky, they are easy to use without needing a lot of instructions. They are, however, currently not very well-known or widely used in France.

Using a booster with a 3-point seat belt leads to kinematics comparable to that of a restrained adult during impact. Head excursion for the child remains low. Table 3 gives test results for different booster models:

- test 2131: booster with armrests
- test 2263: booster with seat belt routing brackets
- test 2137: booster with armrests similar in design to test 2131
- test 2356: booster with back having an adjustable belt routing device at the shoulder level

Table 3. Results for Different Booster Models

TEST NUMBER	CONFIGURATION 3 POINT AUTOMATIC BELT	THORAX V3ms	R3ms	COMMENTS
2131	6 years old dummy	21	65	Booster with armrests
2263	3 years old dummy	29	80	Important sub-marining
2137	6 years old dummy	22	83	Booster with armrest
2356	3 years old dummy	20	47	Booster with armrest

In all of the cases given, except for test 2356 where there was a booster back, resultant thorax acceleration in test conditions was over the regulatory limitation which is 55 g for booster certification. This result was obtained in the majority of our tests with boosters. As there are currently few results available from tests with boosters having a back it is too early to reach any conclusions as to additional effectiveness in terms of thorax accelerations with this booster type.

The fact that the central back seat position is currently only equipped with a 2-point lap belt excludes use of a standard booster. At this time, existing solutions to this problem are the use of shield type restraint systems adapted to the child's size.

CRS Adaptability to Vehicles

Anchorage of the CRS in the Vehicle

The CRS described earlier are all "universal" CRS, which means they all receive certification based on the same criteria and they are all designed to be mounted in all vehicles. Every day actual experience has shown this to be untrue for a number of reasons (8):

Anchorage point positions. The anchorage points used in certification test procedures are much farther back than in most recent cars where these external rear anchorage points have been "moved forward" in order to reduce the risk of submarining for adult occupants of these seats (approximately 170 mm forward, on the average, of certification anchorage points).

Because of this, certain CRS cannot be correctly mounted in cars because slack is added. For example, slack is added because the webbing strap passes in front of the back tubular frame instead of against it. This slack lowers the quality of the CRS anchorage to the vehicle. It is therefore necessary to find a compromise between the certification procedure and actual conditions. The most obvious change would be to make the anchorage points required in certification procedures be based on those found in current vehicles.

CRS to bench interface. Whether the CRS has a tubular or flat base, there is still the problem of positioning it correctly on the bench because of the design particular to each bench. These seats are designed for adult comfort with a flat area in the middle and raised foam-cushion sides or back. The CRS, having a wider central section, is often badly positioned and lacks stability. The ideal solution to this problem would be to have the dimensions of the CRS base be closer to those of the seating space taken up by the 50th percentile adult dummy.

Inertia reel seat belts. The generalized use of inertia-reel seat belts in cars has resulted in slack in CRS mounting. To improve CRS anchorage to the vehicle given this type of seat belt, it could be necessary to find an easy way for the user to block the reel, without possible error.

Head excursion limits. Looking at tests across CRS type, head impact against the front seat back or the front seat head rest was frequently observed. However, French certification procedures, as well as the ECE44 procedures, do not include a limitation on head acceleration. The only criteria is the maximum forward head excursion which is required to be within a specific area (550 mm measured from the cushion intersection). Yet a study, which looked at the distance between the back seat cushion and the front seat back placed in the comfort position, (50 mm forward of the rearmost position) in the majority of French vehicles, showed that this distance is almost always inferior to the 550 mm set for certification procedures. Figure 3 shows the distances measured in this study compared to the maximum distance permitted in the certification procedure. Of all the vehicles looked at, only one has a possible head excursion distance superior to the authorized 550 mm. Therefore, this regulatory distance needs to be reconsidered in order to minimize the risk of head impact in cars.

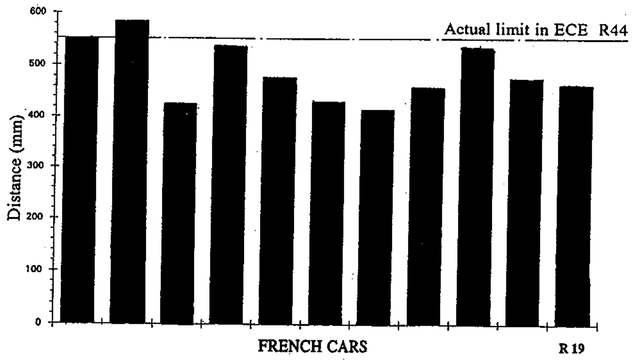


Figure 3. Distance Between the Back Seat and Front Seat in Most French Cars

These different observations illustrate that the protection offered by certified CRS is dependent upon the vehicle in which they are mounted, while certification procedures make no difference between them but rather class them as "universal".

CRS Mounting and Misuse

Having looked at the technical difficulties in mounting CRS in a vehicle due to the inadequate certification procedures when compared to actual vehicle conditions, we would now like to examine other outside factors which can reduce, sometimes even reverse, actual protection performance.

Mounting the CRS in the car usually falls to the parents who try to follow the instructions given by the manufacturer. However, the more complicated the mounting instructions, the higher the risk of misuse. It is of course difficult to imagine beforehand all the possible mistakes in mounting which can be made for any given CRS. Our work consists of emphasizing the mistakes that must not be made. This is of such importance that it is considered a high priority task of the ISO working group on child restraint systems (ISO/TC22/SC12/WG1).

During our study it was often noted that the CRS offering the highest performance were those that were the easiest to mount (except for group I, backward facing CRS). From one vehicle to another there can be very different CRS installation situations, and in certain cases these situations can be very impractical. For example, in a two-door vehicle, handling and placing the infant in the CRS is often annoying and troublesome.

Even for certain CRS considered as being highly performant, specific situations can exist in which the CRS can be misused. For example, with boosters which must always be used with a 3-point seat belt, it can happen that the child easily disengages himself from the shoulder strap, putting it behind his back, thereby ending up only restrained by a lap belt. As well, care must be taken to ensure that the seat belt clasp disengagement button at the bench level be facing away from the booster so that it does not come undone whenever the child moves. In order to limit as much as possible the risk of misuse, it is indispensable to provide clear instructions. Instructions for use should be permanently written on the CRS without possible erasure. They should be clearly written, always visible, and easy to understand in the language of the country where they are sold.

CRS design should not allow more than one possible way of mounting the system. For example, small rearward facing restraint systems should not be able to be mounted facing forwards.

There is still a lot of work to be done in this field. More work needs to be done on actual conditions of use in order to evaluate the extent of this misuse problem and to record actual misuse (9). Based on this criteria, CRS could be evaluated before being put on the market and those which have a risk of being misused can be refused certification. In fact, possibility of misuse, which is currently not taken into account in certification procedures, could become a criteria like any other (10).

In conclusion, we would like to stress the importance of informing parents of the correct way to use the CRS they choose. This means not only informing them how to fasten their child into the CRS at the start, but also informing them of the special need to check throughout a car journey that the child has not disengaged himself from the straps.

Discussion and Conclusion

Based on the dynamic tests of frontal impact and the evaluation of CRS adaptability to vehicles discussed above, the APR has chosen a number of criteria which it considers necessary and indispensable to CRS effectiveness:

- an effective protection in dynamic testing
- an easy, clear mounting and good adaptation to the vehicle
- an acceptable level of comfort for the child

These criteria must be applied to CRS for all age categories.

For infants, around 0 to 9 months old, small rearward facing CRS seem to satisfy the above criteria best. These CRS must consist of a "shell" with supporting sides, on a base which can be adapted to fit a vehicle's seat bottom cushion perfectly. The addition of padding inside the shell supports the infant laterally, in particular the infant's head. The back surface should be at an angle of 25 to 45 degrees from vertical when the CRS is mounted in the vehicle in order to ensure maximum comfort. The infant should be restrained by a Y-shaped harness with two shoulder straps and one strap between the legs. The harness buckle should have a clasp disengagement button which is easily accessible and preferably on the upper face of the buckle to avoid any untimely opening of the harness, such openings having been observed when this device was on the side of the buckle. This type of CRS must be anchored in the vehicle using a production seat belt (2-point or 3-point).

For children from 9 months to 2 years old, we recommend a type of CRS which does not exist at the present time. This CRS would also be rearward facing but larger to be adapted to the weight and size of the child. It would be anchored in the vehicle by means of a production seat belt. However, if this proved to be insufficient to ensure adequate restraint, additional webbing straps or any other additional device would be acceptable as long as it is easy to install in current vehicles. Such a CRS should be able to be mounted in front as well as rear seats.

For children 2 to 3 (or 4) years old, a shield type system is recommended as currently they give better kinematic results as well as obtaining more acceptable injury criteria than forward facing harness restraint systems.

From 3 (or 4) years old and up, boosters used in conjunction with a 3-point seat belt are currently considered the best solution. They lift the child up when seated so that the car seat belt fits better. Moreover it is necessary to guarantee that booster type CRS be correctly designed to avoid submarining and to ensure that the shoulder strap crosses the child's thorax correctly.

These recommendations should provide more effective protection, while at the same time offering more comfort and providing a CRS which will be accepted and which takes into account children morphological and psychological changes.

The research carried out for this paper was limited to evaluating CRS performance in frontal impact tests. A few side impact tests without intrusion were carried out, but this test configuration is not very representative of actual side impact conditions. To look more completely at the protection provided by different types of CRS would require complementary work including simulations of side impacts and rollovers in order to take into account the often complex configurations found in actual accidents. Another necessary development in the field of child safety is the improvement of dummy instrumentation and biofidelity.

In France, a lot still remains to be done in order to improve CRS design as well as how they fit into the vehicle. There is also the need to greatly increase the availability and distribution of information to parents about the use of the different CRS types best adapted to their child's age. A concerted effort on the part of public authorities, CRS manufacturers, car manufacturers, consumer organizations, the medical profession, parents and all those concerned must take place for France no longer holds the sad record of having the highest number of children killed in car accidents.

References

1. Règlementation Française. Arrête du 11 juin 1985 relatif au transport des enfants dans les voitures particulières (texte n°875).
2. Vallee H., Cailleret M.C., "Children involved in Fatal Car Crashes," 13th International Technical Conference on Experimental Safety Vehicles, Paris, France 1991.
3. United Nations Agreement Regulation n°44.
4. Weber, M.A, "Comparison of car-bed and rear-facing infant restraint systems," 12th International Technical Conference on Experimental Safety Vehicles, Goteborg, Sweden 1989.

5. Langwieder K., Hummel Th., Huk-Verband, "Injury risks of Children in cars- Epidemiology and Effect of Child Restraint Systems" 23th Fisita, Torino, Italy 1990.
6. ISO Document. July 1991 ISO TC22/SC12/WG1 N227.
7. Langwieder K., Hummel Th., "Children in cars—Their injury risks and the influence of child protection systems," 12th International Technical Conference on Experimental Safety Vehicles, Goteborg, Sweden, 1989.
8. "Considerations regarding the development of Regulation n°44" Transmitted by the Experts from France, Meeting of Experts on Passive Safety (Tenth session—Sept.91 TRANS/SC1/WP29/GRSP/R72).
9. Czernakowski W., Muller M., "Misuse Mode and Effects Analysis (MMEA) An Approach to predict and quantify Misuse of Child Restraint Systems," 35th Annual A.A.A.M. Conference, Toronto, Canada, October 1991.
10. Bell R., "Misuse Test Panels. A Technique for the identification and Prevention of misuse of child restraints," 35th Annual A.A.A.M. Conference, Toronto, Canada, October 1991.

S3-W-18

Initial Conclusions of an International Task Force on Child Restraining Systems

C. Tarrière, X. Trosseille
Département des Sciences de l'Environnement, Renault
G. Carlsson
Volvo Car Corporation

Abstract

Eighteen experts from 13 teams and 7 countries are joining their efforts:

- to gather and analyze together the maximum number of accident cases where restrained children are involved,
- to select the most useful cases for experimental reconstructions:
  - to check and quantify certain mechanisms,
  - to increase knowledge of child tolerance to impact through linkage of parameters recorded with the injuries (or lack thereof) in real life accidents.

The paper describes the work already done, presents the program going on and the first available conclusions.

Introduction

Our knowledge of child safety has increased only slightly with advances in biomechanics over the last two decades, made possible by the donation of body organs for scientific research. There are still many unknowns with respect to impact tolerance, in terms of injury mechanisms and even more so in terms of the behavior of restraining systems, of which there are a large variety of types, of varying quality.

In these circumstances, the best way to improve our knowledge was to perform case-by-case analysis of real-world accidents involving children wearing a specific restraining system. This meant compiling a sufficient number of case studies to cover the various questions involved, with for each configuration a sufficiently large sample to avoid bias due to anecdotal defects and allow a truly statistical approach to the problem.

To meet these requirements of sample diversity and size, numerous teams of accident researchers had to pool their efforts and work out jointly the conditions of free and open cooperation. This ideal scenario has been in operation since May 1990, with 18 experts (see below) from seven different countries taking part.

But by taking the initiative of inviting the experts to carry out this essential task, Renault proposed enhancing this scenario with a set of experiments. The aim is to obtain reconstructions of certain selected accidents so as to establish correlations between the measurements taken on child dummies and the injuries observed or not on the road.

This experimental programme allows us to verify the injury mechanisms suggested by accident research and especially to quantify them in terms of forces, accelerations, and physical stress levels at which injuries occur. In this way, we can develop a real knowledge of child crash tolerance with age. This fundamental research is under way, with an initial selection of five crash cases for reconstruction. The five reconstructions should lead to five series of simulations in which each case could be reproduced by mathematical modelling and by dynamic sled tests.

The aim of this paper is to describe briefly yet thoroughly the essential aspects of the work already performed by this group of highly dedicated experts, who form an international action group working for a rapid, significant improvement in the conditions in which children can and must be protected in vehicles.

Two years after the launching of an initiative to improve as quickly as possible the quality of child protection in cars, the time has come to sum up and publish the first set of available conclusions for use by the international community.

Before setting out these conclusions, it is worth describing the human and methodological environment of the work already performed, in order to make the results easier to understand.

The Starting Point

In the spring of 1989 Renault conducted a communication programme at Lardy, its Safety Research Centre near Paris. Every day for a full week, about 150 people from the public responded to the invitation of Renault through radio broadcasts and newspapers to visit the Test Centre and view an educational show on automotive safety. The purpose of this programme was to enable the public at large concerned with this subject to better understand certain fundamental laws governing impacts and consequently protective measures.

Every day, a 30° barrier test at 35 mph (56 km/h) with fully instrumented dummies was performed for the audience, accompanied by the relevant comments. After the impact, a lively discussion took place for more than an hour. One of the questions most frequently asked was: "What is done to effectively protect child passengers?"

Renault was thus stimulated to continue its efforts to improve automotive safety and to inform the public about this subject, focussing on protection of child passengers.

Throughout the following year, this itinerant show was displayed in major French cities with a booth devoted entirely to child-rider protection means from birth to adulthood.

In order to conduct this work in a serious and orderly manner and to be able to recommend the most effective means of protection, it was necessary to evaluate the various systems available on the marketplace throughout the world. This evaluation must be based on accident research data obtained from various independent researchers brought together specially in a Task Force to review, case by case, accidents involving protection of child passengers.

At each meeting of this Task Force, lasting a whole week if necessary, these cases would be presented, analyzed, and discussed one by one by the group of experts to endeavor to reach a common conclusion and to obtain general knowledge useful for the international community.

The Goals to Achieve

1) From a global sampling consisting of several hundred cases, light would be shed on:

- the most effective Child Restraint Systems (CRS),
- the most serious flaws of these CRS resulting in injuries.

Recommendations could then be made to:

- provide information concerning the best available CRS and specify the limits of use in terms of age, position in the car and type of fastening to the car,
- design better CRS,
- suggest to manufacturers of such CRS the necessary improvements, not only related to the crash performance but also in terms of usage convenience to increase the comfort and avoid the misuse.
- recommend certain specific modifications to be incorporated in the vehicles for improved installation of CRS.

2) The task force would select the accidents yielding the most information to be reconstructed (with mathematical modeling and experimental testing with dummies):

- to check and quantify certain mechanisms,
- to gain greater knowledge of child tolerance to impact through correlation of parameters recorded with the injuries (or lack thereof) in real-life accidents.

This is surely the most appropriate way to move forward in this very difficult field.

3) Biomechanical developments will of course lead to the discovery of child-dummy shortcomings, and consequently to improvements.

4) To make sure that the regulations, whatever they are, concerning child safety not diverge from reality and to suggest changes in accordance with the improvement of dummy design, the development of transducers and the establishment of reliable biomechanical criteria.

The Spirit of Cooperation

Renault has therefore taken this initiative to meet public demand. This initiative would clearly require:

- fully independent research partners,
- each participant retaining complete control of the data generated by it,
- any possible developments remaining strictly voluntary.

There was also the hope that Renault's suggestion would be considered favorably in view of the great human value of the project.

The criteria for inviting the participants was clear and simple: "ability to provide for the other partners a sample of accident cases involving child restraint systems and readiness to submit them for collective analysis by the Task Force experts."

Of the 14 experts invited, nine gave an immediate and enthusiastic answer. Other answers were received later in 1991. Still others gave a negative answer. Overall, 18 experts have already made a contribution to the Task Force.

These are the names of these experts and of their organizations:

BIARD, Roger, Laboratoire des Chocs et de Biomécanique. Institut National de Recherche sur les Transports et leur Sécurité (INRETS), France.

BURLEIGH, David, Director Technical Services. Britax Childcare Products, Great Britain.
CARLSSON, Gerd, Volvo Crash Safety Centre, Traffic Accident Research, Volvo Car Corporation, Sweden.
CASSAN, Françoise, Laboratoire d'Accidentologie et de Biomécanique Peugeot S.A./Renault, France.
DALMOTAS, Dainius, Transport Canada, Place de Ville, Ottawa, Canada.
GRIFFITHS, Michael, Road Safety Bureau (Crashlab), Roads and Traffic Authority, Australia.
HENDRICK, Brian, Senior Collision Investigator, Transport Canada, Place de Ville, Ottawa, Canada.
MacLEAN, John, NHMRC Road Accident Research Unit, The University of Adelaide, Australia.
MELVIN, John, GM Research Laboratories, General Motors, USA.
LANGWIEDER, Klaus, Head of Department for Automotive Engineering and Accident Research, German Association of Third-Party Liability, Accident and Motor Traffic Insurers (HUK-VERBAND), Germany.
OTTE, Dietmar, Accident Research Unit, Medical University Hannover, Germany.
PEDDER, Jocelyn, Biokinetics and Associates Ltd., Canada.
TARRIERE, Claude, Department des Sciences de l'Environnement de Renault, Renault, Direction des Etudes, France.
TINGVAL, Claes, Folksam Insurance Company, Sweden.
THOMAS, Christian, Laboratoire d'Accidentologie et de Biomécanique Peugeot S.A./Renault, France.
TROSSEILLE, Xavier, Department des Sciences de l'Environnement de Renault, Renault, Direction des Etudes, France.
TURBELL, Thomas, Chief Engineer, Biomechanics, VTI, Swedish Road and Traffic Research Institute.
WEBER, Kathleen, Director, Child Passenger Protection Research Program, University of Michigan Medical School, USA.

The number of partners could be slightly increased for the second step, involving reconstructions of experimental accident cases.

The Results of the First Two Years

- *Initial Proposal*: October 5, 1989.
- *Meetings*:
  - First Meeting: April 30 to May 4, 1990 - Paris, France.
  - Second Meeting: July 5, 1990 - Munich, Germany.
  - Third Meeting: September 9-10-11, 1990 - Lyons, France.
  - Fourth Meeting: November 6, 1990 - Orlando, USA.
  - Fifth Meeting: February 28, 1991 - Berlin, Germany.
  - Sixth Meeting: April 22-23-24, 1991 - Paris, France.
- *Sample Collected*:

The size of the samples collected varies greatly from one expert to another. Some have only about ten cases, which are sometimes very interesting, while others have several hundred cases. It was not possible to analyze all the cases, for want of time.

Only those cases relating to topics considered by the group to be of greatest importance were studied in detail. Among these, for instance, eleven cases were identified in which children suffered neck injuries while apparently properly restrained in forward facing child restraints (table 1).

Table 1. Case for Accident Reconstruction Involving Three Children Sustaining Reversible Injuries in a Very Severe Frontal Crash

Participants	C. THOMAS			K. LANGWIEDER			
Case Reference	9172 1	7484 2	9227 3 D	52590 1	50733 2 B	51128 3	53217 4
Type of collision	Frontal	Frontal	Frontal	Frontal	Frontal	Frontal	Frontal
ΔV km/h	50-60	40-45	60-65	40-45	35-40	40	45-50
O'clock direction	2	10	12	11	10	12	10
Child, age, sex	7m, m	18m, f	6m, m	12 m, f	10m, f	10m, f	9m, m
Seat position	central rear	central rear	right rear	left rear	right rear	central rear	left rear
Type of C.R.S.	bébé confort	Baby Relax Mustang	Pullman bébé confort	Storq Mühle	Storq Mühle Prestige	Gabel Safety	Storq Mühle
Type of harness	4 pt	4 pt	4 pt	4 pt	4 pt	4 pt	4 pt
C.R.S. attachment	lap belt	lap belt	3 pt belt	3 pt belt	lap belt	lap belt	lap belt
Head contact	prob. no	?	prob. no	no	possible	possible	no
Fracture and injury to the spine	no fracture Nerv.medulla C7/T1	no fracture C2 hematoma	no fracture vascular inj. C7/T1	C1/C2	C1/C2	no fracture	C1/C2 lux.
Occurrence of submarining	?	prob. no	no	no	no	no	possible
Other injuries	f. ribs + clavicle	medulla rupture at T3	no	no	brain oedema Cut Jaw	cereb. com. fract. Jaw rib fractures	liver rupture
Consequence of injuries	Paraplegia		Tetraplegia	Tetraplegia below C7	Tetraplegia	Tetraplegia below C5/C6	Tetraplegia Death (25 days)
Highest M. AIS recorded among adult occupant (s)	1	2	2	?	?	?	?

Note : The letters A, B, C, D indicates the first cases selected for reconstruction.

Participants	D. OTTE	K. WEBER		HENDRICK	SUMMARY
Case Reference	N° 8 1 C	UP3 1	UP4 2	N° 3 1 A	
Type of collision	Frontal	Frontal	Frontal	Frontal	Frontal
ΔV km/h	40	< 25 km/h	45-50 km/h	50-60 km/h	> 30
O'clock direction	12	12	11	01	2 - 10
Child, age, sex	23m, f	23m, f	9m, m	6m, f	7-23 months more female
Seat position	left rear	left rear	left rear	left rear	
Type of C.R.S.	Renolux	Boddy Mac 2-in-1	Cosco Commuter	Strollee	
Type of harness	4 pt	5 pt	5 pt	5 pt	harness
C.R.S. attachment	3 pt belt	lap belt	lap belt	lap belt	
Head contact	yes probably	possible on shield	possible	possible	possible
Fracture and injury to the spine	C1/C2 Odontoïde (Dens fracture)	Type II Odontoïde fracture C2	Atlanto-occ. dislocation C1	Contusion at T2 level	C1/C2
Occurrence of submarining	no	no	no	no	
Other injuries	no			no	
Consequence of injuries	Short duration of hospitalisation	Neur. intact after hospitalisation	Death 24 hours	Paraplegia	
Highest M. AIS recorded among adult occupant (s)	1	4	6	6	

Out of all documented cases only 14 cases could be found, in which children suffered cervical spine injury. For each of these cases the detailed description of accident situation, collision angles, impact positions and occupant kinematics were discussed in the group of experts. Common influence factors were examined (see last column of table 1).

As the result of the accident research team Hannover (Otte, D. et al: Erhebungen am Unfallort, Unfall- und Sicherheitsforschung, Heft 37, Bundesanstalt f. Strassenwesen, Bergisch-Gladbach 1982), the percentage of cervical spine injuries in accidents is estimated to be lower than 1 per thousand, of all restrained children in CRS.

- *Cases Selected for Experimental Reconstructions*:

  Five cases have already been selected for Experimental Reconstruction with child dummies:
  - 4 cases to better understand the mechanism of neck injuries for young children below the age of two involved in a frontal impact (Table 1, cases A-D).
  - 1 easy-to-reconstruct case (barrier crash) where, despite a very high severity (V = 70 km/h), three children were involved with fully reversible injuries (table 2).

Table 2. Case for Accident Reconstruction Involving Three Children Sustaining Reversible Injuries in a Very Severe Frontal Crash

Cases	Ref. N° 1		
Type of collision	FRONTAL		
Vehicle / Vehicle	VOLVO 245 / CONCRETE BARRIER		
ΔV or EES km/h	70 km / h		
Child : age, sex	6 months - male 8.5 kg - 68 cm	4 years - female 19 kg - 107 cm .	6 years - female 24 kg - 120 cm
Seat position	right front	right rear	left rear
Type of C.R.S.	infant seat AKTA Loveseat reward facing	booster AKTA DUO	booster VOLVO
Type of C.R.S. attachment to the vehicle	3 point belt	3 point belt	3 point belt
Injuries			
Dead (on site/later)	no	no	no
Neck	no	no	no
Head/face	bruises left temporal suspected skull fracture AIS = 2	concussion AIS = 3	suspected concussion AIS = 2 laceration back head
Abdomen	no		
Lower members or	left femur infraction	no	no
pelvis	bruises left leg	no	no
Others		no	no
Comments	Leaves hospital after few days.	Optical damage on the left eye. Full recovery one month after.	Laceration on the back of the head probably caused by impact against a luggage on the back of the car.

It must be specified that for the Task Force, the proper reconstruction with the car involved in the accident, to allow a comparison between the test conditions (configuration, speed, acceleration) and real-life accident conditions and to check similarities, is only one step in the work programme. After each reconstruction, a set of sled tests will be performed, reproducing the same deceleration pulse and speed, so as to extend the scope of the work:

- comparison of the effectiveness of other CRS systems with that involved in the real case,
- comparison between different ways of using the same CRS:
  - same as in the real accident case,
  - with or without the tether strap,
  - forward-facing versus rearward.

It will also be possible to introduce variations in impact parameters (speed, deceleration), to observe their influence on the performance of the CRS.

The implementation of such a programme will be speeded up by cooperation between the different laboratories involved in the Task Force.

These laboratories are as follows:

- INRETS (Institut National de Recherche sur les Transports et leur Sécurité) - France.
- RENAULT - France.
- ROADS AND TRAFFIC AUTHORITY - Australia.
- TRANSPORT CANADA - Canada.
- UNIVERSITY OF MICHIGAN - USA.
- VOLVO - Sweden.

More recently, the Berlin Technical University, in conjunction with Volkswagen, has given favourable consideration to the reconstruction of a case.

Two experimental studies have already been conducted:

- a comparison of U.S. shield-boosters with the European system called "Römer-Peggy," which has excellent effectiveness in crashes (work performed by University of Michigan, Child Passenger Protection Research Program).
- an evaluation of the effect of a tether strap as used in Australia for the forward-facing CRS (work performed by Renault).

The results show that the incorporation of a tether strap improves the effectiveness of the CRS, reducing head excursion and neck loads. This tends to justify the Australian method which shows that, thanks to the tether strap, there is no neck injury in the national accident-research sample of young children using the CRS in forward-facing configuration.

Conclusions

An Initial Set of Five Conclusions

Conclusion 1: Concerning the Risk of Neck Injury for Children Under Age Two

It is on the basis of eleven cases of frontal crashes (Table 1), most of which are under 50 km/h and in which many of the adults seated on the front seat suffered reversible injuries, that the first conclusion was drawn.

We should emphasize that in these cases, only conventional child restraints with 4 and 5-point harnesses were used in the forward-facing configuration on rear seats (left, right or centre rear). Of course, it should not be forgotten that these eleven tragic cases are taken from thousands of cases of children using such a restraint system in Europe and North America and involved in accidents without neck injury. However, the experts of the task force, convinced that neck vulnerability is specific to the youngest children and that existing countermeasures are likely to overcome the risk, WANT

TO INFORM ALL INTERESTED PARTIES ABOUT THE PROBLEM AND ITS SOLUTION. This is the purpose of Conclusion One:

"Case studies of accidents in Europe and North America involving vertebral fractures and spinal cord injuries in the cervical region indicate a risk of severe neck injury among children less than 2 years old in some forward-facing harness restraint configurations. There are, however, no such cases in Australian crash experience, where forward-facing child restraints with 6-point harnesses are regularly anchored with a top tether strap, and such injuries have also not occurred in North America in severe crashes where a top tether was used with a 5-point harness restraint. There are also no known cases of such injuries for this age group in rearward-facing child restraints in several countries.

It is difficult to determine in all forward-facing neck-injury cases whether there was head contact when the neck was flexing and in tension. Top tether straps would reduce the likelihood of such head contact and may provide neck protection in other ways as well. Rearward-facing restraints would also reduce the likelihood of severe neck flexion and tension, whether installed in the front or the rear vehicle seat.

Although it is recognized that the rear passenger compartment poses a lower risk of injury to vehicle occupants than the front, experience in Sweden and North America indicates that rearward-facing restraints installed in the front seat provide effective child occupant protection and that the use of this location may be necessary for monitoring small children and for restraint system fit. The limits of effectiveness of rearward-facing systems in front seats were also observed in (1) one case of an asymmetrical frontal collision of high severity with intrusion to the passenger compartment on the side of the child, and (2) one case where rear-seat passengers were unrestrained and thrown directly against the child. (Even in Sweden, the rate of rear-seat belt use is less than 60%).

Further research is needed to determine the effect of top tether straps, in combination with 5- or 6-point harnesses, on the prevention of child neck injury. However, these straps are currently known to improve overall child restraint performance, and their use should be encouraged. In addition, the development and use of rearward-facing restraints should be encouraged for children up to 2 years old, and their use should be allowed in either the front or the rear seat."

Conclusion 2: Concerning the Discrepancies Between the Results in Certification Testing and Evaluation Testing in a Real Car Environment

This conclusion is based on the diminished effectiveness of many Child Restraint Systems observed in crash tests with actual vehicles as compared with the acceptable behaviour required by the certification tests. This is especially true in EUROPEAN countries.

This conclusion is an invitation to the European manufacturers to define new specifications for the testing procedure:

"ECE Reg 44 and similar standards simulate compliance procedures that do not represent current world conditions. Bench stiffness is believed to mask inadequate CRS design. Cushion stiffness and anchorage geometry must be reviewed by ACEA so that the testing environment may be updated to reflect current vehicle design. Belt tension limits must also be reviewed and defined."

Conclusion 3: Concerning the Use of a Lap-only Belt When No Other Child Restraint is Available in a Car

This conclusion was the most controversial. It is clearly demonstrated that, in frontal crashes, children aged 3 years and over, and also adults, are exposed to a direct head impact against the back of the front seats when using this restraint. But it is also true that the protection is acceptable in the other crash configurations, especially to prevent ejection from the car. So it remains questionable for some experts, although not for others, whether it is justified or not to recommend the wearing of this lap-only belt when nothing else is available in the car to protect a child of any age.

After lengthy discussions, carried on from letter to letter and from meeting to meeting, it was concluded that, as a whole, it is better to recommend the use of this restraint if nothing else is available.

Hopefully, in the future, this problem will be more and more restricted to the center rear seat only for a large majority of cars:

"A lap-only belt is not an optimal child restraint system. However, a lap belt can be effective in many cases, especially in preventing ejection, and it should be used if no other restraint is available. Lap-only belts may allow head, neck and lower torso injury, with and without impact with other parts of the vehicle interior. More effective restraints than lap belts should be used by all child occupants in the center rear positions."

Conclusion 4. Concerning the Shield and Table-Shield Child Restraint Systems

Some experts, including the author of this paper, thought it was a strange idea to put a large pad in front of the abdomen to restrain the child through its weaker body segment. In reality, the situation is different: this large, deformable shield not only faces the abdomen but makes firm contact with stiffer body segments such as the thorax, pelvis and thighs (figure 1). There is a good load distribution. This, moreover, explains the excellent effectiveness of such CRS's observed in Germany, where they are very popular.

In the Task Force, actual accidents take priority over *a priori* or theoretical ideas. So the CRS's called ROMER-PEGGY and ROMER VARIO, the effectiveness of which is clearly supported by the cases analyzed, are

Figure 1. "Table-Shield" Child Restraint System for Children Between 2 and 4 Years Old (installation with 3 points or 2 points safety belt)

strongly recommended provided that the age limits specific to each of them be complied with:

"A well-designed "table-shield" child restraint system appears to offer effective crash protection, especially as a complement to the lap-only belt. However, two limitations on the usage of this type of system, in relation to child age, have been observed in road accidents. For children under 2 years, there is a risk of ejection from the CRS, especially in a rollover. For children over the age recommended by the CRS manufacturer, the risk of sustaining a direct head impact against the front seat back increases with the length of the child's torso. Even so, in seating positions equipped with only a lap belt, this "table-shield" CRS could be specially recommended for use, but, for children under 3 years, a rear-facing CRS may be a better alternative."

Conclusion 5. Concerning a Very Effective CRS—The Well-designed Boosters—Used Only as a Complement to a Three-Point Belt

This type of CRS, light, requiring little space for use as a restraint or for storage in the trunk, and very easy to use, is an excellent device but must be used only as a complement to a three-point belt.

The only restriction is the risk of serious misuse, when the child puts the shoulder strap behind his torso. The consequence is the use of the booster as a complement to the remaining lap-belt, with a high risk of direct head impact against the back of the front seat in the event of a frontal crash. Some fatalities have been reported by the Task Force:

"A well-designed booster cushion is an excellent child restraint device in combination with the 3-point belt." The risk of submarining due to poor lap belt placement is greater for a child than for an adult, and a critical feature of good booster design is properly placed guides to keep the lap belt flat on the thighs of the child.

The booster/3-point-belt CRS can be used from age 2 or 3 until the child's body is large enough to be compatible with the 3-point belt alone. The limitation for younger children is a lack of sleeping comfort, and for older children a lack of rear-head/neck restraint as the child's head rises above the top of the vehicle seatback. Boosters having a back structure with side support and a headrest provide an increased level of comfort and rear impact protection.

Important remark

These five conclusions were unanimously endorsed by the experts of the Task Force.

Future Activities of the Task Force

1. The first and essential goal, defined as ongoing case-to-case analysis of crashes in which children wearing a specific restraint are involved, could last for some months or years. The interest of this activity is to discover some new features provided by innovative CRS's. For the sake of example, it would be valuable to ascertain the comparative effectiveness of universal (add-on) and integrated (built-in) CRS's. The latter have just been brought onto the market, first by Volvo in 1990, then Chrysler in 1991 and Renault in early 1992.
2. The second goal will be more demanding. It centres around experimental reconstruction and simulations, and will require a lot of work and money. Since it deals with basic, essential questions relating to child injury mechanisms and biomechanical tolerance according to age, in the range from birth to 10 years old, it justifies some help from governmental agencies. A project is being prepared along these lines by the Berlin Technical University and the Task Force, for submission to the European Community and other governmental agencies.

So the Work Goes On ...

Probably, the second set of conclusions will be based more on experimental findings. The main drawback at present is the lack of well-instrumented, biomechanically realistic child dummies. Technical work carried out in Europe and North America is centred on improvements to the existing dummies, or the development of new composite dummies Table 3 gives current status of available dummies and related instrumentation.

Table 3. Status of available Dummies and Related Instrumentation

DUMMY (Make)	AGE	WEIGHT (kg)	INSTRUMENTATION		COMMENTS Improvements
			Prescribed	Possible	
HUMANETICS (FTSS)	6 months	8	-	-	
HUMANETICS (FTSS)	3 years	15	- 3 γ thorax	- 3 γ head - 3 γ pelvis	
HUMANETICS (FTSS)	6 years	21	- 3 γ thorax	- 3 γ head - 3 γ pelvis	
AIR BAG (OOP)	3 years	15	-	- 4 γ head - 3 F, 3M neck - 3 x 1 γ sternum - 2 x 3 γ spine	OOP : Out Of Position
CRABI	3 years	15	-	- 4 γ head - 3 F, 3 M neck - 3 γ thorax - 3 γ pelvis	CRABI dummy is standard HUMANETICS 3 years dummy with head and neck of OOP dummy. (Adaptation under study)*

* There is a problem with the "original" head which rang badly and should no more be used. This head has been replaced, by NHTSA, with a fiberglass skull/rubber skinned head with unknown and somewhat disputed "ringing" properties. Some modifications are under study. The SAE Infant Dummy Task Group agreed that when the work is finished, everyone should be using one head/neck assembly for all 3-years old dummy testing, which will mean a petition for reconsideration to NHTSA.

DUMMY (Make)	AGE	WEIGHT (kg)	INSTRUMENTATION		COMMENTS Improvements
			Prescribed	Possible	
P0 (TNO)	New born	3.4	-	-	
P3/4 (TNO)	9 months	9	- 3 γ thorax - Absence of abdominal penetration	- 3 γ head - 3 γ pelvis	Under development : neck cell load (Fx, Fz, My) and 1 γ on skull cap. To be presented at next ESV**
P3 (TNO)	3 years	15	- 3 γ thorax - Absence of abdominal penetration	- 3 γ head - 3 γ pelvis	**
P6 (TNO)	6 years	22	- 3 γ thorax - Absence of abdominal penetration	- 3 γ head - 3 γ pelvis	
P10 (TNO)	10 years	32	- 3 γ thorax - Absence of abdominal penetration	- 3 γ head - 3 γ pelvis	

** Development of a two component sensor for abdominal loadings. It allows to ascertain the force transferred in the abdominal region to the lumbar section of the spine as the X component and the force transferred in the abdominal region to the diaphragm as the Z component.

Acknowledgments

Because none of this work would have been possible without the great dedication of the experts involved, it is of prime importance to thank very sincerely each of them and the organization behind them.

In a world which is too often rigidly organized, such informal and open cooperation is a very simulating example of our ability to carry out such an ambitious program, in order to advance our knowledge about child safety.

S3-W-20

Wheelchair and Occupant Restraint System For Use In Buses

Jan Petzäll
Chalmers University of Technology

Abstract

This paper presents the results of experimental studies on wheelchair and occupant restraint systems. The experiments were carried out using a mock-up wheelchair place complete with a three-point seat belt and four restraint straps for the wheelchair. The mock-up was tested both in the laboratory and in a minibus during normal travel. The anchor points of the seat belt could be varied and the loads in the restraint system could be measured with load cells. Impact tests were carried out to determine the loads generated and the safety risks the wheelchair could cause. The restraint system consisted of a three-point seat belt and two restraint straps directed backward to secure the wheelchair to a support wall behind the wheelchair. The tests were carried out at speeds and retardations of 30 km/h, 10 g and 50 km/h, 20 g. The forces in the restraint system were measured with load cells. The speed and retardation were measured and the tests were filmed with a high-speed camera. The results obtained form the basis for the Swedish regulations on wheelchair and occupant restraint systems. Performance requirements are presented in the paper.

Introduction

Many people who are using wheelchairs are dependent of the possibility to travel in vehicles sitting in their wheelchairs. In the latest years great attention have been paid to the questions of safety and comfort for these passengers. It is known that some of the equipment used are insufficient in the matter of comfort and safety for the passenger as well as the handling operations when restraining the wheelchair and the occupant. A wheelchair and occupant restraint system should provide good safety and comfort and be easy to handle, so it will be used in the right manner.

This paper presents performance requirements for wheelchair and occupant restraint systems for use in buses. The requirements are based on research work (1, 2, 3) carried out with the hypotheses that it is possible to improve both the safety and comfort by having a car-type seat belt for the occupant and suitable restraints for the wheelchair. The work consists of an experimental study on wheelchair users travelling in special minibuses equipped with a research prototype restraint system and sled crash tests. The results obtained form the basis for the Swedish regulations on wheelchair and occupant restraint systems (4).

In Sweden the regulations on seat belts for use in vehicles are issued by The Swedish National Road Safety Office (5). These regulations stipulate requirements on the positioning of anchor points and the testing of anchor points and seat belt components. The regulations are not applicable when a wheelchair is being used as a vehicular seat because they use the original car seat as a reference system, but they can be a guidance when formulating requirements on belt type restraints for passengers seated in wheelchairs.

Australia (6, 7) and Germany (8) have standards on wheelchair and occupant restraint systems for use in vehicles. These standards have the national transportation system in mind, with the types of vehicles and equipment used, and are not directly suitable for application in the Swedish transportation system. The International Standards Organization is working on standards for requirements and test procedures for "wheelchair tie-down and occupant restraints systems" (9).

The vehicles used for the transportation of people in wheelchairs in Sweden have strap type or clamp type restraints for the wheelchair. The occupants are usually restrained with a belt round the upper body and the back rest of the wheelchair. Sled crash tests of this type of restraint systems have shown that the wheelchairs became badly damaged and a traveller would probably not have survived a 10 g impact. Severe injuries in the abdomen caused by the belt were supposed to appear at a 5 g or lower impact (10).

Driving tests with different wheelchairs with dummies as riders in vehicles having different restraint systems have shown that the displacements of the wheelchairs were high, especially of the upper portions, when subjected to severe driving conditions (11, 12). Sled crash tests and injury investigations of different types of wheelchair and occupant restraint systems have been carried out (13, 14, 15, 16) showing advantages and disadvantages of the different systems.

A Framing of the Problems and the Principal Starting Points

A restraint system for passengers travelling in vehicles sitting in there own wheelchairs must comply with the following two main functions:

- Restrain the wheelchair and give the passenger postural support during a normal journey in the vehicle.
- Protect the passenger in the event of an accident or other sudden movement or change in the speed of the vehicle.

These functions are fundamentally different. Physically disabled people often need postural support in order to sit comfortable and safe during a normal journey with normal vehicle movements. Many of these people have a reduced sense of balance or a decreased muscle strength which makes it difficult for them to hold on to handrails and safeguard themselves. In the event of a collision the passenger must be protected as far as possible from being injured. In the case of collisions, very high forces are generated in all the equipment being used.

The starting points for a wheelchair and occupant restraint system for use in public transportation vehicles and in special transportation service vehicles for wheelchair users in Sweden are the following:

- The safety and comfort for the wheelchair occupant should as far as possible be the same as is offered a traveller sitting in a original seat in the vehicle.
- A restraint system should consist of two parts, a seat belt for the traveller and restraints for the wheelchair.
- The restraint system must fit common wheelchairs in Sweden and no parts of it must be fixed mounted to the wheelchair.
- The restraint system should be easy to handle when restraining the passenger and the wheelchair.

Performance requirements for wheelchair and occupant restraint systems must use a reference system in the vehicle when defining areas for the location of seat belt anchor points and the positioning of the wheelchair in order to obtain the maximum safety for travellers in different wheelchairs.

Seat Belts

The purpose of a seat belt system in a vehicle is to catch the traveller and stop his or her frontal movement before hitting stiff parts of the vehicle if the vehicle suddenly stops. In order to make full use of the distance in front of the traveller to stiff parts in the vehicle for the safety, the traveller has to be restrained to the vehicle with a restraint device that in a suitable manner absorbs the energy set free during the deceleration of the body (17). For practical reasons the restraints must be located on limited areas of the body, making the load area small and thus the forces to the body becomes high. The restraint device must be located on the parts of the body that can withstand these forces.

When restraining the lower part of the body the restraint device can be located at the pelvic bone which can withstand high forces. At the upper part of the body the chest is the most suitable part for a restraint, but it is not as strong as the pelvic bone. Here the restraint must use the whole space available to decelerate the body to make the forces as small as possible. The best safety effect is obtained with a combination of an upper torso restraint strap anchored at a point above the shoulder and below the hip and a lap belt anchored below the hip (18).

A car-type seat belt, a three point belt, should be located at the travellers body in the following manner:

- The lap belt should be resting against the pelvic bone and extend downward and backward. The lap belt should be placed round the body at the height of or below the hip-joint, to prevent the pelvic bone to turn and glide under the lap belt.
- The shoulder belt should be resting against the chest having as large load area as possible. The upper anchor point should be placed over the shoulder to let the belt run between the throat and the shoulder of the traveller.

Experimental Study During Normal Travel

An experimental study on seat belts for travellers seated in wheelchairs has been carried out using a mock-up wheelchair place equipped with seat belts, shoulder and lap belts, and four restraint straps for the wheelchair. The anchor points of the seat belt could be adjusted and the wheelchair could be placed in different positions, see figure 1. The seat belt had separate shoulder and lap belts. The retractors were electrically operated so they could either be locked or free as ordinary seat belts on inertia reels. The wheelchair could be restrained with two straps to the rear and two straps forward to hooks in the floor of the mock-up wheelchair place. The loads in the shoulder belt and the restraint straps for the wheelchair could be measured with load cells.

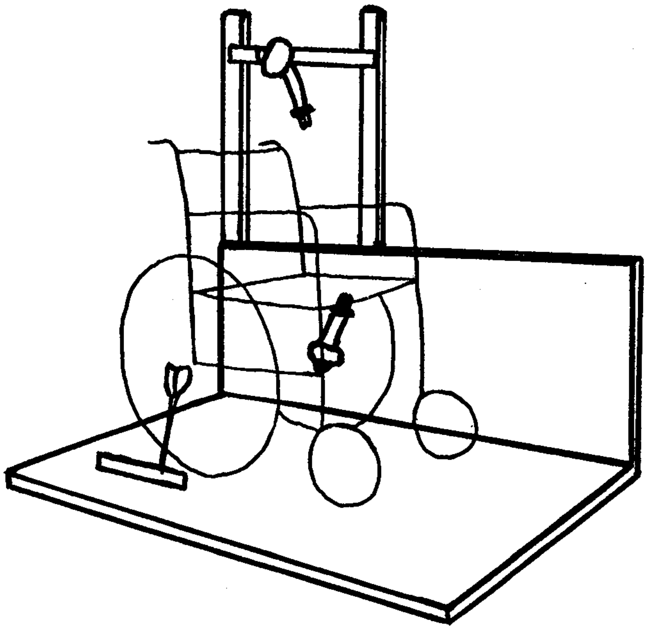


Figure 1. The Research Mock-Up of a Wheelchair Place

The objectives was to find a basis for the positioning of anchor points for seat belts in order to obtain a suitable belt configuration for travellers seated in wheelchairs and to evaluate the subjects opinion about the safety and comfort during normal vehicle movements. The mock-up wheelchair place was tried in a minibus during normal travel and in a laboratory.

For the trials the mock-up wheelchair place was installed in a Toyota Traveller minibus used for transportation of passengers seated in their wheelchairs. A number of 22 subjects with different ordinary wheelchairs participated in the trials. The subjects were 9 women in the ages of 21 - 56 years and 13 men in the ages of 25 - 60 years. The length of the women were 157 - 176 cm and the men 165 - 185 cm. The weight of the women were 46 - 84 kg and the men 60 - 93 kg. Two of the women and 10 of the men were not disabled but used a wheelchair at the trials. All of the disabled subjects normally travelled in their own cars, one as passenger and the other as drivers, but sometimes they used the special transportation service.

One of the subjects used a heavy powered wheelchair, two used older types of wheelchairs and the other used modern light active chairs. The powered wheelchair had a length of 128 cm, a breadth of 62 cm, a seat height of 58 cm and a weight of 148 kg. The manual wheelchairs had a length of 90 - 110 cm, a breadth of 56 - 64 cm, a seat height of 40 - 55 cm and a weight of 9 - 22 kg.

The anchor points of the seat belt were adjusted for each subject to obtain a suitable belt configuration. The subjects told their opinion about the seat belt and their feeling of the degree of safety and comfort during the ride. The vehicle was run a selected tour in ordinary urban traffic. The tour was 15 km and took about 25 minutes. It contained several typical types of streets and traffic situations like ordinary asphalt street permitted for 50 and 70 km/h, corners, crossings, old bumpy streets and a speed-reducer. The driver tried to drive careful and in the same manner at all tours.

The Positions of the Seat Belt Anchor Points

During the trials the anchor points of the lap belt were positioned at floor height and adjusted within a horizontal distance of 0 - 400 mm backward of the intersection between the seat and the back rest of the wheelchair for the different subjects. The lower anchor point of the shoulder belt was positioned at the same place as the lap belt and the upper anchor point was placed 1200 - 1350 mm above the floor at a horizontal distance of 140 - 400 mm backward of the intersection between the seat and the back rest of the wheelchair. See figure 2.

All the subjects, the disabled as well as the not disabled, said that they felt the ride very safe due to the seat belt. The shoulder belt, well adjusted and locked, gave a good postural support during the vehicle movements. A seat belt with normal inertia reel retractors did not give such a support because the normal vehicle movements were so small so the retractor did not lock but let the band run out instead of supporting the traveller.

The disabled subjects felt the ride very comfortable and appreciated the seat belt. Some of the subjects pointed out that they usually did not use seat belts when travelling in cars, sitting on the original car seat, because belts usually pressed onto the throat or other places making it very uncomfortable. Even these subjects felt comfortable when the seat belt was well adjusted.

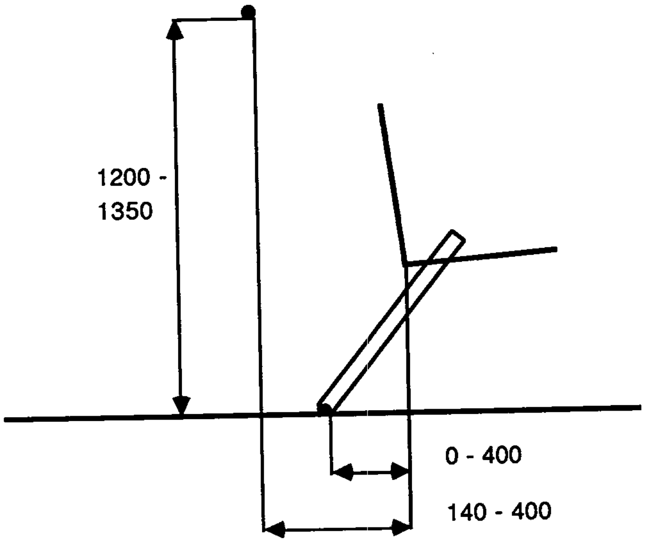


Figure 2. The Positions of the Seat Belt Anchor Points During the Trials

The subjects who were not disabled felt the ride very uncomfortable, in contrary to the disabled subjects. They did not feel the ride unsafe but they felt the wheelchair uncomfortable and pointed out that the vehicle movements made their upper body move back and forth as well as sideways much more than when travelling sitting in an ordinary car seat.

The observer noticed that the travellers in the wheelchairs moved back and forth and sideways much more than the driver or a passenger in an ordinary seat. There were no differences between the disabled and the not disabled subjects in this respect. The vehicle movements were more striking at the wheelchair place in the back of the minibus than they were at the ordinary seats. Besides that the wheelchair seat came higher over the ground, due to the floor height in the minibus, than a normal car seat. That made the vehicle movements have a higher amplitude, especially sideways, at the traveller seated in the wheelchair. The wheelchairs themselves had movements due to elasticity in the tyres, wheels and probably even in the chassis. An ordinary car seat is more rigid and can better damp the vehicle movements.

The Loads Generated in the Restraint System

The loads in the shoulder belt and in the restraint straps to the wheelchair were measured with strain gauge-type load cells during the trials. Extra trials were carried out with load cells in the floor at the left main wheel of the wheelchair with two subjects of 60 kg and 93 kg.

A portable computer equipped with analog-digital converter and signal conditioning amplifiers were used to record and store the data. The sampling frequency was five times per second. The rms (root-mean-square), peak and absolute value of the loads were measured in order to catch the actual forces at all times, even those with short duration. The rms value is a type of "average" value allowing the magnitudes of all types of voltage, or current, wave forms to be compared to one another and to direct current. The rms is a direct measure of the power or heating value of an alternating current voltage compared to that of direct current. The rms value is calculated by squaring the signal, taking the average and then obtaining the square root. The peak value is the highest value occurring during the measured times and the absolute value is the exact value measured by the computer.

A video camera placed in the front seat of the minibus recorded the road and the traffic situations through the front window. The computer transmitted time codes through a special modem to the microphone socket on the camera. When evaluating the measured data this system made it possible to find the exact event on the video-film where an interesting force appeared. It also made it possible find the corresponding data to an interesting situation find on the video-film.

In the evaluation five typical traffic situations were chosen and studied for all trials. The following situations were identified on the video-film to be the exactly same parts of the tour and the corresponding data were analysed:

1. Driving on an ordinary street in a speed of 50 km/h.
2. Driving over a speed-reducer constructed in the street.
3. Cornering in city traffic.
4. Driving on an old bumpy street in city traffic.
5. Driving on an ordinary road in a speed of 70 km/h.

All the data from each trial were analysed to find the events with high loads in the restraint system. Thereafter the video-films were studied to find the situations that had caused the high loads.

The wheelchairs had their brakes activated and were restrained with four straps, one in each corner, two heading forward and two heading backward. The straps at the back formed an angle of 36° - 50° to the floor and at the front 22° - 35° for the different wheelchairs. The straps were stretched by hand so the wheelchair felt well fastened. At the beginning of the trials the loads in the straps were 30 - 60 N. If a subject leaned to the side the loads changed with some 10 to 30 N.

1. Driving on an ordinary street in a speed of 50 km/h. It took about four minutes to get to this part of the tour. Here the street had no bumps or other things causing excess loads. The loads were 0 - 50 N in the straps for some subjects and 0 - 170 N for others. The loads in the different straps had changed from the values at the start of the trials. Often there was no load in one of the straps and a higher load in the other strap in the same direction. This was not related to the weight of the subject. The loads fluctuated with about 50 N when driving on this street. In the shoulder belt there was a load of 0 - 70 N, the higher value for the heavy subjects. The load on the floor at the left main wheel was about the same as when standing still but with some peaks up to 35% more.

2. *Driving over a speed-reducer constructed in the street.* The speed-reducer was a bump 10 cm high, 3 m long with a 1 m long ramp on each side. The vehicle speed was 20 km/h when passing the bump. The maximum loads in the restraint straps were 320 N for heavy subjects. In the shoulder belt there was a load up to 110 N. The maximum load on the floor at the left main wheel was 440 N for a heavy subject, which was 70 % more than the load when standing still. Figure 3 shows the different loads sampled with a higher frequency when passing the speed-reducer in a speed of 30 km/h.

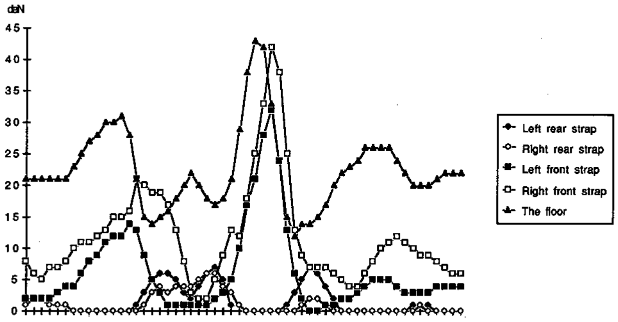


Figure 3. Loads in the Restraint Straps and on the Floor at the Left Main Wheel of the Wheelchair When Passing a Speed-Reducer in a Speed of 30 km/h (wheelchair occupant weight 60 kg, total duration 2 seconds)

3. *Cornering in city traffic.* The vehicle made a turn to the right in the studied corner. The straps at the right side of the wheelchair were stretched to a load of up to 330 N for heavy subjects. The loads in the straps at the left side were low. The load distribution in the different straps varied much between the different subjects. The load in the shoulder belt was 10 - 30 N. The load on the floor at the left wheel were a bit more than 50 % higher then the load when standing still, up to 430 N for a heavy subject.

4. *Driving on an old bumpy street in city traffic.* This street had several small bumps. The maximum loads in the restraint straps were 190 N for heavy subjects and 150 N for light subjects. The loads fluctuated from zero up to the maximum. They appeared in different straps in different situations. In the shoulder belt the maximum load was 50 - 100 N. The peak loads on the floor were about 50 % higher then the load when standing still, up to 390 N. The duration of the peak loads, both in the straps and on the floor was 0.2 - 0.8 seconds.

5. *Driving on an ordinary road in a speed of 70 km/h.* This road was in good condition. The loads were 0 - 250 N in the straps. The loads fluctuated from zero up to the maximum. Often there was no load in one of the straps and a higher load in the other strap in the same direction. In the shoulder belt there was a load of 0 - 80 N. The load on the floor at the left main wheel was about the same as when standing still but sometimes there were peaks up to 38 % more.

In some situations during the tours there appeared high loads in the restraint straps. A rather big cavity in a street caused a peak load of 320 N in one of the restraint straps. A cavity in the street caused a peak load on the floor at the left wheel of the wheelchair of 70 % more than when standing still, in this case the peak was 340 N. When the minibus run into the edge of a curb when cornering the peak load in one restraint strap reached 290 N for a heavy subject. A very rapid start from standing still caused loads of 220 N. A very hard braking from 30 km/h with a subject of 60 kg in the wheelchair turned out to be a different situation. The loads in the rear straps to the wheelchair were almost none but the load in the shoulder belt rose to about 160 N during the braking. All of these loads are in the same range as the loads in the studied situations.

Laboratory Trials on Seat Belt Anchor Points

Different positioning of the anchor points of the seat belt were tried in laboratory. One subject having the length of 170 cm and the weight of 65 kg using an ordinary manual wheelchair with a length of 107 cm, a breadth of 53 cm and a seat height of 50 cm participated. The configuration of the seat belt on the body of the subject was studied when changing the anchor points. The subject was asked how the seat belt was felt in the different positions.

In the trial the anchor point of the lap belt on the right side was placed at floor height and the anchor point on the left side was placed 300 mm above floor height. The two anchor points were placed at the same horizontal distance from the back rest of the wheelchair. The breadth between the anchor points was 800 mm. The lower anchor point of the shoulder belt was placed in the same point as the lap belt. The position of the wheelchair and the upper anchor point of the shoulder belt were varied. See figure 4.

The best configuration of the lap belt was obtained when the horizontal distance from the anchor points to the intersection between the seat and the back rest of the wheelchair was a = 0 mm, which gave an angle between the lap belt and the floor of a = 74°. The best configuration of the shoulder belt was obtained when the horizontal distance from the upper anchor point to the intersection between the seat and the back rest of the wheelchair was b = 300 mm and the height over the floor was c = 1300 mm. Table 1 shows the results when using different location of the anchor points.

Impact Tests

Sled crash tests of a restraint system for passengers in wheelchairs has been carried out in order to determine the loads generated in the restraint system and what risks to safety for the traveller the wheelchair could cause. Six

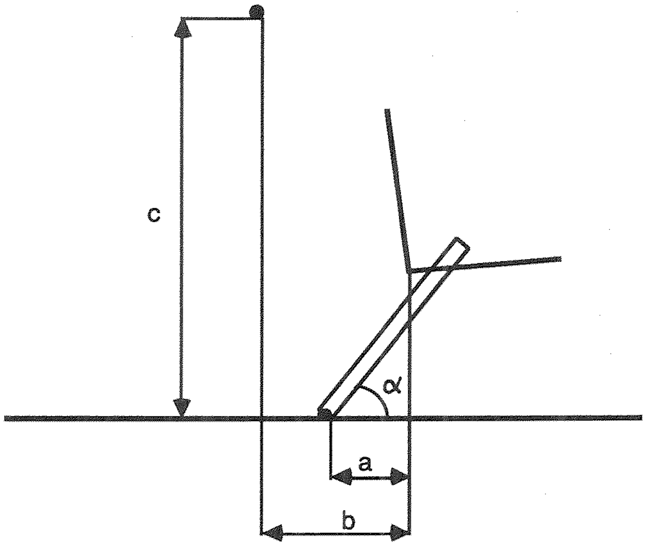


Figure 4. The Location of Seat Belt Anchor Points

Table 1. The Results Obtained from Different Positions of the Seat belt Anchor Points (definition of a, b, c, a1, a2 shown in figure 4)

a	b	c	α1	α2	Comments
0	0	1200	74	62	The shoulder belt is to far forward
0	200	1200	74	62	The shoulder belt lies onto the shoulder
0	300	1200	74	62	The shoulder belt is felt good positioned
0	200	1300	74	62	The shoulder belt is slightly to far forward
0	300	1300	74	62	The shoulder belt is felt good positioned
200	300	1300	65	45	The shoulder belt is felt good positioned
200	500	1300	65	45	The shoulder belt lies to near the throat
400	300	1300	57	34	The lower anchor point of the shoulder belt is to far backward and the lap belt presses onto the abdomen
400	500	1300	57	34	The shoulder belt presses to the throat and its lower anchor point is to far backward and the lap belt presses onto the abdomen

frontal impacts were carried out at speeds and retardations of 30 km/h, 10 g and 50 km/h, 20 g see table 2. Five different ordinary manual wheelchairs having a length of 100 - 110 cm and a breadth of 56 - 64 cm were used in the tests.

Table 2. The Conditions for the Impact Tests

Test nr.	Velocity (km/h)	Decelera-tion (g)	Type of wheelchair	Weight (kg)
1	30	10	The main wheels at the back	25
2	30	10	The main wheels at the front	21
3	50	20	Pushing chair	15
4	30	10	The main wheels at the front	22
5	50	20	The main wheels at the back	19
6	50	20	The main wheels at the back	25

The restraint system for the passenger was a three-point type seat belt with separate shoulder and lap belts. The upper anchor points of the shoulder belt was mounted on a pillar 1200 mm over the floor and the lower anchor point was mounted on the floor, as was the lap belt anchor points. All the anchor points were mounted in the same vertical plane, perpendicular to the travel direction. A part of that plane was a support wall behind the wheelchair. The restraint system for the wheelchair consisted of two webbing straps, directed horizontally backward at a height of 300 mm over the floor, which secured the wheelchair to the support wall, see figure 5.

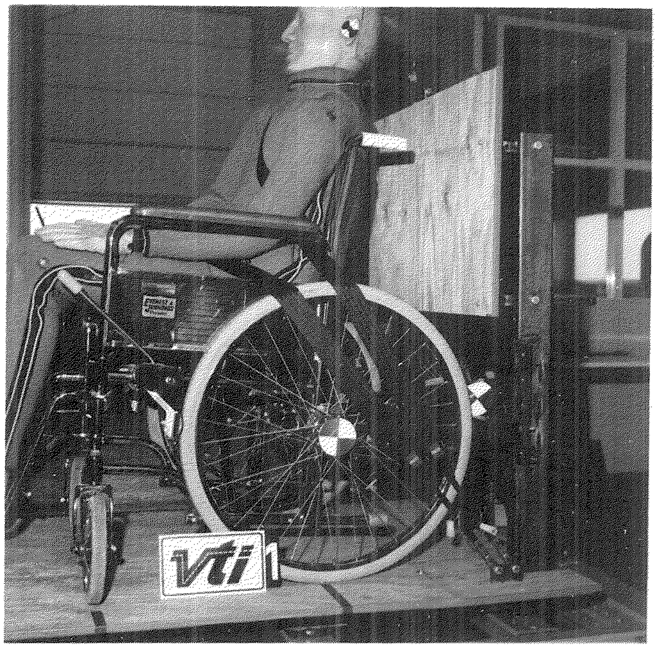


Figure 5. The Restraint System Used in the Impact Tests

The dummy used was of the type Ogle representing a 50-percentile male having a length of 174 cm and a weight of 73 kg. The forces in the shoulder and lap belts and the restraint straps to the wheelchair were measured with load cells. The speed and retardation were measured with sensors on the trolley. All of the tests were filmed with a high-speed camera taking 500 frames per second.

Before every impact the wheelchair was restrained with the two straps and pulled back onto the support wall behind it. The dummy was placed in the wheelchair in a normal sitting position and the shoulder and lap belts were put on. Care was taken to ensure that the belt configuration was the desired. The belts were threaded under the armrests of the wheelchair if necessary to obtain the right positions for the belts.

The sequence of events during the impacts can be described as follows. When the impact begins the wheelchair and dummy move forward stretching the restraint straps. A movement of the wheelchair of 2 - 5 cm was observed. Then the dummy continues the frontal movement stretching hard in the lap and shoulder belts. The force in the lap belt, which is directed backward and downward, presses the dummy hard onto the seat. This makes the wheelchair frame and wheels to be slightly deformed. The pneumatic tires were flattened to the rim. The dummy remained for the main part in its original sitting position but with its legs and arms stretched forward. The lap and shoulder belts remained at their positions on the dummy. Excursions of the head of 17 - 26 cm and of the hip of 11-25 cm from their original positions were observed. At the end of the impact the dummy moved backward due to the rebound and pressed onto the back rest of the wheelchair and onto the support wall behind the wheelchair. Figure 6 shows the sequence during the impact nr 3.

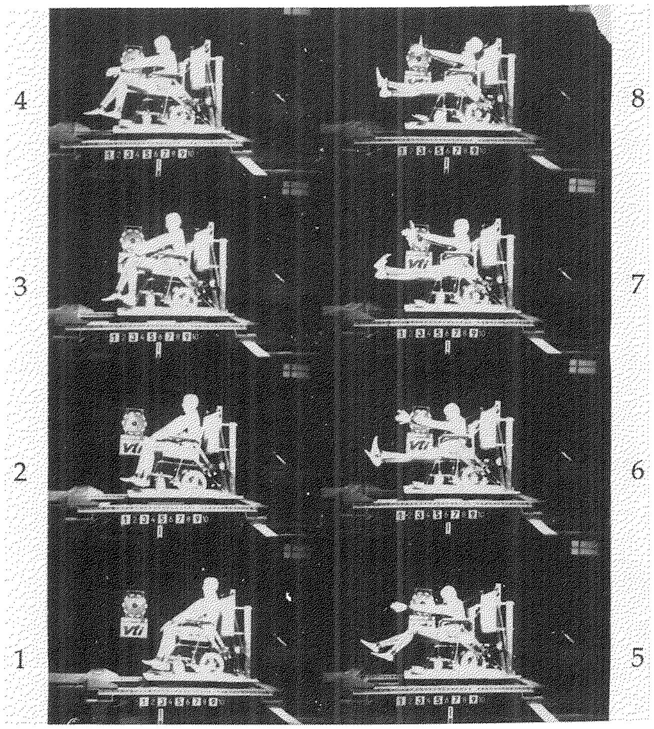


Figure 6. A Frontal Impact From 50 km/h With a Deceleration of 20 g: Crash Test Number 3

On two of the wheelchairs the pushing handles at the top of the back rest were the backmost part of the chair. When restrained the pushing handles pressed onto the support wall. These wheelchairs stood steady during the rebound phase. On the other wheelchairs the back wheels were the backmost part. Those wheelchairs tilted backward during the rebound phase so the pushing handles reached the support wall.

The wheelchairs were only slightly deformed during the impact. They got their frames and back rests slightly bent and some of them got their wheels slightly bent. The wheelchair in impact nr 5 got its castors, at the front, broken off.

In the impact nr 6 the shoulder and the lap belts were put on the dummy in the easiest way over the armrests of the wheelchair to show what happens if the belts are misused. In this case the lap belt pressed onto the abdominal region of the dummy. During the impact the dummy submarined under the lap belt and moved forward ending up in a lying position.

The maximal loads in each of the wheelchair restraint straps were about 3.6 kN at a 10 g impact and 4.7 kN at a 20 g impact, except at the impact nr 6 where the load were as high as 9.5 kN, see figures 7, 8, 9. These loads are higher than what is expected from the wheelchair itself, because the dummy generates excess loads to the wheelchair restraints due to friction between the dummy and the seat. In impact nr 6 this effect was very high when the dummy submarined under the lap belt. The load in the shoulder belt had a maximum of about 4.8 kN at a 10 g impact and 8.2 kN at a 20 g impact. In the lap belt the maximum load was 2.8 at 10 g and 5.7 kN at 20 g.

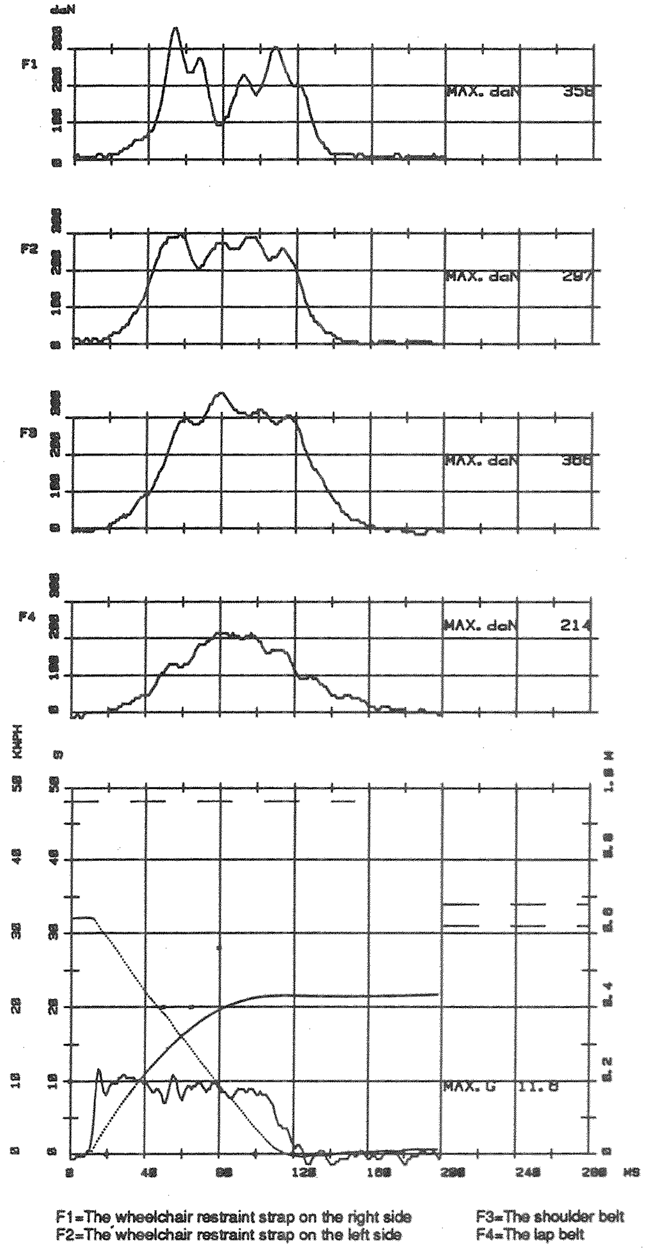


Figure 7. The Forces Generated During the Impact nr 1

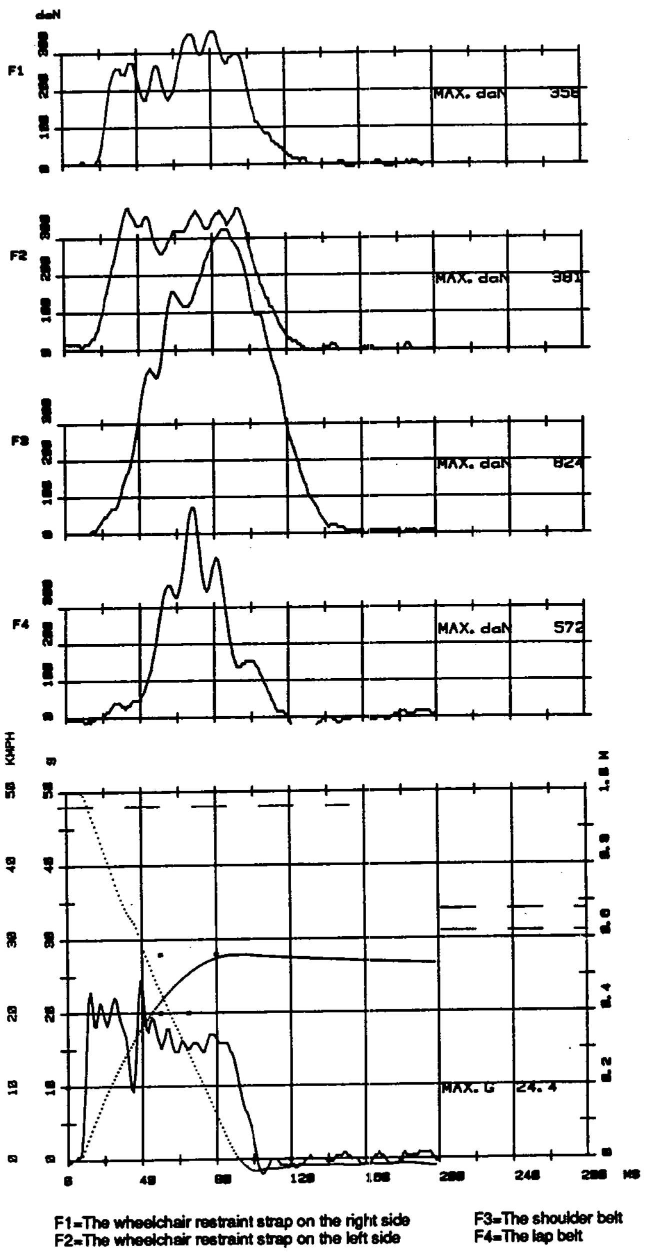


Figure 8. The Forces Generated During the Impact nr 3

The results from the impact tests show that the restraint system, correctly used, worked satisfactorily. The wheelchairs were suitable as seats to support the dummy during the impact. They did not apply any extra forces to the dummy nor did they entail any safety risks to the dummy. Even in the case when the castors were broken, the wheelchair still supported the dummy in a suitable way. Some of the wheelchairs tilted backward during the rebound phase. Restraint straps at the front of the wheelchair or a more suitable support wall would probably have prevented that. The peak loads from the occupant restraints and the wheelchair restraints did not appear simultaneously. Therefore the peak loads cannot be added to represent the total load on the restraint system as a whole.

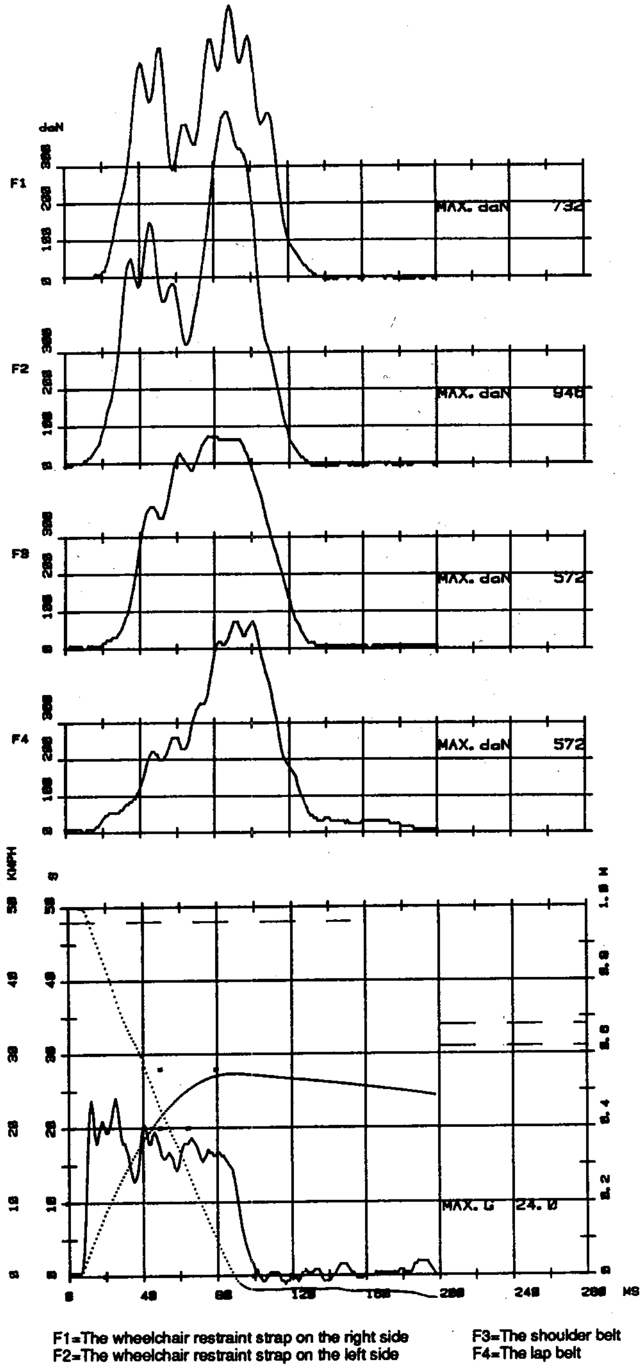


Figure 9. The Forces Generated During the Impact nr 6

The wheelchairs were slightly distorted, but it was possible to wheel the wheelchairs on their wheels after the impact. In a real accident it would have been possible to wheel them out of a vehicle in the event of making an emergency evacuation. None of the wheelchairs would have entailed any risk to the safety for the occupant.

Performance Requirements

This chapter presents performance requirements for wheelchair and occupant restraint systems installed in buses where the traveller is seated in his or her wheelchair. The performance requirements cover seat belts for passengers in wheelchairs and restraints for the wheelchair and can be applicable also for restraint systems installed in cars and minibuses. The wheelchairs in mind are ordinary manual wheelchairs (19), which means that sport chairs and other special chairs can be excluded. The performance requirements are based on the results from the experimental studies and on the regulations on seat belts issues by the Swedish National Road Safety Office (5).

General

The place intended for a passenger seated in a wheelchair shall be designed in an appropriate manner so that travelling is comfortable and safe. It must be equipped with seat belts for the passenger and restraints for the wheelchair. The occupant restraints and the wheelchair restraints shall be separate, although interacting with each other.

The wheelchair and occupant restraint system shall be easily handled.

If the passenger is to travel sitting in the rearward facing direction there must be a back and head rest adjustable to the passenger and the wheelchair.

Seat Belt

The seat belt shall be of a three point-belt type. It should preferably have separate shoulder and lap belts so, if necessary, it is possible to thread them under armrests or other devices on the wheelchair.

The seat belts shall be locked when positioned or shall lock at the acceleration obtained during normal vehicle movements in order to give postural support. Belts on retractors makes it easy to position the seat belt on the traveller.

The lap belt shall rest over the pelvic bone and extend downward and rearward to form an angle of 45° - 80° to the horizontal plane, preferably as close to 60° as possible. The shoulder belt shall rest diagonally across the chest and extend upward and rearward to pass between the throat and the shoulder. The upper anchor point of the shoulder belt shall be positioned over the shoulder height and should be adjustable to suit different people seated in different wheelchairs. See figure 10.

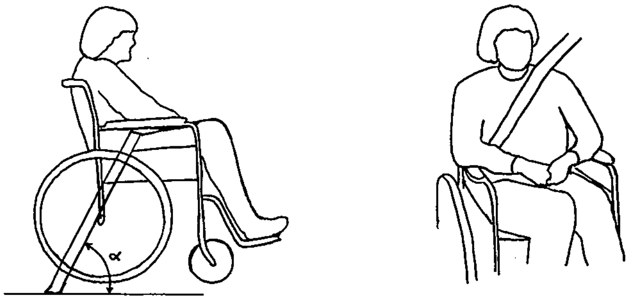


Figure 10. The Configuration of Seat Belts for a Passenger in a Wheelchair

The seat belt anchor points shall be mounted to the vehicle or to support devices mounted to the vehicle within the zones described as follows, see figure 11.

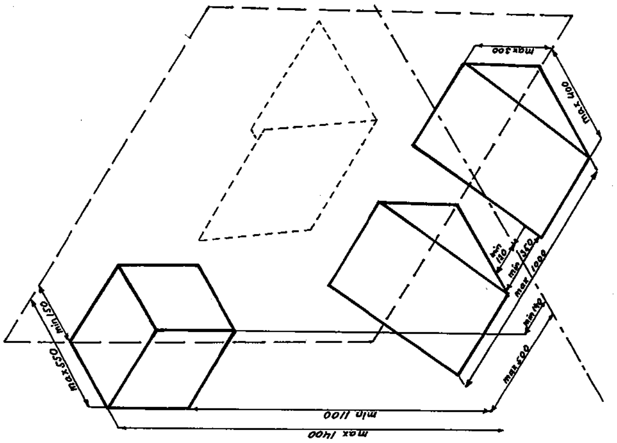


Figure 11. Suitable Zones for Mounting the Seat Belt Anchor Points to the Vehicle (measurements in mm)

The lap belt anchor points shall be mounted at floor height at a distance of at least 120 mm from the centre line and 0 - 400 mm rear of a vertical plane through the intersection between the seat and back rest of the wheelchair, called the plane B. The distance between the anchor points shall be at least 350 mm and at most 1000 mm. The anchor points can be mounted above floor height within a zone formed by the measurements mentioned above and a height of at most 300 mm at the forward side.

The shoulder belt upper anchor point shall be mounted at a horizontal distance of 140 - 500 mm from the centre line and be adjustable in height and/or in distance from the plane B. When adjustable in height, the anchor point shall be mounted at a distance of 150 - 550 mm to the rear of the plane B and be adjustable within a height of 1100 - 1400 mm above the floor. When adjustable horizontally the anchor point shall be mounted at a height of 1200 - 1400 mm and be adjustable within a distance of 150 - 550 mm to the rear of the plane B.

The lower anchor point of the shoulder belt shall be mounted on the other side of the centre line as the upper anchor point and in the same zone as the anchor point of the lap belt.

The mounting points of the seat belt must withstand the forces occurring when the shoulder belt and the lap belt are exerted to a force of 13,5 kN each, with a duration of at least 0.2 seconds, in the forward facing direction.

Wheelchair Restraint System

The wheelchair restraint system must keep the wheelchair safe when it is exposed to horizontal and vertical forces. When exposed to these forces, a wheelchair must not overturn, twist or shift its position. The restraint system shall fit ordinary types of wheelchairs.

The wheelchair restraint system shall be symmetrically affixed to the wheelchair. It shall be attached to the chassis or another robust part of the wheelchair. The restraint system must hold the wheelchair steady even if the wheelchair becomes deformed by the loads subjected to it.

The wheelchair restraint system shall be designed to enable a wheelchair to be anchored in a suitable position to get the right configuration of the occupant restraint system. If the wheelchair can be anchored arbitrary, clear instructions shall be found in the vehicle on positioning the wheelchair.

The wheelchair restraint system installed in a vehicle shall be able to secure a manual wheelchair when it exposed to a force of 15 kN in the forward facing direction, with the duration of at least 0.2 seconds.

The wheelchair restraint system may consist of straps attached to the wheelchair, two straps directed downward and backward and two straps downward and forward or two straps directed backward in conjunction with a support wall behind the wheelchair. A wheelchair restraint system may also consist of other devices that meet the above requirements.

Discussion

This paper presents the results from experiments on wheelchair and occupant restraint systems carried out during normal travel and sled crash tests. In the travel trials participated disabled persons having there own wheelchairs and able bodied persons seated in wheelchairs. All of the subjects found the travel safe due to the seat belt, which was adjusted to fit them perfectly. The disabled subjects found the travel comfortable but the able bodied subjects did not find it comfortable at all.

The different opinions between the disabled and the able bodied subjects can depend on the fact that the disabled used their own wheelchairs, which were selected to fit them, and that they were used to travel in vehicles having only a support belt placed round the body and the back rest of the wheelchair. The able bodied subjects were used to travel sitting in a normal car seat. The two categories of subjects therefore compared the trial situation with two completely different travel situations.

A striking fact during the trials was the displacements of the wheelchair, which made the subjects move back and forth as well as sideways. Even small vehicle movements resulted in large displacements of the wheelchair and occupant. This has been found also in other trials during extreme conditions with dummies as riders in the wheelchair (11, 12). The displacements were caused by elasticity in the tyres, wheels and probably in the chassis of the wheelchair and the fact that the vehicle movements had higher amplitude in the back where the wheelchair place was situated.

The wheelchairs did change their position a little during the travel, which caused the load distribution between the different straps to differ. The data shows different load distribution before and after a force generating situation, e.g. a sharp turn or a bump. Because of this, the peak load in one strap could be higher for a light person than it was for a heavy person in one particular situation. For all the trials the peak loads for the lightest subject never exceeded 150 N but for the heaviest subject it exceeded 400 N.

This seems reasonable as a severe driving test (11) carried out on a vehicle containing a scooter type wheelchair, much heavier than a manual one, with a dummy as a rider showed loads in the restraint straps of up to 900 N. The acceleration of a minibus floor during extreme conditions (12) showed 0.9 g when braking, 0.8 g sideways when driving slalom and 1.3 g upward when driving over a hobble. The trials described in this paper were carried out during "normal" conditions with people in the wheelchair. The tried powered wheelchair however did not generate higher forces than the manual ones. That must be due to good brakes on the wheelchair and careful driving of the vehicle.

In the shoulder belt loads up to 160 N were recorded. Often the load exceeded 70 N. This is a very low load from a technological point of view but it is very much for disabled persons to hold themselves if they do not have a shoulder belt to support them. Maybe this explains why people sometimes get injured when travelling in a vehicle sitting in their wheelchairs.

In the impact trials the movements of the dummy looked in principal the same as impacts with the dummy seated in a car seat. The wheelchairs seamed to support the dummy satisfactorily during the impacts. Non of them failed in this respect. The wheelchairs used in the crash tests were second-hand wheelchairs, but still they could withstand the forces subjected to them.

Wheelchairs, which are going to be used as seats in vehicles, must permit the seat belt to be applied correctly. It is essential that the lap belt can be applied low on the pelvis to prevent submarining. The wheelchairs must withstand the forces subjected to them during an impact and not collapse in an uncontrolled manner. The wheelchairs used in the tests were rather robust and heavy and maybe a bit stronger than modern light active chairs. It is very important to develop standards or regulations for wheelchairs suitable as seats in vehicles. The International Standards Organization has started a work on that issue (8).

The excursions at the upper body of the dummy was rather small. It could be possible to use a shoulder belt that can stretch more, making the acceleration of the head as small as possible. The wheelchair has to be restrained to support the dummy during the rebound. Some of the wheelchairs tilted backward at the tests. For restraint systems in cars and minibuses it seems necessary to have restraint straps both at the front and rear of the wheelchair or have the wheelchair restrained onto an adjustable support plane at the back. Maybe it is not necessary to have the support plane adjustable in coaches.

The loads generated in the restraint system during normal travel are much smaller than the loads obtained during an impact. It seams to be no problems to design restraint systems to withstand the loads during normal travel. The future research and development on wheelchair and occupant restraint systems should be concentrated on the comfort for the traveller, the handling situation for an attendant and on the safety during an impact.

Acknowledgement

The research projects on which this paper is based were funded by the Swedish Transport Research Board and the Swedish Board of Transport.

References

1. Brattgård, S-O., Petzäll, J., Anpassning av landsvägsbussar till rörelsehindrade och andra handikappade. (Adaptation of coaches to mobility disabled and persons with other kinds of handicap). Report 74, 1982. Department of Handicap Research, University of Gothenburg. (In Swedish).
2. Petzäll, J. Säkerhet för rullstolsbundna resenärer i fordon. (The safety for travellers seated in wheelchairs in vehicles). Report 1987:3. The Swedish Board of Transport. Stockholm. (In Swedish).
3. Petzäll, J. Kriterier för val av fordon för färdtjänstresor med taxi- och specialfordon. (Criteria for the choise of vehicles for the special transportation service for disabled people). Department of Transportation and Logistics. Chalmers University of Technology. Gothenburg. (Research project in progress).
4. The Swedish Board of Transport. Regulations for adapting public transport vehicles for use by disabled persons. (English version). Stockholm 1989.
5. The Swedish National Road Safety Office. Trafiksäkerhetsverkets föreskrifter om bilbälten. (The Swedish National Road Safety Office regulations on seat belts). TSVFS 1985:24. (In Swedish).
6. The Standards Organization of Australia. Wheelchair occupant restraint assemblies for motor vehicles. Australian Standard AS 2942 - 1987.
7. Fisher, W. E., Seeger, B. R., Svensson, N. L. Development of an Australian Standard for Wheelchair Occupant Restraint Assemblies for Motor Vehicles. Journal of Rehabilitation Research and Development. Vol 24, No 3, pp 23-34. Summer 1987.
8. Deutsches Institut für Normung. Behindertentransportkraftwagen. Rückhaltesysteme, Begriffe, Anforderungen, Prüfung. DIN 75078 Teil 2, 1985.
9. International Standards Organization. Wheelchair tie-down and occupant restraint systems and wheeled mobility devices intended for use in motor vehicles. ISO draft standard CD 10542, 1991.
10. Aldman, B., Brattgård, S-O., Hansson, S. Säkerhet vid färdtjänstresor. Del 1. Under resa med färdtjänstfordon. (Safety in special public transport. Part 1. During the journey with special public transport vehicles). Report 29, 1974. Department of Handicap Research, University of Gothenburg. (In Swedish).
11. Mercer, W., Billing, J.R. Assessment of a Transportable Mobility Aid in Severe Driving Conditions—An Exploratory Test. Vehicle Technology Office. Transportation Technology and Energy Branch. Ministry of Transportation of Ontario. December 1990. Canada.
12. Kooi,J., Janssen, E.G. Safety of wheelchair occupants in road transport. Proceedings 1987 International IRCOBI Conference on the Biomechanics of Impacts, pp 167-180.
13. Orne, D., Barak, E., Fisch, R. F. Design, test and development of a wheelchair restraint system for use in buses. Proceedings of Twenties Stapp Car Crash Conference 1976, pp 271-302.
14. Kallieris, D., Mattern, R., Schmidt, G., Glitsch, G. D., Harres, M., Leis, B. Behavior and responce of wheelchair, passenger and restraint systems used in buses during impact. Proceedings of Twenty-Fifth Stapp Car Crash Conference 1981, pp 613-650.
15. Red, E., Hale, K., McDemott, M., Mooring, M. Wheelchair restraint systems, dynamic test results and the development of standards. Proceedings of Twenty-Sixth Stapp Car Crash Conference 1982, pp 269-290.
16. Petty, S. P. F. The safe transportation of wheelchair occupants in the United Kingdom. Proceedings of Tenth International Conference on Experimental Safety Vehicles 1985, pp 488-491.
17. Aldman, B. Biodynamic studies on impact protection. Acta Physiologica Scandinavia, vol 56. Stockholm 1962.
18. Aldman, B., Nellborn, O. Standardisering av säkerhetsbälten. (The standardisation of seat belts). Teknisk Tidskrift (Technical Journal) 1964:1;7-11.
19. International Standards Organization. Wheelchairs—Maximum overall dimensions. Ref. No. ISO 7193-1985.

S3-W-22

Bonnet Leading Edge Sub-systems Test for Cars to Assess Protection for Pedestrians

G.J.L. Lawrence, B.J. Hardy, J. Harris
Transport and Road Research Laboratory

Abstract

This paper describes the research that has been undertaken by the Transport and Road Research Laboratory to develop a sub-systems test to assess the protection that is afforded to pedestrians by the leading edge of the bonnets of cars. This work forms a part of the research by a Working Group of the European Experimental Vehicles Committee, developing test methods that may be used in a Directive by the European Commission, which provided financial support for the work. The paper identifies the existing accident data and full scale cadaver and dummy testing that provide a basis for the work. The safety requirements of both child and adult pedestrians are discussed. Results of additional tests that have been conducted to develop, calibrate and validate the proposed impact device and test method are described. Different car frontal shapes influence the velocity, the effective mass and the direction of the pedestrian's impact with the bonnet leading edge. This variation has been allowed for by adjusting the conditions of the sub-system test. Proposals for the resolution of these variations with respect to the sub-system test and recommendations for acceptance levels are given.

Introduction

In the twelve countries of the European Community alone there were nearly 9000 pedestrians killed in road traffic accidents in 1989. This represents approximately 20% of all their road user fatalities (1). Accident data show that approximately sixty per cent of these casualties were struck by the fronts of cars (2). The design of car fronts can be improved to reduce the frequency and severity of pedestrian injuries as has been demonstrated by research (3, 4 and 5). Five European research institutions, working under the auspices of the EEVC - Working Group 10, have collaborated to develop test methods, in the form of a draft regulation, for assessing the protection afforded to pedestrians by cars.

The test procedures proposed are in the form of three sub-system tests: one for the bumper, concerned with adult lower leg and knee injuries, one for the leading edge of the bonnet, concerned with upper leg and pelvis injuries of adults and the third for the bonnet area concerned with child and adult head injuries. This paper gives details of the work by TRRL to develop a test method to assess the protection afforded by the bonnet leading edge. The requirements of both child and adult pedestrians have been considered, but these first proposals are based on the requirements of adults, who are identified by accident data as the age group most at risk from impacts with this location on a car. The objective was to develop a test procedure that reproduces the bonnet leading edge impact characteristics of a pedestrian struck by a car at an initial impact speed of 40 km/h.

Work in the literature (6) has shown that in pedestrian accidents at any given speed, the kinematics of the pedestrian will vary significantly depending on the shape of the vehicle. These variations in kinematics result in major variations in the impact velocity and impact energy to the bonnet leading edge. A requirement of this study was to establish a method of determining how to represent these in the sub-system test.

Data from impacts between instrumented cars and dummies (7 and 8) have been used to determine the initial sub-system parameters of impact energy, velocity and direction, for the test method. Further tests of popular cars into dummies have been conducted to provide data to develop the sub-system test. A bonnet leading edge impactor and guidance system has been developed that represents a pedestrian femur and this has been used to reproduce the vehicle damage recorded in the tests to popular cars. Well documented pedestrian accident cases were also simulated using the bonnet leading edge impactor to reproduce the accident damage and thereby assess and develop the performance of the impactor with respect to real world conditions. The results of the tests showed the variations in the sub-systems impact conditions that were necessary to reproduce accident damage for a range of car models, and also gave a comparison of impactor instrumentation outputs against accident injuries.

These variations in sub-system impact conditions were further studied by mathematical computer simulations conducted by TNO. These data in combination with the full-scale test and accident simulation results have been used to produce a series of graphs that enable the determination of the sub-system impactor energy, impact velocity and direction of impact for a given car shape.

Acceptance levels for the test method have been considered, using the measurements of force and bending moments obtained in the accident simulation sub-system tests, and preliminary estimates for both values are given.

Accident Data

To form a basis for the project, the published accident data (particularly associated with European style cars) and also more recent work by the Medical University of Hannover were studied. The Scottish Hospitals In-Patients' Statistics (SHIPS)(9) have been examined and

During an accident or dummy test the upper leg is restrained by the effect of the body mass, and to a lesser extent by the lower leg mass. These effects restrict the rotation of the upper leg around the bonnet leading edge. The upper leg is effectively part of a system which has a high moment of inertia. To give the impactor a high moment of inertia it was mounted on a guide ram which was constrained to move only forwards and backwards.

Dummy testing and mathematical computer simulations suggest that, for most cars, adult pelvic injuries will come from the femur contact loading the pelvis through the hip joint. To assess these conditions the adult femur impactor that has been developed is fitted with load cells at the ends of the femur section to measure the relative distribution of the impact force between the top and bottom of the femur. Three sets of strain gauges on the femur section measure the resulting bending moment and these, with the force measurements, can differentiate between a concentrated or a distributed loading.

An adjustable mass can be added to the impactor to allow for the required change in pedestrian effective mass for different shapes of car.

For the development of this sub-system test the bonnet leading edge impactor was attached to the end of a light-weight guide ram mounted on a small trolley that could be accelerated to speed along a track. This method was adopted mainly because the track and propulsion system were in existence. Roller bearings supported the guide ram allowing it to move freely in a horizontal direction, but during trolley acceleration this movement was inhibited by a weak shear pin. The trolley was propelled up to test speed and stopped independently by contacting crumple tubes, just before the impactor hit the car. This action also released the shear pin and the impactor was then free to strike the car, under the impetus of its own mass but restrained by the bearings to move only in the horizontal plane (see Figures 1 and 2).

Variations in the angle of impact to the bonnet leading edge were achieved by raising the rear of the car to give the required angle of tilt (see Figure 2). Heavy duty screwed props, reacting against 2000 kg of concrete blocks, were used to support the rear of the car.

The Sub-system Impactor

The impactor consists of a vertical front end representing the femur, supported at top and bottom via load cells to a vertical rear member which is in turn mounted on the end of the guidance ram through a clutch (see Figure 1).

The front end of the impactor is a hollow tube with hemispherical caps fitted to each end. The tube is strain gauged to measure bending at three locations. To simulate flesh the tube is covered with 50 mm thick "Confor"[1] foam type C-45, covered with an outer skin of 1.5 mm thick reinforced rubber sheet. Confor foam was chosen for its very low rebound characteristics. The choice of impactor length was a compromise between the full length of a typical femur to give realism, balanced against the problems of designing an impactor that is robust yet sufficiently light-weight and able to withstand large off-centre loads that can cause damaging bending moments to the guidance system.

The load cells were attached to the end caps of the front end via slotted pin joints. The slotted pin joints isolate the load cells from the bending moments generated in the simulated femur, which could cause

Figure 1.
Bonnet leading edge impactor.

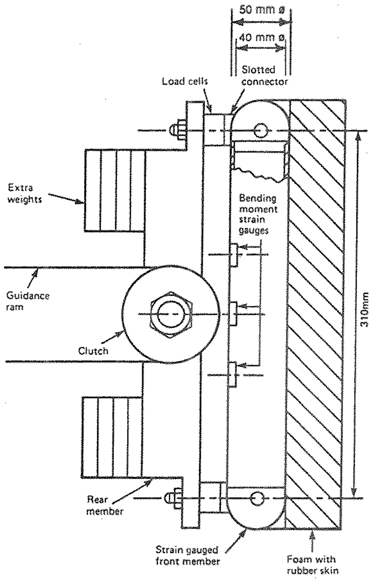


Figure 1. Bonnet Leading Edge Impactor

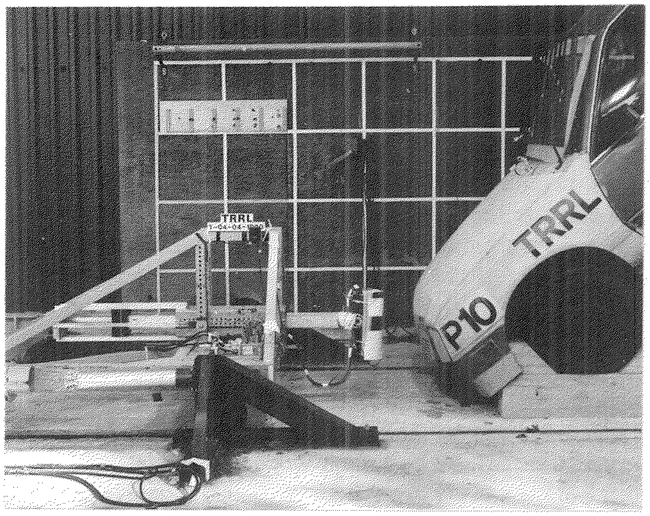


Figure 2. TRRL Bonnet Leading Edge Impactor System and Car

---

[1] Confor™ foam is a polyurethane foam manufactured by EAR Specialty Composites in the USA. The UK distributor is Polyformes Ltd.

pedestrian accident data extracted (see Annex I of Reference 10). From these data the following conclusions have been drawn with respect to injuries caused by the bonnet leading edge.

Injuries from Bonnet Leading Edge Contact

Accident data (2) have shown that the body regions most frequently sustaining serious injury from contact with the bonnet leading edge are the femur and pelvis. These injuries, although serious, are rarely life threatening. Life threatening injuries are, however, experienced by the abdomen and thorax, particularly of children, but these tend to occur at higher speeds.

Influence of Vehicle Impact Speed

The cumulative distribution, with respect to vehicle speed, of injuries of severity AIS 3 or greater attributable to bonnet edge contact has been derived from the Hannover study(11). For each body region considered cumulative injuries, as a percentage of injuries to that body region at all speeds, are shown in Table 1 as a function of vehicle impact speed. Generally, injury of this severity from the bonnet edge is rarely reported from impacts at speeds of 20 km/h or less. Approximately 9% of these injuries were reported at speeds of 30 km/h or less, 35% at speeds of 40 km/h or less and about 50% at speeds of 50 km/h or less. Recently reported data (12) give a similar distribution, but at a slightly lower impact speed. To give significant improvements in safety, it will be necessary to incorporate protection at the bonnet edge that is effective at speeds of up to approximately 40 km/h. Incorporating protection into this part of the car to be effective at speeds above 40 km/h, would require depths of crush for some vehicle shapes that may be considered impracticable.

Table 1. Cumulative Distribution of Injuries, of Severity AIS 3 or Greater, to Body Regions Associated with Bonnet Contact, by Vehicle Impact Speed (derived* from Reference 11)

Vehicle speed (km/h)	Cumulative injuries as a percentage of injuries to body region at all speeds			
	Child		Adult	
	Pelvis† (N=209#) (%)	Abdomen (N=209#) (%)	Femur (N=277#) (%)	Pelvis (N=295#) (%)
0-20	--	0	4	0
0-30	--	7	24	2
0-40	--	17	64	26
0-50	--	33	76	50
All speeds	100 (n=2)	100 (n=15)	100 (n=25)	100 (n=50)

* Cumulative distribution of injury percentages for some vehicle speeds were estimated by interpolation between the figures given in Reference 11, and therefore may not correspond to an integer number of casualties.

† As there were only 2 child pelvic injuries out of the 209 children in the sample (of which 1 injury out of 155 at vehicle speeds up to 50 km/h) it would not be justifiable to derive a cumulative distribution for this body region.

Number of cases in sample, of all severities, including those who were uninjured.

The child with its smaller stature is more at risk than the adult of being struck directly on the pelvis or abdomen by the bonnet leading edge. However the accident data show that child pelvis and abdominal injures of severity AIS 3 or more were rarely reported as occurring at speeds of 40 km/h or less. Studies by Ashton (13) show that, at speeds up to 40 km/h, the child femur is less likely to suffer fractures than the adult. 6.4% of the 0 to 14 year age group in Ashton's sample suffered femur fractures, compared with 13.5% of the 15 to 59 year age group and 18.8% of the 60 year plus age group. This suggests that in accidents at speeds up to 40 km/h adults have a higher risk of sustaining serious injury than children from impacts with the bonnet edge and for this reason it was decided to develop an impactor to represent an adult, since is was judged impractical to provide effective protection at high impact speeds.

Dummy Test Data

In order to establish the requirements of a sub-system test it was necessary to determine the differences in pedestrian impacts to the leading edge of the bonnet that result from variations in the shape of the fronts of cars. This requirement had been the subject of earlier research programmes at TRRL (7 and 8). These studies showed that variations in car shape resulted in changes to the velocity, the effective mass and the direction of the pedestrian impact with the bonnet leading edge. These studies identified the bonnet height, bumper lead and bumper height as the most significant characteristics of car shape with respect to bonnet leading edge impact and they provided a basis for using these parameters to establish the impact conditions for different vehicles.

To investigate impact damage to the car bonnet leading edge and the corresponding femur bending moments caused by impacts at the proposed test speed, adult pedestrian dummy tests were conducted against three popular car models. These data were used for the development of the sub-systems tests. To improve the bio-fidelity of the dummy the legs were fitted with modified joints to the hip and the knee as previously reported (14).

The Bonnet Leading Edge Sub-system Test Equipment

Anthropometric studies (15) have reported that the adult trochanteric height for 5th to 95th percentile males varies from 890 to 1040 mm, and from 800 to 900 mm for females. As a part of the compatibility work of this co-operative study by APR and TNO (16), a range of popular cars were measured for overall shape and under bonnet clearance, and the highest and lowest bonnets recorded were 811 and 688 mm respectively. Consequently, for the majority of adult pedestrians, impact of the bonnet leading edge will be directly on the femur. An impactor representing an adult femur has therefore been chosen for this sub-systems test.

false readings of force, and also isolate the bending gauges from bending moments that would otherwise be generated outside the femur form. The load cell centrelines are 155 mm above and below the impactor centreline. Piezo-electric load cells were selected, because they are small, light-weight and have a low sensitivity to both shear loads and to non-uniform load distributions caused by imperfections at the mounting surfaces.

Clearly, the load cells only measure the impact force that is generated by the impactor components that are mounted behind the active elements of the load cell. Those components mounted in front of the load cells contribute to the force exerted on the car but are not included in the force measurement. For this reason the mass of the front part of the impactor, the foam and those parts of the load cell mountings forward of the load measuring elements have been kept to a minimum (approximately 2.7 kg of which the foam and rubber skin contribute about 0.7 kg). Also, the additional weights, which are added as necessary to achieve the desired impactor mass, are added to the rear section so that their mass acts through the load cells.

The guide ram is a horizontal box section which can slide fore and aft within a set of roller bearings fixed to the trolley.

The front of the guide is attached to the rear vertical of the impactor through a torque loaded clutch. For car structures that result in high off-centre loading of the impactor, the clutch acts as a weak link, allowing the part in front of it to rotate before the guide ram is overloaded in bending. The friction torque selected for the clutch was such that only off-centre forces in excess of the likely acceptance load would cause the clutch to rotate.

Sub-systems Tests

The objectives of these tests were:

a) To demonstrate that sub-system impact parameters can be determined from the car shape.
b) To determine the deformation energy for real pedestrian accident cases.
c) To determine acceptance levels by comparing sub-system transducer outputs with pedestrian injuries.

In order to achieve the above objectives the tests were based on the reconstruction of the structural damage caused to the leading edge of the bonnet observed in dummy tests with popular cars, in-depth pedestrian accident cases and cadaver tests from the KOB series (17). These accident cases were taken from the Birmingham University and Medical University of Hannover studies and from the KOB series. Further tests were conducted on most of these car models used in the reconstruction tests to determine the sensitivity of the resulting structural damage to the energy of the impact.

Method of Defining the Initial Sub-system Test Parameters

The initial procedure for determining impact parameters was established from the car shape as identified by the bonnet height, bumper lead and bumper height. Initial values of impact velocity, impactor angle and impactor mass were determined for accidents at speeds of about 40 km/h for each shape of car from the appropriate results of instrumented car into dummy tests (7). If the shape of the car being tested did not correspond to one of the shapes used in the dummy tests then the test conditions were determined by interpolation between shapes. The impactor mass adopted was the horizontal effective mass of the upper leg striking the bonnet leading edge. The dummy test data suggest that, in an impact to the bonnet leading edge, the horizontal component is a high speed low mass contact, but the vertical component has low velocity and high mass. In effect the horizontal component accelerates a section of the leg approximately up to the speed of the car, while the vertical component gives a low velocity lift to much of the pedestrian. In view of this it was decided that the best way of determining impactor angle would be to use the angle of the resultant impulse, calculated from time histories of the horizontal and vertical impact forces into the bonnet leading edge. The impactor velocity was based on the resultant of the measured changes of horizontal and vertical velocities of the upper leg from impact with the bonnet leading edge. For the reconstruction of accident cases this was then adjusted pro rata from the dummy test speed of 40 km/h to the reported accident vehicle speed.

When replicating accidents at lower speeds, the determination of sub-system test parameters was in some cases based instead on instrumented car to dummy impacts at test speeds of 32 km/h (8). The sub-system test parameters for accidents involving youths were based on results of both adult dummy tests and six year old child dummy tests into instrumented cars. Interpolation on the basis of weight was used for the impactor mass and interpolation on the basis of height was used for impactor velocity and angle. If the weight or height of these accident victims was not known, then an average value for youths of that age was used. For some tests, particularly those reproducing accidents to youths, the desired impactor mass was lower than the minimum mass that could be achieved with the impactor used in these studies. In these cases the impactor velocity was reduced so that the impactor kinetic energy was correct. If the test damage did not match the accident damage adjustments were made as necessary to the test parameters, and the sub-systems tests were repeated until a correct result was obtained.

Results of Sub-system Tests

The dimensions of the vehicles tested, namely bonnet and bumper heights and bumper lead, are given in Table 2. The impact parameters and the results of the sub-systems tests that matched the car damage from pedestrian accidents or popular car tests are shown in Table 3. Tests to models A, B and E aimed to replicate dummy tests with popular car models, while tests to models C, D, F, G and H aimed to replicate actual pedestrian accidents. Typical impactor output time histories, of bending moment and force, are shown in Figure 3. Details of reported accident or cadaver injuries from the bonnet leading edge impact are shown in Table 4. The values of kinetic energy of the impactor are shown in Table 5 adjusted from the reported accident speed to a standard vehicle speed of 40 km/h by multiplying the impactor kinetic energy required to reproduce the accident damage by the ratio of the squares of the velocities.

Table 2. Bumper and Bonnet Leading Edge Dimensions of Cars Tested

Car model code	Bonnet leading edge height (mm)	Bumper top edge height (mm)	Bumper lead (mm)
A	760	525	145
B	710	495	115
C	735	515	30
D	700	420	130
E	735	530	165
F	700	290	120
G	780	490	80
H	805	540	115

Table 3. Parameters for and Results of Sub-system Tests to Bonnet Leading Edge that Gave Similar Vehicle Deformation to Popular Car Tests or Accident Cases

Test No. †	Car tilt angle (Degrees)	Impactor velocity (m/s)	Impactor mass (Kg)	Impactor kinetic energy (J)	3 ms exceedence ‡			
					Force (kN)			Maximum bending moment (Nm)
					top	bottom	sum	
A2	41.0	8.12	15.67	516	3.2	3.4	6.7	235
A3	41.0	8.24	15.67	532	2.8	3.3	6.1	227
B6	38.0	7.60	12.80	370	2.3	2.3	4.7	218
C1	15.0	7.53	8.78	249	1.7	2.0	3.7	213
D2	35.0	9.77	16.30	778	3.7	3.3	6.7	260
D3	35.0	9.70	16.30	768	3.8	3.3	6.9	265
E3	44.0	7.32	16.50	442	3.2	3.2	6.3	274
E4	44.0	7.12	16.50	419	3.1	3.7	6.8	303
E5	44.0	6.79	16.50	381	2.9	3.2	6.1	270
F2	28.0	6.37	14.80	300	2.0	3.8	5.8	232
F4	29.5	10.52	9.06	501	1.9	1.9	3.6	138
G2	30.5	9.07	9.60	395	2.3	2.4	4.7	247
G3	30.5	8.31	9.60	332	2.3	2.2	4.5	228
G4	28.0	10.18	9.06	469	3.3	2.3	5.5	286
G5	28.0	10.20	9.06	471	3.1	2.1	5.2	278
H3	37.5	7.47	12.10	337	1.5	2.3	3.6	154
H5	37.5	6.72	12.10	273	1.4	2.1	3.5	169
H7	37.5	6.75	12.10	275	1.5	2.1	3.7	189

† The letter of the test number indicates the car model.
‡ The exceedence is calculated as a cumulative exceedence. The CFC is 600 Hz.

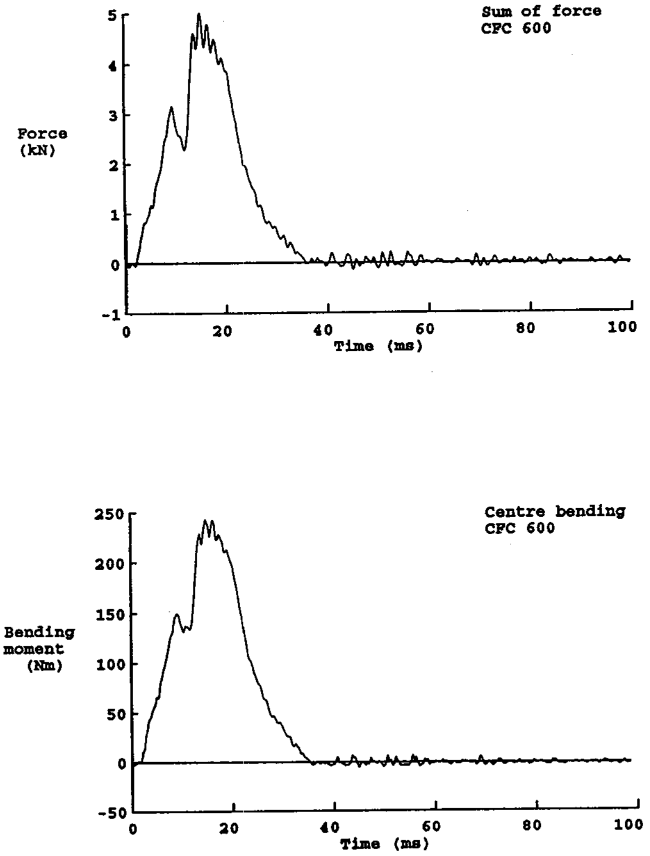


Figure 3. Typical Sub-system Test Load Cell and Bending Gauge Outputs

Table 4. Accident and Cadaver Injuries, and Sub-system Tests that Gave Similar Vehicle Deformation

Test No. *	Maximum bending moment‡ (Nm)	Maximum impactor force ‡ (kN)	Sum of impactor forces ‡ (kN)	Reported accident car speed (km/h)	Accident and cadaver injury from bonnet leading edge.
C1	217	2.2	3.8	32	Minor injury. Accident and cadaver case Cα †. 78 year old male.
D2	263	4.0	6.9	48	Minor injury. Accident and cadaver case Dα †. 60 year old female.
D3	271	4.1	7.1		
G3	244	2.6	4.8	25-35	AIS 1. Accident case Gβ †. Minor leg injury. 20 year old female.
F2	236	4.0	6.0	20-30	AIS 2. Accident case Fα †. Fracture of superior and inferior pubic rami. 76 year old female.
G2	254	2.6	4.9	45-50 before braking	AIS 2. Accident case Gα †. Fracture of pubic rami. 19 year old female.
G4	403	4.8	7.6	45-50	AIS 2. Accident case Gγ †. Fracture of pubic rami. 13 year old male.
G5	400	4.5	7.5		
F4	167	2.0	3.6	40-50	AIS 3. Accident case Fβ †. Fracture of femur. 13 year old male #.
H3	246	2.6	4.8	20-30	AIS 3. Accident case Hα †. Fracture of pelvis. 37 year old female.
H5	177	2.2	3.6	38	AIS 3. Accident case Hβ †. Fracture of pelvis. 19 year old.
H7	215	2.4	4.2		

* The letter of the test number indicates the car model.
‡ These values are peaks of data filtered at CFC 180 Hz.
† Pedestrian accident cases are taken from Birmingham, Hannover and the KOB programme. Cadaver tests are taken from KOB.
# This victim was below average height and weight for his age.

Table 5. Kinetic Energy of Impactor Tests Reconstructing Accidents Involving Adults, Adjusted to Represent Tests at Standard Speed of 40 km/h, Compared with Deformation Energy from Computer Simulation

Test No. †	Accident case	Car Shape # (mm)	Impactor Kinetic Energy (J)	Accident Speed * (km/h)	Adjusted Kinetic Energy ‡ (J)	Energy from Computer Simulation ¶ (J)
C1	Cα	735/515/30	249	32	389	730
D2	Dα	700/420/130	778	48	540	541
F2	Fα	700/290/120	300	20-30	533-1200	558
G3	Gβ	780/490/80	332	25-35	434-850	807
H3	Hα	805/540/115	337	20-30	599-1348	833
H5	Hβ	805/540/115	273	38	302	833

† The letter of the test number indicates the car model.
# Cars shapes are given as Bonnet height / Bumper height / Bumper lead.
* Sub-system test G2 reproducing accident case Gα is not included here because accident speed quoted was speed before braking.
‡ Kinetic energy adjusted from the reported accident speed to a standard speed of 40 km/h by multiplying the impactor kinetic energy (required to reproduce the accident damage), by the ratio of the squares of the velocities.
¶ Deformation energy for car shape, obtained by interpolation between computer simulation curves (see Figure 4).

To show if small changes in test conditions resulted in identifiable changes in structural damage, sub-system tests were conducted in which the kinetic energy of the impact was increased and decreased by, on average, 17% (8% in velocity). In all cases but one the change in kinetic energy was matched by comparable changes in vehicle damage. Car type E (one of the popular cars used in the dummy tests) was insensitive to a small reduction in impact energy, although it was sensitive to an increase in impact energy.

Discussion

Impactor Performance

The design of sub-system impactor used in the tests reported herein, and proposed for the legislative tests, has been proven to be capable of producing structural car damage which is similar to the damage occurring in the popular car dummy tests and in real accident cases. The sub-system impactor has been used to make a total of forty tests against eight car models. The impactor has reproduced nine accident cases and three popular car adult dummy tests. Tests at speeds up to 40 km/h with the impactor have shown that it is generally robust. The foam covering has, however, shown evidence of deterioration from successive impacts and this was replaced when damage was noted. Studies will be necessary to determine a precise life for the foam covering or to find an alternative that will maintain the required performance for a greater number of tests.

In tests to date the clutch, provided to protect the guidance ram from high bending moments, has not rotated. It should be retained, however, for protection from car structures that result in off-centre loading in excess of the acceptance level.

The piezo-electric load cells gave outputs which provided an indication of the general stiffness of the car over the whole contact area, and hence of its potential to cause pelvic injuries. Piezo-resistive load cells could be used instead, however, provided that there is a uniform load path through the active elements, but this can be difficult to achieve with short load cells of this type.

The bending gauges gave outputs which could provide an indication of localised stiff areas within the contact area of the car under test which could cause femur injuries. The short length of the impactor compared with a typical adult femur has to be taken into account when comparing impactor bending outputs with those from dummy or cadaver tests (see Table 6).

Table 6. Femur Bending for Popular Car Tested with Adult Dummy, and Sub-system Impactor Tests that Gave the Same Damage

Test No.	Car model code	Femur bending ‡ (Nm)		Ratio: $\frac{D}{SS}$
		Dummy (D)	Sub-system (SS)	
Aγ	A	415	---	----
A2	A	---	235	1.77
A3	A	---	227	1.83
Bα	B	356	---	----
B6	B	---	218	1.63
Eα	E	441	---	----
E3	E	---	274	1.61
E4	E	---	303	1.46
E5	E	---	270	1.63

‡ 3 ms cumulative exceedences. The CFC is 600 Hz.

To make it possible for test houses to use existing propulsion systems, only the most significant features of the impactor and guidance system need to be specified. In general some form of linear propulsion and guidance system was considered to be most suitable for the test method. Pendulum systems may prove to be difficult. A gravity pendulum would need to be very long to achieve the test velocity and the mass of the pendulum arm would be a high percentage of the effective mass of the impactor. Short powered pendulums may be more practical but in both cases the effect of reducing the moment of inertia of the impactor by moving some of its mass to the pendulum arm would require study.

Determination of Impact Parameters

The parameters of vehicle shape that have been identified as important for specifying impact parameters are the height of the bonnet leading edge and the distance by which the bumper leads the bonnet leading edge (bumper lead). Computer simulations (18) indicate that the bumper height has less influence and, to simplify the proposed legislative procedure, the specification of the test parameters are given using only bonnet leading edge height and bumper lead.

Method to determine car shape. A range of different shaped vehicles, including models used in the popular car tests and involved in pedestrian accidents, were measured using a straight edge held at different angles to the vertical. These measurements were then compared with the points of contact found in the instrumented car to dummy tests and in the accident and dummy tests to popular cars. A method was then chosen to best identify the bumper and bonnet leading edge reference lines, and the extremes of the test area.

Impactor kinetic energy. The kinetic energy of the impactor is the most critical of the impact parameters as most of the applied energy is absorbed in deforming the vehicle structure, and the amount of kinetic energy determines the degree of structural damage to the car. The accident case cars were tested at higher and lower impact energies than that which reproduced the accident damage. All were found to be sensitive to energy changes, in that the car structural damage varied with impactor energy. Therefore, by reproducing accident damage the sub-system tests have established the accident energy of deformation.

Because kinetic energy is the most critical of the impact parameters it is preferable in a regulation to provide look-up graphs for impactor energy and velocity, rather than mass and velocity as the latter would increase errors in obtaining energy.

Changes in the energy of deformation that result from different heights of bonnet leading edge and from different bumper leads have been derived from mathematical computer simulations of dummy impacts by TNO (18) (see Figure 4). A curve at zero bumper lead is also shown derived from another computer simulation (19), as this was not available from the TNO simulation. Values of impactor kinetic energy from the sub-systems tests replicating accident damage, adjusted to a standard vehicle speed of 40 km/h are shown in Table 5. Where a velocity range has been quoted by the accident investigators, the adjusted kinetic energy also is given as a range. However, velocities and thus adjusted energies quoted as a single value may be equally uncertain.

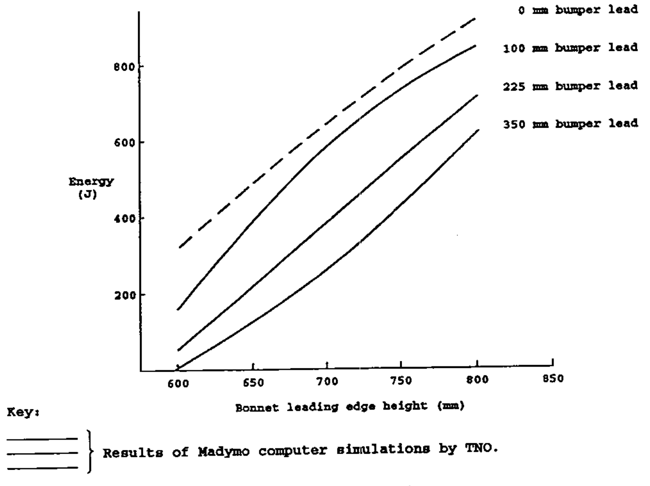


Figure 4. Energy of Deformation of Bonnet Leading Edge at Car Speed of 40 km/h

Also shown in Table 5 are values of deformation energy for each car shape obtained by interpolation between the computer simulation curves. Research (17) has shown that in identical crashes a dummy will cause more damage to the leading edge of a bonnet than a real pedestrian and the energy of deformation of the structure will therefore be less in real accidents. In the sub-systems tests the values of impactor kinetic energy that reproduced accident damage relate to real accident data, while the computer simulations were based on the performance of dummies. Also, the accident cases reflect the uncertainty in the reported accident speeds and the real world variation in the physiques of adults. The adjusted kinetic energies of the adult accident cases, calculated from the middle of the accident speed range, are on average 23% lower than the corresponding deformation energies obtained from the simulation curves. However the kinetic energy required to reproduce accident case Hβ, again adjusted to 40 km/h, is in very poor agreement with the simulation curves, and comparison with the similar accident case Hα suggests that the reported speed is not compatible with the accident damage. If this case is omitted from the above comparison, the average difference between adjusted values of kinetic energy and values of deformation energy derived by computer simulation is reduced to 11%. Therefore, the current best values of kinetic energy for use in a regulation are the computer simulations values reduced by 11%.

Femur and pelvis injury severities from cadaver studies (20) have been compared with the proposed impactor kinetic energies for the shapes of car used, adjusted to be appropriate for the reported car impact speeds. Impact energies below 188 J caused no substantial injury (AIS 0), energies in the range 240 to 334 J were responsible for injuries of severity AIS 2, and energies in the range 470 to 840 J related to AIS 4 level injuries. From this it can be seen that there would be no point in testing cars for which the impactor kinetic energy would be below 200 J.

Angle of impact. In the sub-system tests to reproduce accident damage the angle of impact was determined from the angle of the resultant impulse as derived from the instrumented car test data (7), discussed in an earlier section. Impactor angles obtained in this manner have needed no further adjustment to reproduce accident damage.

The instrumented car data (see Table 7) show that angles of impulse, and thus sub-system impact angles, for bumper leads of 250 mm are similar to those for leads of 150 mm, so the 150 mm lead angles could be used for all bumper leads greater than 150 mm. The major part of the instrumented car test programme used bumper heights of 400 mm. The average value for current European car designs and for the accident case cars is 500 mm. This difference in bumper height produces a difference in impact angles (+6° at 150 mm bumper lead). As bumper height is not to be used as a parameter in the look-up graph, an appropriate modification to the impact angle specification is required.

Table 7. Calculated from Reference 7 of 40 km/h Impacts between Instrumented Car and Pedestrian Dummy Adult—Angle of Resultant Impulse of Upper Leg Striking Bonnet, with Respect to Car Shape

Car dimensions (mm)				
Bonnet Height of leading edge	Bumper Height of top edge	Bumper lead		
		50	150	250
		Angle of resultant impulse (degrees)(from horizontal)		
600	400	29	--	--
700	400	26	35	35
750	400	29	35	34
850	400	22	25	26
750	350	--	35	--
750	400	29	35	34
750	450	--	43	--
750	500	--	44	--
750	550	--	46	--

Impactor mass. As discussed above the kinetic energy of the impactor is the most critical of the impact parameters and it is therefore better to obtain mass from kinetic energy and velocity. By permitting small variations in velocity, convenient increments of impactor mass can be used whilst maintaining the correct energy.

Impactor velocity. In the sub-system tests to reproduce accident damage the impact velocity was initially determined from the resultant velocity from the instrumented car test data (7), as discussed in an earlier section. Impactor velocities obtained in this manner have for the most part needed little adjustment to reproduce accident damage. This adjustment is accounted for by the adjustment to the impactor energy previously discussed, so no correction of velocity is required.

For a look-up graph, variations in impact velocity to the bonnet leading edge by car shape have been determined from the instrumented car tests and from computer simulations (18). The instrumented car test and computer simulation results are basically similar, although the differences increase slightly with increased bumper lead. The absolute values of velocity from the instrumented car tests should be more reliable than the computer simulation as it is based on a real dummy, whereas the simulation is based on a simplified mathematical model. However the trends of the simulation have been used to interpolate between the instrumented car data (see Figure 5). The results may need to be adjusted so that the required impactor mass is never impractically low (minimum 9.5 kg). This adjustment will only be required for low bonneted cars.

Methods of Determining Significant Values

For research purposes load cell and bending gauge outputs have been filtered to CFC 600 Hz and results quoted using 3 ms cumulative exceedences. Filtering to a different frequency or using peak rather than exceedence does however give different values, and in some cases the differences are large (see Table 8). The methods differ essentially in the timescale (of unfiltered data) over which they operate. The method chosen for the regulation should have a timescale which is similar to the timescale over which injuries can occur to the pedestrian femur and pelvis. However, in an accident it may take longer than in the sub-systems test to reach the force level necessary to initiate buckling, because the human femur is more compliant than the femur impactor. Methods involving 3 ms exceedences or data filtered at CFC 60 Hz may well produce values which do not reflect the injury causing potential of the car under test. It is therefore considered that the peak value of data filtered at CFC 180 Hz would be more appropriate.

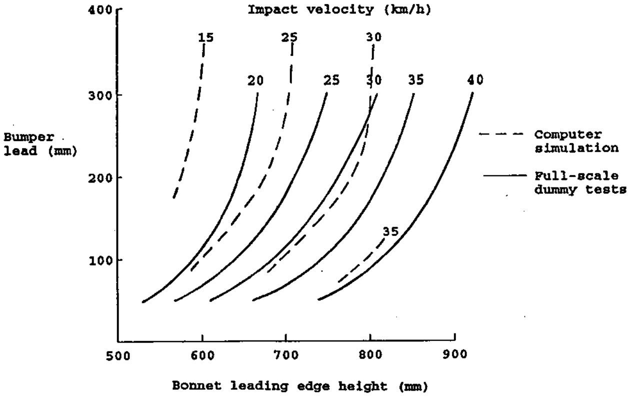


Figure 5. Impact Velocity from TNO's Computer Simulation and Derived from TRRL's Instrumented Car into Dummy Tests (7), with Respect to Vehicle Shape

Table 8. Comparison of Methods for Determining Significant Values, for Tests Reproducing Accident Damage

Test No.	Maximum bending moment (Nm)				Maximum impactor force (kN)				Sum of impactor forces (kN)			
	Exceedence †		Peak		Exceedence †		Peak		Exceedence †		Peak	
	CFC 600 Hz	CFC 180 Hz	CFC 180 Hz	CFC 60 Hz	CFC 600 Hz	CFC 180 Hz	CFC 180 Hz	CFC 60 Hz	CFC 600 Hz	CFC 180 Hz	CFC 180 Hz	CFC 60 Hz
C1	213	214	217	218	2.0	2.0	2.2	---	3.7	3.7	3.8	---
D2	260	257	263	258	3.7	3.7	4.0	3.7	6.7	6.7	6.9	6.8
D3	265	264	271	265	3.8	3.8	4.1	3.9	6.9	6.9	7.1	7.0
F2	232	233	236	237	3.8	3.8	4.0	3.9	5.8	5.8	6.0	5.9
F4	138	139	167	150	1.9	1.9	2.0	2.0	3.6	3.6	3.6	3.6
G2	247	244	254	250	2.4	2.4	2.6	2.4	4.7	4.7	4.9	4.7
G3	228	230	244	236	2.3	2.3	2.6	2.4	4.5	4.5	4.8	4.6
G4	286	278	403	326	3.3	3.2	4.8	3.6	5.5	5.2	7.6	6.1
G5	278	280	400	325	3.1	3.1	4.5	3.6	5.2	5.2	7.5	6.0
H3	154	165	246	198	2.3	2.3	2.6	2.4	3.6	3.5	4.8	4.0
H5	169	168	177	175	2.1	2.1	2.2	2.2	3.5	3.5	3.6	3.6
H7	189	185	215	197	2.1	2.1	2.4	2.3	3.7	3.7	4.2	3.9

† The exceedence is calculated as a 3ms cumulative exceedence.

Acceptance Levels

The maximum impactor force, sum of impactor forces and maximum bending moment for the tests which reproduced accident damage are shown in Table 4 as peak values at CFC 180 Hz. The corresponding accident and injury details are also shown.

Unfortunately, the relationship between forces and bending moments measured in the replication tests and the observed injury levels in the accident cases is confounded by the wide variability of injury tolerance in individual pedestrian casualties. For example, in the three tests that reproduced accident damage resulting in injury severities of AIS 3, the maximum measured values of force were between 2.0 and 2.6 kN from individual load cells and between 3.6 and 4.8 kN for the summation of the top and bottom load cells. Comparable values associated with injury severities of AIS 2 or less were 2.2 to 4.8 kN for individual load cells and between 3.8 to 7.6 kN for the summation of the forces. The maximum values of bending moment measured were between 167 and 246 Nm with respect to accident cases involving injuries of AIS 3 and between 217 and 403 Nm with respect to accidents involving injuries of AIS 2 or less.

The wide overlap of force and bending moment levels associated with different levels of injury in this study may be partly attributed to the wide range of tolerance strengths that exist in pedestrians and partly because the accident cases were chosen to include only cars which sustained an identifiable amount of damage. This damage would tend to ameliorate the severity of resulting injuries and thereby bias the test sample to cars having a limited risk of causing injury, except to the weaker members of the population.

On the basis of these values of force, 4 kN would be an appropriate acceptance level for the sum of impactor forces. This value is an average force for the AIS 3 cases studied and will require further evaluation. Because of the mass of the impactor that is forward of and not measured by the load cells this would in practice allow a total force of at least 5 kN to act on the bonnet edge.

On the basis of these values of bending, 220 Nm would be an appropriate acceptance level for the bending moment. This value is an average of the two higher bending moments associated with injuries of AIS 3 (after first averaging bending moments from the two tests reproducing accident case Hβ). The lowest value of 167 Nm associated with an AIS 3 injury reproduced an accident involving a youth who was particularly undersized for his age.

From Table 6 it can be seen that the bending moments measured during popular car into dummy tests are on average 1.65 times the magnitude of those recorded in impactor tests that caused similar vehicle damage. This difference is largely due to the ratio of lengths of the impactor and dummy femur. Using this ratio the acceptance value of 220 Nm for the impactor bending moment can be compared with reported values of ultimate strength given in the literature from static three point tests on complete femurs. Reported test values of force and span (21) have been used to calculate bending moments at fracture, which ranged from 150 to 468 Nm and averaged 293 Nm. Bending moments at fracture were reported (22), averaging 180 Nm for female and 310 Nm for male femurs in one series of tests, and ranging from averages of 234 Nm for the 20 – 39 year old age group to 184 Nm for the 70 – 89 year old group in a second series. Taking into account the reduced length of the impactor 'femur', the acceptance level is towards the higher end of the range found in these static tests of human femurs bones. However, static tests may cause fractures at lower values of bending moment.

Test Proposals

In a test the sub-system impactor is propelled into the location on the bonnet leading edge that is to be assessed, and the safety afforded is evaluated by measurements of force in the load cells and of bending moments from strain gauges attached to the simulated femur (see Figure 6). The general shape of the car influences the parameters of the sub-systems test and the important test parameters are therefore varied with respect to certain aspects of car frontal shape. These proposals are based on the sub-system tests, instrumented car into dummy tests and computer simulations as discussed in the previous section.

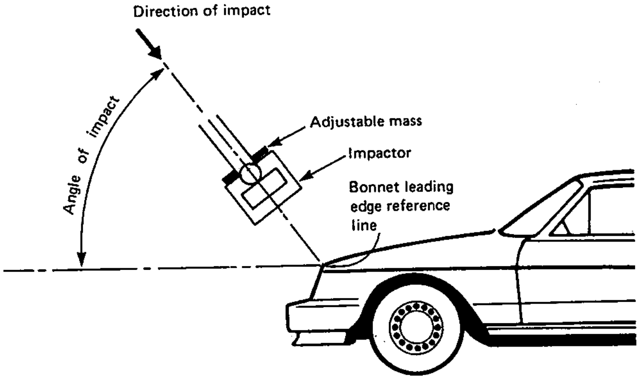
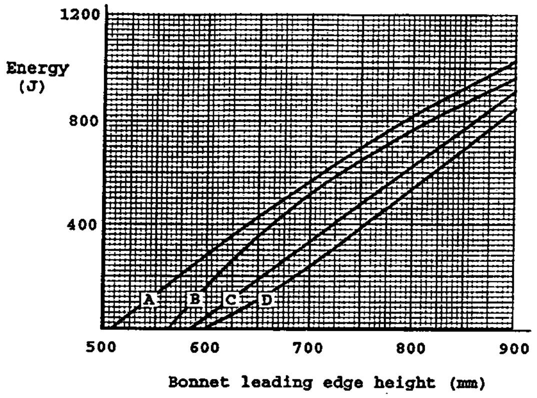


Figure 6. Proposed Upper Leg to Bonnet Leading Edge Impact Test

The method of determining sub-system impact parameters for the proposed regulation is outlined below. The proposed look-up graphs for impactor kinetic energy, velocity and angle can be found in Figures 7, 8 and 9.

Measurement of car shape to determine the bonnet and bumper reference lines is specified as follows:

The bumper reference line is the line of the uppermost points of contact between bumper and a straight edge inclined at an angle of 20° (see Figure 10). The bonnet leading edge reference line is the line of the points of contact between car and a straight edge inclined at an angle of 50° (see Figure 11). The bumper lead is the horizontal distance between these reference lines. Values of these measurements are then taken for the lateral position that is to be tested.



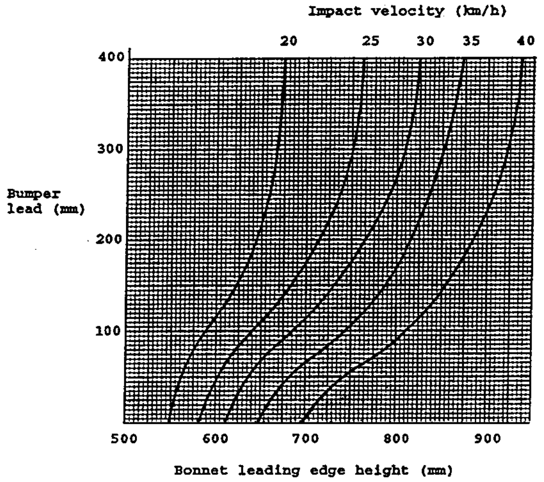
Key:-

A = 0 mm bumper lead
B = 100 mm bumper lead
C = 225 mm bumper lead
D = 350 mm bumper lead

Notes:

1. Interpolate vertically between curves.
2. With negative bumper leads - test as for zero bumper lead.
3. With bumper leads above 350 mm - test as for 350 mm.
4. With bonnet heights above 900 mm - test as for 900 mm.

Figure 7. Kinetic Energy of Impactor with Respect to Vehicle Shape

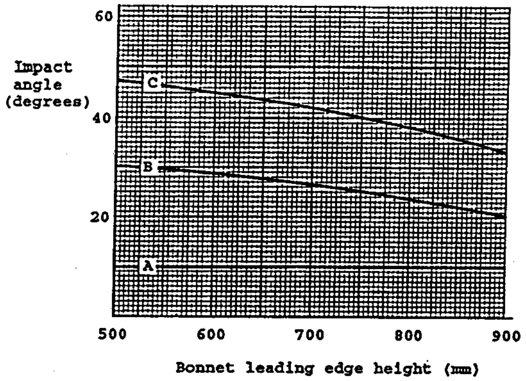


Notes:

1. Interpolate horizontally between curves.
2. Minimum test velocity 20 km/h.
3. With configurations above 40 km/h - test at 40 km/h.
4. With bumper leads above 400 mm - test as for 400 mm.

Figure 8. Velocity of Impactor with Respect to Vehicle Shape

The impactor kinetic energy, velocity and angle of impact for a particular vehicle shape is read off the look-up graph using the measurements of bonnet height and bumper lead as determined above. No bonnet leading edge test will be required for cars for which the impactor kinetic energy would be below 200 J. The impactor mass will then be calculated from the specified values of kinetic energy and velocity. Small (±5%) variations in velocity will be permitted to allow the use of convenient increments of impactor mass. The proposed velocity curves have been adjusted so that the required impactor mass is never impractically low (minimum 9.5 kg).



Key:-
A = 0 mm bumper lead
B = 50 mm bumper lead
C = 150 mm and greater bumper leads

Notes:

1. Interpolate vertically between curves.
2. With bumper leads above 150 mm - test as for 150 mm.
3. With negative bumper leads - test as for zero bumper lead.
4. With bonnet heights above 900 mm - test as for 900 mm.

Figure 9. Angle of Impact of Impactor with Respect to Vehicle Shape

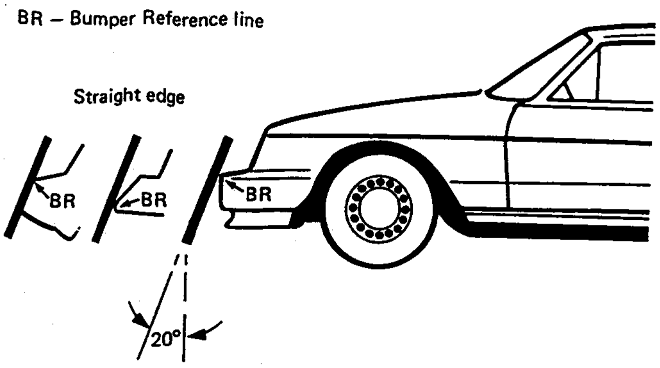


Figure 10. Determination of Bumper Reference Line

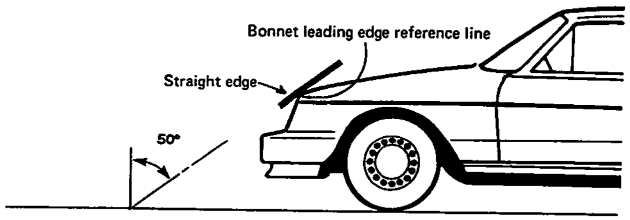


Figure 11. Determination of Bonnet Leading Edge Reference Line

The proposed acceptance levels are: the sum of impactor forces shall not exceed 4 kN, and the maximum value of femur bending shall not exceed 220 Nm (peak values at CFC 180 Hz).

Conclusions

1. Accident data have shown that significant reductions in pedestrian injury can be anticipated from improvements in the protection afforded to pedestrians that are effective at speeds up to 40 km/h.
2. The accident studies, supplemented by dummy tests and computer simulations, show that there are three

principle contact areas on the vehicle that need to be addressed, the bumper, the bonnet leading edge and the bonnet top.

3. TRRL has developed a sub-systems test method to assess the protection afforded to pedestrians against injuries from the bonnet leading edge. This test method is based on an impactor representing an adult femur and which is permanently mounted on a guidance ram.
4. The general shape of the car influences the parameters of the sub-systems test method and the important test parameters are therefore varied with respect to certain aspects of car frontal shape. A set of look-up graphs are provided in the proposal so that impactor energy, angle of impact and impact velocity can be determined for any car shape.
5. Comparisons between sub-systems test data and the injuries and vehicle damage sustained in car to pedestrian accidents have been used to examine the relationship between the measured force and bending moment on the impactor and likely injuries to pedestrians, but this is confounded by the large variation in strength between individual pedestrians. Performance requirements are given in terms of peak impactor force and bending moment and the proposed acceptance levels are 4 kN for peak total force and 220 Nm for peak bending moment.
6. The impactor has proved to be simple to use, repeatable and generally robust.

Acknowledgements

The work described in this paper forms part of the programme of the Transport and Road Research Laboratory and the paper is published by permission of the Director. Partial financial support from the European Commission is gratefully acknowledged.

References

1. Statistics of Road Traffic Accidents in Europe. United Nations - New York, 1991.
2. EEVC Committee. Pedestrian injury accidents. Proceedings 9th International Technical Conference on Experimental Safety Vehicles, Kyoto, Japan, November 1982.
3. Hobbs C A et al. PSC1 - Demonstration car with improvements for pedestrian protection. Proceedings Tenth International Technical Conference on Experimental Safety Vehicles, Oxford, England, July 1985.
4. Huber G. Aspects of passive safety in Mercedes-Benz research car. Proceedings Ninth International Technical Conference on Experimental Safety Vehicles, Kyoto, Japan, November 1982.
5. Kramer M. Improved Pedestrian Protection by Reducing the Severity of Head Impact onto the Bonnet. Proceedings Seventh International Technical Conference on Experimental Safety Vehicles, Paris, France, June 1979.
6. Harris J. Simplified test recommendations for pedestrian protection. Proceedings 10th International Technical Conference on Experimental Safety Vehicles, Oxford, England, July 1985.
7. Lawrence G J L. The influence of car shape on pedestrian impact energies and its application to sub-systems tests. Proceedings 12th International Technical Conference on Experimental Safety Vehicles, Gothenburg, Sweden, May 1989.
8. Lawrence G J L., Harris J. Car to pedestrian impact energies and their application to sub-systems testing. Proceedings 11th International Technical Conference on Experimental Safety Vehicles, Washington, United States, May 1987.
9. Tunbridge R J. The use of linked transport-health road casualty data. Department of Transport, TRRL Report RR96. Transport and Road Research Laboratory, Crowthorne, 1987.
10. Lawrence G J L et al. Development of a bonnet leading edge sub-systems test to assess protection for pedestrians. TRRL report under Contract No. ETD/89/7750/M1/28 to the European Commission. January 1991.
11. Otte D. Influence of vehicle front geometry on injuries to pedestrians involved in accidents. Study of accident research at Medical University of Hannover under contract to BASt, 1988.
12. Ohashi H et al. The present situation of pedestrian accidents in Japan. Proceedings 1990 IRCOBI Conference, Lyon, France, September 1990.
13. Ashton S J. et al. Pedestrian injuries and the car exterior. Society of Automotive Engineers Transactions, SAE paper 770092, Warrendale, Society of Automotive Engineers, 1977.
14. Fowler J E., Harris J. Practical vehicle design for pedestrian protection. Proceedings 9th International Technical Conference on Experimental Safety Vehicles, Kyoto, Japan, November 1982.
15. Gaebler F S. Anthropometric data for designers, a critical evaluation. Warren Spring Laboratory. Research Report No: RR/ES/58.
16. Janssen E G. Protection of vulnerable road users in the event of a collision with a passenger car, part II - Sub-system test method evaluation and compatibility study. TNO report No: 75405002/II December 1, 1990.
17. Lenz K H. Joint biomechanical research project KOB, BASt, Cologne, F R Germany. Unfall- und Sicherheitsforschung Straβenverkehr, Vol. 34, 1982.
18. Janssen E G., Nieboer J J. Protection of vulnerable road users in the event of a collision with a

passenger car, part I - Computer simulations. TNO report No: 75405002/I December 1, 1990.

19. Harris J., Grew N D. The influence of car design on pedestrian protection. Proceedings 10th International Technical Conference on Experimental Safety Vehicles, Oxford, England, July 1985.
20. Eppinger R., Kulkarni Y. Relationship between vehicle front structure and injury to the adult pedestrian hip area. Proceedings 8th International Technical Conference on Experimental Safety Vehicles, Wolfsburg, West Germany, October 1980.
21. Stcherbatcheff G., Fayon A., Tarrière C. Biomechanical simulation of the legs. Proceedings 1973 IRCOBI Conference, Amsterdam, the Netherlands, June 1973.
22. Nyquist G W. Injury tolerance characteristics of the adult human lower extremities under static and dynamic loading. Proceedings SAE symposium on biomechanics and medical aspects of lower limb injuries, California, United States, October 1986.

S3-W-23

Inadequate Head and Neck Protection of Child Seats

Donald Friedman
Liability Research Group

Abstract

Eleven case investigations of the severe to fatal (AIS 4 to 6) injuries sustained by young children (two weeks to 2 years) in FMVSS 213 certified child seats, during foreseeable accidents and circumstances, are described in some detail. Using the analytical protocol of SAE #890382 (Live Subject Safety Research), head injuries to the involved infants and children were duplicated and the injury reduction effects of simple and inexpensive child seat modifications were demonstrated. The conclusions are as follows: the forces to a child's head through child seat head surfaces are not limited when contacting an intruding vehicle interior, although such energy absorption protection could be provided at little additional cost. Furthermore, child seats designed for infants "up to 20 pounds" are unsafe for newborn infants.

Introduction

The purpose of this document is to describe some typical case studies identifying two areas of foreseeable injury accidents (that are not addressed in the current version of FMVSS 213) and potential countermeasures, as well as to inform the safety community of the conclusions resulting from these efforts. This paper will discuss:

1. Head injury results from intruding vehicle interior contacts.
2. Seats are unsafe for children weighing less than ten pounds.
3. Head protection by low cost energy absorption.

Background

After 15 years of European experience in injury reduction (as a result of mandatory belt use laws), a similar national effort was undertaken in the late 1970's to get American adults and children "buckled up."

The Laws of Physics and the Biomechanical knowledge of the human body make clear that no one design can accommodate the entire range of human sizes. Addressing restraint performance through dynamic testing, the Federal Government has identified six general size and weight categories: 6'2", 210#; 5'10", 165#; 5'2", 105#; 46", 65#; 39", 34#; and 25", 17#. NHTSA is currently adding a 7.5# dummy to represent the newborn infant. Such categorizing doesn't mean that a 165#, 5'2" woman shouldn't be protected. In fact, Federal standards are "minimum performance" requirements, leaving considerable latitude to manufacturers to design for "foreseeable" circumstances within size and age categories.

NHTSA is required to regularly assess the efficacy of production restraint designs in use and produced to the standards, to recognize statistical product deficiencies and to encourage improvement. In 1985, a published government study about 1978 to 1983 products summarized for the industry what they already knew: "misuse" of child seats was the leading cause (60%) of injury to children in such seats.

When child seat restraint-use laws went into effect (now in every State of the Union), it became incumbent on parents, hospitals and manufacturers to take the necessary steps to protect all children during transportation, from birth to 4 years of age; it was not legally acceptable for a newborn infant to ride home from the hospital in its mother's arms.

Principally, because manufacturers identify and label their infant seat products "for use by children up to 20#," hospitals and parents are led to believe that use of the product will reasonably protect such infants (implied warranty). Such seats, in the rigorously defined circumstances of an FMVSS 213 dynamic test, will perform adequately with a 7.5# and even a 5.5# dummy. But it is well understood that this test is only the tip of the iceberg of manufacturers' real responsibility which is to protect real live infants under foreseeable circumstances.

Since my retirement from MCR Technology, Inc. in 1984, I have developed an analytical protocol to understand real world injury accidents and the effect of vehicle and restraint design parameters on the level of injury. The procedure was reported in SAE paper #890382, March 1989, entitled "Live Subject Safety Research Side Impact." The work has been financed by litigating attorneys located across the United States, and now encompasses some two hundred investigations in most accident modes; more than twenty of those cases involve children in child seats.

I have also developed several types of car seats and carriers for newborn infants as reported in SAE paper #890753, March 1989 entitled, "The Cradle Infant Restraint: A Low Cost, State-of-the-Art Advance in Infant Occupant Protection." In addition two U.S. patents, #4,804,230 and #4,934,004, cover the safety features of these designs.

Case Studies

Two case studies involve two different child restraints which are basically designed to accommodate a 17# dummy, to represent a 6 month old child, and for children sufficiently well developed to support or raise their head. Child seats are designed to sell and therefore attempt to provide for usage by the child for the longest possible time.

The result is a defective compromise of the ability of the seat to accommodate the newborn infant of one-half to one-third of the design weight and size. In the case of the "Century Infant Love Seat," instructional videos for parents recognize the danger to newborn infants and suggest rolled towels to help support the head from falling sideways when the child sleeps. But no consideration is given to the infant's propensity to roll its head forward (chin to chest) and block his air passage because of the verticality of the seat back.

A second defect of the "Century Infant Love Seat," with respect to small newborn infant children, is the internal harness. Infant seats are also used as carriers for newborns. They are frequently placed in the seat in the nursery and carried to the car. In the nursery, the seat on a flat surface is more reclined than in the car, which is when the infant is placed in it, the shoulder harness straps and their cross-tie or clip is fastened. Then, the infant in the "Infant Love Seat" is carried and installed in the car which increases the verticality of the seat back due to the typical 15 degree inclination of the seat cushion.

While the seat is reclined, the seat back supports the child's head and spine. However an unaided newborn infant's spinal musculature cannot support its head or torso in a near vertical sitting position. In fact, the head and spine want to go into the fetal position, and the crotch strap of this particular harness does nothing to prevent this. The result is that the child tends to slide down in the seat, increasing the probability that the correctly positioned cross-tie will end up at the throat, subsequently cutting off its air supply.

Another case involving the "Century Infant Love Seat" focused on the plastic protrusion molded into the upper portion of the seat back. The seat with a harnessed six month old child was secured, and facing forward into the rear seat of a car which was rear ended. The seat and child were propelled forward from the rear end intrusion before the seat belt and inertial forces caused them to move rearward. The child's head struck the protrusion producing a linear displaced fracture of the skull and brain damage.

No reasonable explanation was given as to why the protrusion was there in the first place, why it had never been removed during the twenty year sales life of the seat, and why it had never been padded as was the remainder of the seat interior.

From the previous case descriptions it was concluded, to a reasonable degree of engineering certainty, that the defects in the design and labeling of the "Century Infant Love Seat" were the direct cause of brain damage.

The seat as designed, produced, sold and labeled (warranted) was therefore unsafe, defective and unreasonably dangerous. The seat has now been voluntarily taken off the market by the manufacturer.

Five other case studies involve side impact intrusion into contact with a rear facing child seat. During the accident, the infant's head comes into contact with the near side forward interior of the rear facing child seat as the seat belt restrained seat swings towards the interior and the intrusion. In effect, the child's head is struck by, or strikes, the intruding vehicle surface through the simple interior padding and single wall thickness of the child seat.

Evidence of such events is clearly recorded by injury to the intruding side of the side/rear of the child's skull and from markings on the plastic exterior of the seat or the distortion of its tubular frame resulting from its contact with the vehicle interior.

Two other cases involved forward facing seats in which the small child's head, 11 months and 16 months old, properly restrained in the seat, struck a portion of the vehicle interior through the wing of the seat as a result of side impact inertial and intrusion forces.

Another case involved an 11 month old infant in a convertible child seat, forward facing and properly secured in the front passenger bucket seat with an unrestrained adult in the rear seat. During an accident of moderate severity, the rear adult augmented the inertial angular rotation of the child seat and the child's head to peak neck angular acceleration at near 15,000 radians/second squared, resulting in a severe neck extension (the opposite of compression) and permanent quadriplegia.

Analysis and Instrumentation

Each of these cases were analyzed using computer simulations of the vehicle trajectory, occupant kinematics and the resulting injury measures. These were compared to modified seat configurations which incorporated energy absorbing deformable surfaces using the same analytical configuration. In the computer models, we can define the instrumentation outputs with the stroke of a key. But the ability to compare computer simulations with physical testing is limited by the lack of instrumented dummies in the "under three-year old" size.

A petition to include accelerometer instrumentation in child dummy heads has been denied by the NHTSA. Until such instrumentation is available, the current containment standard cannot be modified to require child seat manufacturers to protect the child's head from interior contact through the seat. The computer test procedure which includes instrumented dummies has been accepted in litigation since there is no feasible alternative.

Recognizing that regulatory tests are for minimum performance, perhaps manufacturers should consider foreseeable accident circumstances by means of an analytical protocol. Restraint and automotive design people often implement such results in their design process, although they rely on physical testing to establish regulatory compliance.

An uncertainty about the level of force safely sustainable by the newborn-to-infant child head is sometimes given as the reason why dummy head instrumentation is unnecessary. This is based on the presumption that such instrumentation would lead to further regulations. In the meantime, infants are seriously injured and killed by a lack of energy absorbing padding to protect the head from a direct strike rather than an inertial force.

It would be possible and appropriate to conduct a physical side impact sled test with a part 572 infant dummy properly secured in a child seat which tilts into a surface wall of the sled. This test could then be modeled from photographic target analysis to produce the same kinematic time history. The model then would provide all instrumentation output and allow parametric variations to identify the effect of design changes.

We could certainly wait a few years to determine the optimum allowable force level, but there is enough data to establish a reasonable criteria for design if not for regulatory purposes.

Conclusions

Based on this research and case experience, I have come to the following conclusions:

1. FMVSS 213 provides for child seat protection of children from inertial forces by containment;
2. except for misuse, injuries in child seats are not often the result of inertial forces alone;
3. neither protection for children in child seats or the appropriate design of the seats for non-inertial impacts result from FMVSS 213 testing;
4. serious injuries are the result of contact forces with the interior of the seat and the interior of the car through the seat;
5. because of the fragility of the head and neck of a 5 to 20 pound infant, foreseeable accident circumstances require protection from the following three features of an infant child seat, yet they are currently unavailable:
   a. it must fit the current size of the rapidly growing newborn;
   b. it must have appropriate energy absorbing thickness and resilient load distributing interior padding; and
   c. it should preferably separate the head and padding from the potential external-to-the-seat strike (blow) by a deformable double walled energy absorbing structure.

   These features have already been incorporated in the "Cradle-Safe" newborn/infant seats, and they can be inexpensively incorporated into current designs.

In essence, the rejection of petitioned modifications for head instrumentation to FMVSS 213 dummies and testing, removes any incentive to incorporate or produce infant seats with such improved safety features.

References

1. *An Investigation of the Increase in Child Passenger Fatalities Since 1984*, Department of Transportation, September 1990.
2. Clark, Carl C., *Learning from Child Protection Devices and Concepts from Outside the United States*, SAE 831666, October 1983.
3. Friedman, Donald, *The Cradle-Safe Infant Restraint: A Low Cost, State-of-the-Art Advance in Infant Occupant Protection*, SAE 890753.
4. Friedman, Donald, *Live Subject Safety Research Side Impact*, SAE 890382
5. Hitchcock, Ralph J., Nash, Carl E., *Protection of Children and Adults in Crashes of Cars with Automatic Restraints*, October 1986.
6. Kahane, Charles J., Ph.D, *An Evaluation of Child Passenger Safety: The Effectiveness and Benefits of Safety Seats*, NHTSA Technical Report, February, 1986.
7. Melvin, John W., Weber, Kathleen, *Dynamic Testing of Innovative Solutions to Child Occupant Protection Problems*, September 1984.
8. Stephenson, R. Rhodes, *NHTSA Child Safety Activities*, SAE 791015, 1979.

Technical Session 4
Safety Improvements from Advanced Vehicle/Highway Technology

Chairperson: Bernard Durand, France

S4-O-01

Driver Needs and Safety Effects of PROMETHEUS Functions

Hélène Fontaine and Gilles Malaterre
Institut National de Recherche sur les Transports et leur Sécurité

Abstract

The research program PROMETHEUS aims at improving road safety, traffic flow, comfort of road users, with less impact on the environment. For that, 23 functions have been envisaged. Among them, 14 are directly linked to safety. One of the tasks of the PRO-GEN Safety Group has been to estimate the potential efficiency of these PROMETHEUS functions. The work was carried out in different countries. An assessment of the safety effects of these functions has been made by INRETS, sponsored by RENAULT. We used for this study, a sample of 3200 police reports, nationally representative of the injury-producing accidents occurred in 1989. We tried to answer two questions:

- What are the driver needs in information and assistance from a safety point of view? 17 main needs have been detected from the police reports. The accidents would have been probably avoided if these needs had been completely satisfied.
- What is the efficiency of each PROMETHEUS function, when a driver need is identified? It is difficult to answer this question in so far as the practical features of the functions are not well known. So we used theoretical descriptions of them.

Conclusions are drawn about the main driver needs from a safety point of view, and about the evaluation of potential efficiency of some functions, which aim at assisting the driver in his task. But there are some limits in this research according to the assumptions made:

- all things being equal: the results will not be canceled out by side-effects,
- all technical problems will be solved.

These assumptions are theoretical, so the results must be used mainly in order to hierarchize the safety effects of the PROMETHEUS functions.

Introduction

The research program PROMETHEUS has several objectives, and while safety is of considerable importance, other aspects such as traffic control, reducing pollution and increasing user comfort must not be neglected. Although the link between these aspects and user safety is no longer in question, the nature of this link and the resulting effects have yet to be studied. Better control can indeed reduce conflicts, but at the same time increases flow, and perhaps speeds: side effects cannot therefore be discounted. Most importantly, as certain driving sub-tasks will be taken in hand by automatic devices, the task will be modified to an extent which is difficult to imagine at the present time, and will thus most probably influence behaviour. It is therefore to be expected, even desirable, and certainly not as some maintain to be condemned, that man will adapt to these new driving conditions, with all the positive and negative effects this may entail. Even if, as one may hope, the positive aspects outweigh the negative, these must nevertheless be taken into account insofar as they are predictable. Both the reliability of the different systems and the way non-equipped users are dealt with will be decisive factors. Greater complexity will obviously result in greater vulnerability, with additional risks for those who trust these automatic devices implicitly, or no longer take unusual events into account.

Assessing the benefits which Prometheus can provide from a safety standpoint is a highly complex work. One of the tasks of the PRO-GEN Safety Group has been to estimate the potential efficiency of 14 PROMETHEUS functions directly linked to safety. The work was carried out in different countries. An assessment of the safety effects of these functions has been made by INRETS.

This paper aims at presenting this evaluation based on accident reports. The method used does not lend itself to speculation regarding changes in behaviour. The frame of reference used for this work will therefore be as follows:

- For each accident situation, determine which needs (information or aid), when not satisfied are directly related to the identified accident mechanism. These needs will be identified using a list based on previous research work (Van Elslande and Malaterre, 1987, Fontaine et al. 1989).
- Evaluate whether the Prometheus functions adapted to these needs, would have provided a means of satisfying them. This evaluation will take into account the performance of the aids which correspond to these functions and the assumed ability of drivers to use them to their full potential.

- The sample used is the nationally representative 1/50 INRETS file for 1989, i.e. approximately 3200 accident reports (Fontaine et al. 1990).
- The reliability of aids is to be assumed as total, and the interfaces (MMI) suitably adapted to driver capabilities.
- It will be assumed that all things will remain equal, i.e. that the changes in the structure of the driving task, in particular side effects resulting from the use of these aids, will not be taken into account.

Despite the inherent limitations of this method, we believe that it is possible to categorize the advantages of the different functions in relation to safety. If these results can be compared to more technical estimates of feasibility and cost, they will provide essential factors with regard to areas which must be given immediate priority.

What are the Driver Needs in Information and Assistance from a Safety Point of View?

We determine needs using accident data. The advantage is that these data are objective and quantifiable. The disadvantage is a lack of detail with regard to data on the psychological procedures used by drivers during the event sequences which result in an accident. This is why, in the first step, use was made of data from the in-depth Salon-de-Provence survey (Ferrandez et al. 1986). The way data was collected (on the spot, in real time) and the depth of analyses (cinematic reconstruction, interviews with those involved) made it possible to list what are termed accident mechanisms. This term applies to modes in which situations, actions and factors can combine in such a way as to result in an accident. The driver is the main regulating factor in the system. It is usually possible to identify "errors" in the driver's Perception-Decision-Action sequence; this concept does not necessarily involve the responsibility of the driver in the legal sense of the term. These "errors" can easily be matched to needs. Had this need been satisfied the error and therefore the accident, could have been avoided.

List of Needs

The list of needs is given below:

Status diagnosis:

- Driver status. When driver performance is diminished by fatigue, alcohol, drugs or certain medicaments. The relevant need consists of having a normal level of alertness. On the other hand, being distracted by an event occurring outside or inside the vehicle was not considered to be part of this need. The "attention" need was not taken into account as it was too difficult to evaluate using accident reports.
- Vehicle status. When a mechanical defect contributes to the accident or the ineffectiveness of the emergency manoeuvre: tyre pressure, condition of tyres (wear, different makes of tyre on the same axle), shock absorbers, braking circuit (pressure and condition of linings), condition of headlights, steering failure. The relevant need is an early failure diagnosis. There is "no need" when the driver is aware of the defect in question.

Timely detection:

- Detecting a road-related difficulty: dangerous bend, particularly if this forms a route discontinuity, intersection with no right of way, ice, fog, etc. For this need to be coded, the driver must have encountered an unexpected difficulty. It will also be coded in cases relating to roadside visibility needs (e.g. fog).
- Obstacle detection. Any obstacle, fixed or mobile, which the driver has not seen or sees too late to avoid the accident. This is not to be confused with understanding the manoeuvre of another road user, or anticipating his intentions. For this need to be coded, the obstacle must be in position on the road sufficiently in advance for drivers to be able to take this information into account.
- Detecting an oncoming user in movement. Vehicles obscured by a bend, a hump, another vehicle or poor visibility (fog, rain, glare from the sun...). This applies to front end or minor collisions, and to certain overtaking manoeuvres, with the exception of those due to poor evaluation of the time required to overtake.
- Detecting a user on a lateral course. To be coded only if it is certain that the other user was seen too late to avoid the accident (in cases of obscured visibility, particularly in built-up areas). This also applies to pedestrians who cross the road without seeing the approaching vehicle (need for pedestrian to detect vehicle).
- Detecting a user outside the frontal field of vision. This applies essentially to vehicles behind or to the side, e.g. in blind spots, when overtaking, changing lane, etc, and which impede the manoeuvre in progress (change of direction, overtaking).
- Detecting a pedestrian. Specific cases of the four previous needs. Applies to pedestrians who cross without having been previously detected, either because they were obscured, or because the driver did not pay attention to them until they started to cross.

Correctly assessing time distance and speed:

- Adapting speed to road conditions. Cases where speed is excessive in relation to road layout or skid resistance (running off the road in bends, loss of control in straight stretches, except when due to falling asleep). Does not apply when speed is excessive only in relation to mobile obstacles which cannot be avoided.
- Catching up on a slower road user. This applies in two cases:

  - When on a fast lane a driver is suddenly faced with a vehicle travelling at a slower speed or which has just stopped, due in particular to traffic congestion, and when it takes him some time to realise that this vehicle is travelling slower than his own vehicle.
  - When travelling in a lane of traffic a road user is surprised by the sudden braking of the vehicle in front of him.
- Estimating a collision course with another user. When at an intersection a user who has not halted at a stop sign, badly assesses relative movements (in relation to another user who has also not halted at a stop sign) and drives on. Does not apply when the other user is seen too late.
- Assessing gaps when overtaking or changing lane. Only applicable if the other users have been seen. Cases where the relative movements or time required to manoeuvre have been badly assessed.
- Assessing gaps when joining or cutting across a traffic flow. This applies to users who generally do not have right-of-way and who have to cut across or join a denser or faster-moving traffic flow. This often applies to moving off from a stop sign, or re-accelerating after changing direction at low speed.

Understanding or predicting the behaviour of another road user:

- Predicting that another user will move off or fail to stop. This applies mainly at intersections. A driver who has or believes he has right-of-way, thinks right up until the last moment that the other vehicle will let him through. This need is related to predicting the intentions of others.
- Predicting the manoeuvre of another user. This is similar to the previous case but is not related to right-of-way. It applies in cases where intentions of others are wrongly interpreted (overtaking, changing direction).
- Predicting pedestrian behaviour. A specific case of the previous need. This applies when a pedestrian who can be seen does not do what is expected of him (e.g. crossing in front of a vehicle, or turning back when crossing, etc.).

Having sufficient control to carry out intended manoeuvres correctly:

- Vehicle control. Note: there may be several causes for lack or loss of control, in particular the non-perception of a difficulty. In this instance it concerns the correct assessment of vehicle capabilities, and putting into effect the appropriate inputs, other than emergency manoeuvres, in particular driving wheel movements.

Needs Analysis

There is a large percentage of users without any need. This corresponds to drivers who are generally passive during the accident sequence, i.e. who are run into and who are unable to attempt evasive action. If the indeterminate category is also removed, it can be seen that a need could only be identified for 70% of the users in this sample. To be more accurate, however, a distinction must be made between indeterminate and no-need users. No aid can be applied to a no-need user, whereas indeterminates probably have needs which it has not been possible to identify.

The needs were coded for all users, even those who cannot, a priori, be equipped with driving aids, namely pedestrians and 2-wheelers. This gives greater flexibility to later analyses, and makes it possible to draw up a complete table of the need structure for all those involved in the accidents. Here, we give only results concerning 4-wheelers (figure 1).

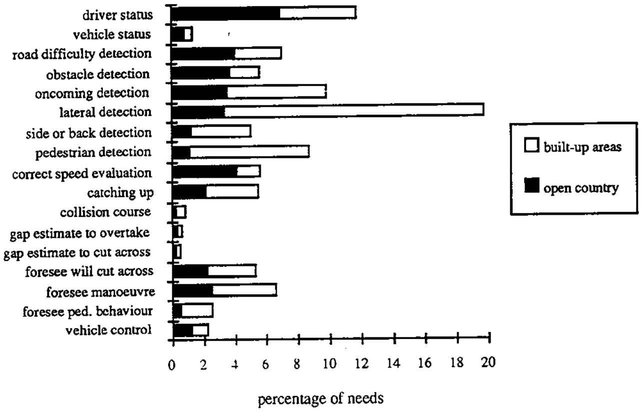


Figure 1. Break-down in 17 Categories of 4-Wheelers' Needs

Seventy-two percent of injury-producing accidents occur in built-up areas. Needs are not the same as those in the open country and will not probably be covered by the same aids. Traffic volume and bad visibility would also seem to suggest that it will be more difficult to operate aids correctly in built-up areas than in the open country. This is why this distinction is made in figure 1. The shaded area of each bar of the figure corresponds to needs identified in open country, where it is thought that some of the driving-aids will first apply. It can be noticed that the needs for detection or prediction are very important. The main need is for lateral detection, that is the need for detecting in time a vehicle approaching the intersection on another carriageway. In open country, the problems related to driver status are paramount (alcohol, fatigue...). The importance of needs such as assessing suitable speeds according to road conditions, or perceiving road-related difficulties can also be seen in the open country. It should be noted that it was not always easy to differentiate between these two needs on the basis of information available from accident reports. This often entails loss of control involving only one road user.

What is the Efficiency of each PROMETHEUS Device, When a Driver Need Is Identified?

The significance of this research work is based for the greatest part on a correct definition of the aids to be evaluated. It was decided to focus on the PROMETHEUS program. Consequently, only documents relating to this project were used when defining aid functions. Documents from the different sub-groups were reviewed, and attempts were made to meet the staff working in the car industry most qualified to provide information on on-going research work and any projects nearing completion.

Twenty-three functions were outlined (Prometheus, 1989) but in a very general way, without setting overall objectives or providing a specification sheet. These documents serve as a framework for manufacturers whose research work comprises part of this program. Function definitions have improved since this evaluation was started. In the same way, present-day Common European Demonstrators CEDs (Clarke, 1990) are considerably more operational than those first planned. Reference is made also to these CEDs. But it is clear that this type of evaluation is a repetitive process, and that research work such as this reflects the status of knowledge at a given time, which is already partially out of date by the time it is published.

The Functions and the Demonstrators

The term function indicates modules which have a common identity, but between which there is considerable disparity with regard to size, level of definition and also type. This therefore includes both global system functions, categorized in terms of what they are expected to ensure (intersection control) and aids to functions usually ensured by the driver (obstacle detection, enhanced vision...). Only the first 14 functions, those which have a direct influence on safety, were examined.

At the same time as function descriptions, which are used as a frame of reference for companies working on projects to form the "basis" of the program, car manufacturers developed demonstrators, which are vehicles fitted with devices covering a certain number of the previously referred to functions. These demonstrators are of particular interest insomuch as they provide a clear indication as to which devices are most likely to be available, within a reasonable time period.

The Functions

After meeting with several people involved in the Prometheus program, it was decided to indicate performances for each function, whilst at the same time attempting to remain reasonably realistic. This reference list is given below:

F1: Obstacle detection. Detecting objects and recognising them as obstacles, sufficiently in advance to avoid a collision. These are fixed or mobile objects located on the road taken by the user (whatever the lane or direction of traffic). They must be sufficiently substantial to represent a danger. To be detected, the obstacles must be motor-driven or located within the field of vision. Also detects moving objects approaching on intersecting lanes.

F2: Monitoring environment/road. Provides information on alignment, specific black spots, skid resistance, signposting, weather conditions. Does not take other users and obstacles into account (contrary to certain sub-functions).

F3: Monitoring driver. Depending on driver activity (wheel movements, use of different controls), determines driver status (fatigue, alcohol) and transmits the appropriate alarms. As projects stand to date, does not immobilise the vehicle.

F4: Monitoring vehicle. On-going diagnosis of status of different vehicle components. Detects wear and risks of breakdown or failure (does not predict "immediate" dynamic behaviour, in which case refer to F6).

F5: Vision enhancement. Improving vision when this is impaired (night-time, fog, glare, rain). Applies only to objects within the driver's frontal field of vision. Does not "pierce" objects which obscure visibility (other users, alignment, vegetation, etc). Helps, in particular, to better discern the road side.

F6: Safety margin determination. Constant calculation of the available margin in terms of stability and skid resistance. The driver is therefore aware whether or not he is nearing the relevant limits. Calculation can be in predictive mode (taking alignment and skid resistance into account) and so warn the driver of any imminent "dynamic" risk.

F7: Critical course determination. Gives warning when an accident is likely, if vehicle course remains unchanged, either by colliding with another stationary or moving vehicle, or by running off the road. In the first instance, it is in theory possible to calculate collision risks in relation to relative speeds and courses, both longitudinally (vehicles which catch up on or come towards one other), and transversally (intersection). In the second instance, however, it is difficult to see how course deviation information could be given sufficiently in advance to be effective, particularly as it must be filtered to allow for computer corrections.

F8: Dynamic vehicle control. Modulates driver inputs so that the safety margins are not exceeded when a function acts directly on these inputs (F7, F10 or F11). This function therefore has no autonomous role and should not be evaluated as a separate entity.

F9: Supportive driver information. This is not a function in itself but an interface, which makes it possible to provide the driver with, in particular, information on vehicle or situation status. Should not be evaluated separately except in one specific situation: helping to maintain a course in relation to road limits.

F10: Intelligent manoeuvres. Prevents changing lane and overtaking when other users could represent a danger. Can detect any equipped or visible user, with the exception of users who are neither equipped nor visible (e.g. 2-wheelers). It functions only on motorways or main roads.

F11: Intelligent cruise control. Homogenizes speeds within a lane of traffic. Makes it possible for traffic to move in convoys or at a predetermined speed, modulated by the presence of other vehicles and speed limits. Does not take fixed obstacles (cf F1 and F7) nor pedestrians into account and does not function in built-up areas.

F12: Intelligent intersection control. Makes it possible to cross or merge traffic flows as effectively as possible with regard to rate and safety. Provides information without activating the controls. Is not sufficiently well defined to be evaluated.

F13: Medium range pre-information. Poorly defined function which consists of providing the driver with advance information (derived from other functions). It is difficult to see how this could be applied to any function other than F2, which could be an interface. This is not a real function in itself, and there is therefore no reason to evaluate it.

F14: Emergency warning. In the event of an accident, transmits automatically an alarm signal to the emergency services and to nearby vehicles so as to prevent further collisions.

The Demonstrators

The definition and make-up of the different demonstrators (CEDs) have been progressively improved (Clarke, 1990). Although it may still be too soon to forecast performance, it is at least now known which group of functions will be ensured by each of them. Table 1 below shows which functions will be covered by the main demonstrators, in the light of information available.

Table 1. Functions Covered by the Different Demonstrators

CED	Name	Functions evaluated	Functions not evaluated
CED1	Vision Enhancement	F2, F5	F9
CED2	Proper Vehicle Operation	F2, F3, F4, F6	F8, F9
CED3	Collision Avoidance	F1, F2, F6, F7, F10	F8, F9
CED4	Cooperative driving	F10, F11, F14	F12, F13
CED5	Autonomous Intelligent Cruise Control	F2, F11	F8, F9, F13
CED6	Emergency systems	F14	

Some functions, which were insufficiently defined at the outset of the study, were not evaluated. This will therefore reduce the estimated effectiveness of the different demonstrators. For each CED the effects of the different relevant functions were cumulated, it being of course understood that this was not just a simple addition, as the needs of one user could be covered by several functions at the same time.

Which Functions for Which Needs?

The last stage consisted of deciding which functions could cover which needs, according to the planned objectives. This correspondence is shown in the table 2 presented below.

Table 2. Functions Applying to the Identified Needs

	F1	F2	F3	F4	F5	F6	F7	F10	F11	F14
driver status			*							
vehicle status				*						
road difficulty detec.		*			*	*				
obstacle detection	*				*		*		*	*
oncoming detection	*				*		*	*		
lateral detection	*				*		*			
side or back detec.	*							*		
pedestrian detection	*				*		*			
correct speed eval.						*				
catching up							*		*	
collision course							*			
gap to overtake								*		
gap to cut across										
foresee will cut							*			
foresee manoeuvre										
foresee ped. behav.										
vehicle control						*	*			

In some cases, considering the objective of the function, it should apply to the need. But when no indication was given on the way it could work, we didn't take it into account. This is why some needs didn't met any function to fulfil them.

It must be stressed that we didn't consider that the functions would be efficient in any case, whatever the circumstances of the accident. For instance, an accident with a child running across the road suddenly, just in front of a car, would not be avoided by any device...It would also be the case when the driver is too drunk to take advantage of any new information. We tried to appreciate case by case depending upon the performances of the function and the accident circumstances, if the accident had chances to be avoided. This assessment would be of course more accurate with more accurate specifications of the functions.

A coding guide was drawn up to indicate which codes could be allocated to which functions and in which cases. Analysis was of course carried out case by case, depending on the circumstances of the accident. This is nevertheless the most controversial part of this work, as it is not known how the aids to cover these functions will perform. It is probable that this has resulted in system capabilities being overestimated.

The advantage of this a-posteriori approach is that it reflects reality, and therefore reveals the problems which must be given priority. It is also unrelated to the aids which are to be evaluated. The definition of these aids could be modified, but the needs remain the same, at least until these aids have in fact become available, which could lead to a change in these needs, with regard to their quantification and their attributes.

The limitations however stem from the quality of the data available. Accident reports are not in fact comparable with in-depth data. The main differences are as follows:

- These are legal documents, drawn up in order to determine responsibility rather than to obtain a more in-depth understanding of the accident.
- User "statements" are in fact drawn up by police officers and then approved by those involved.
- Considerably less time is devoted to data collection, and fewer resources available than for in depth studies.

The Ability of Functions to Cover Needs

The effectiveness of each function was therefore noted in terms of accident avoided. This is shown in figure 2 below.

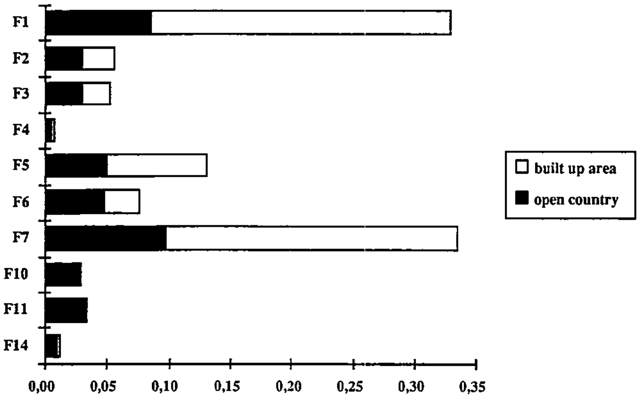


Figure 2. Effectiveness of Functions: Percentage of Avoidable Accidents

The 100 basis is made up of 3179 sampled accidents. It can be seen that functions F7 and F1 head the list, i.e. determining critical course (collisions with other users or running off the road) and obstacle detection. About 33% of total accidents could be avoided with these functions. It corresponds mostly to detection needs. Function F3 monitors driver status could avoid 5% of total accidents. In this instance the assumption put forward (extremely controversial) is that it would discourage 50% of drivers who had consumed alcohol or were overtired, from taking the wheel. On the other hand this aid is not effective when combating distraction, whether from inside (passengers) or outside the vehicle. Globally, 51% of accidents could be avoided: 33% of them in urban area and 18% of them in open country. Efficiency is better in open country: the functions could avoid nearly 57% of accident occurring in rural area, and 48% of accidents occurring in urban area.

In more general terms, the question could be raised as to why effectiveness is not greater insofar as it is calculated in relation to relevant needs. There is no simple answer to this question. It was only by a case-by-case analysis that it was possible to assess whether the driver could have used the information provided by the function effectively. This is not always the case when the driver's capacity is impaired by overtiredness, alcohol, distraction or when risk-taking seems deliberate. There are also cases when the complexity of the situation leaves doubts as to whether the driver would be able to use the additional information, particularly if it is not given in good time (the driver cannot be warned of a danger before this danger arises : e.g. a pedestrian who suddenly decides to cross). This is the greatest limitation of these systems: when detection is no longer sufficient, they must predict; but how is it possible to select the relevant option from a number of unwelcome interaction alternatives, without overwhelming the driver with incorrect or useless information?

The Ability of CEDs to Cover Needs

CEDs efficiency, in terms of part of accidents avoided, is given in figure 3.

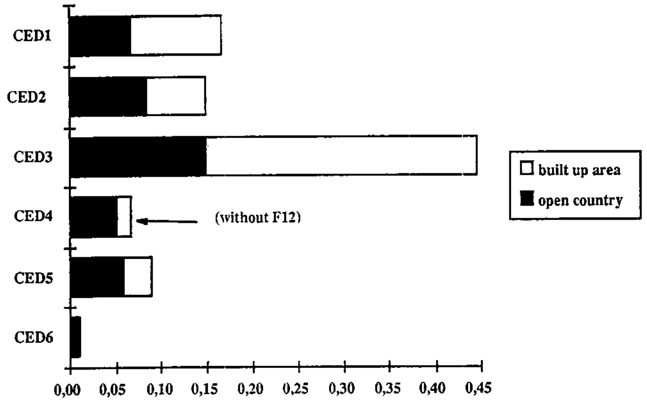


Figure 3. Percentage of Accidents Avoided with Each CED

The 100 basis is made up of 3179 accidents. It can be seen that CED3 has the greatest potential effectiveness, due in particular to function F7. It could avoid 45% of total accidents.

CED4 is probably considerably under-estimated as certain functions, in particular F12, have not been evaluated. Assuming that F12 (Intelligent Intersection Control) would be efficient for all intersections, CED4 could then be able to avoid about 40% of total accidents.

Expected Effectiveness Depending on How the Vehicle Fleet is Equipped

It is possible, although these diagrams must be treated with caution, to calculate the impact PROMETHEUS would have on safety, in relation to the different ways in which the vehicle fleet could be equipped. Assuming that the fleet structure (age and power breakdown) remains practically stable and that all new vehicles are equipped with a full range of functions, the results would be as follows (table 3).

Table 3. Percentage of Accidents Avoided by Prometheus, Depending on How the French Vehicle Fleet is Equipped

effectiveness	Top of range (≥ 90 Hp/ton)	Top + middle (≥ 70 Hp/ton)	All 4-wheelers (inc HGV)
After 5 years	4 %	11 %	24 %
After 10 years	6 %	18 %	41 %
After 30 years	7 %	21 %	51 %

The evaluation of the effects of this equipment was performed after 5, 10 and 30 years, assuming that all new vehicles in the categories under consideration would be equipped. At present, 82% of light vehicles involved in accidents are less than 10 years old and 15% have a power/weight ratio of over 90 HP/ton. The above table was obtained by calculating the percentage of avoidable accidents in each category and by assuming that the structure of the vehicle fleet would remain the same over the next 10 years.

Depending on the assumption considered, it can be seen that PROMETHEUS could reduce accidents from 4 to 51%. It has however been established that this objective will presumably never be reached due to possible changes in behaviour and a probable increase in mobility. The involvement risk per vehicle-kilometer for users equipped with driving aids should nevertheless decrease. This, however, will not be the case when user motivations, which will depend not only on economic factors but also the media coverage given to these aids, are directed more towards technology for its own sake and high performance, rather than a search for improved safety.

Conclusion

It is very difficult to foresee the effectiveness of a range of driving aids which have not yet been developed, and hard to predict how these same aids will be distributed within the vehicle fleet. Work is still at the research stage. The functions, as they have been defined, will not all result in effective aids. Even CEDs are *only* demonstrators, i.e. not yet prototypes. Assuming that all CEDs have reached perfection from a technical point of view, they are still only designed to display know-how, to evaluate performance and operating limitations, and any improvements to be expected in real traffic conditions. That is to say that, at the present time, a-priori effectiveness evaluation can only be approximate.

The feasibility of some functions could be questionable. A great number of problems seem to be very difficult to overcome. These include:

- The allocation of wavelengths required for vehicle-vehicle liaison. There is at present a shortage in this field, which the rapid expansion of telecommunications will do nothing to improve.
- The reliability of sensors and transmissions. Considering that this problem has not yet been completely resolved in the field of civil aviation (cf all-weather landing), despite the greater resources available, there are grounds for concern.
- The cost and maintenance of ground-based installations required for certain functions. The cost of installing these aids on vehicles should also, of course, be taken into consideration. Most systems could not be fitted to vehicles already on the road. This is due to both financial considerations and the technical problems involved in fitting them into the vehicle and, in particular, onto the dashboard.

Two questions arise with regard to new vehicles:

- Will all new vehicles be equipped; which will considerably increase the price of bottom-of-the-range models?
- If only top-of-the-range models are to be equipped, will this be standard practice or only an option?

Should they be an option, effectiveness may be limited by changes in behaviour; users who choose to buy these aids—at a price—expect to get the most out of them ... in their own fashion. This phenomenon is probably the cause of the disappointing results shown by ABS (Biehl, Aschenbrenner & Wurm, 1988).

This is why, from a safety standpoint, it would be better to set more reasonable objectives, by focussing on aids which correspond to the most pressing needs (driver status, detection). Aids should be as simple and as cheap as possible and could therefore be fitted to *standard* vehicles, at least from middle-of-the-range vehicles upwards.

Whatever the case and whatever the objectives selected, a priori evaluations will have to be up-dated as and when CED performances become clear. Insofar as the need definitions chosen are not brought into question, this work can be carried out reasonably easily by re-examining only the accidents reports likely to be relevant to an aid or group of aids. For certain CEDs which are expected to cover a relatively wide range of needs, this work could nevertheless have far-reaching consequences.

Acknowledgements

The authors would like to thank Renault who financed this research work, together with those taking part in the Prometheus programme who gave us access to the data needed for our investigations.

References

Biehl, B., Aschenbrenner, K., Wurm, G. (1988). Einfluss der Riskokompensation auf die Wirkung von Verkehrssicherheitsmassnahmen am Beispiel ABS. In

Schriftenreihe Unfall und Sicherheitsforschung Strassenverkehr, Heft, 63. 65-70. Bergisch Gladbach.

Clarke, N.J.(1990). Common European Demonstrators, in Prometheus Research Newsletter n°9, pub. Prometheus Office, Stuttgart.

Ferrandez, F., Fleury, D., Malaterre, G.(1986). L'étude détaillée d'accidents (EDA).Une nouvelle orientation de la recherche en sécurité routière. RTS Review, n°9-10,17-20.

Fontaine, H., Malaterre, G., Van Elslande, P. (1989). Evaluation de l'efficacité potentielle des aides à la conduite. *INRETS research report*, n°85.

Fontaine, H., Gourlet, Y., Jurvillier, J-C., Malespert, J-P. (1990). Constitution d'une base de données sur les accidents corporels, année 1989. INRETS symposium report.

PROMETHEUS (1989). "FUNCTIONS", or how to achieve PROMETHEUS "objectives". Stuttgart.

PROMETHEUS (1989). Prometheus is rolling; Pre-Dinner Speeches-Thematic Projects-Demonstrator Projects-Presentation Board Members. Munich.

Van Elslande, P., Malaterre, G. (1987). Les aides à la conduite: analyse des besoins en assistance des conducteurs. *INRETS research report*, n°23.

S4-O-02

Impact of PROMETHEUS Functions on Traffic Safety

Jürgen H. Klöckner
Federal Highway Research Institute (BASt)

Abstract

One of the main tasks of PRO-GENERAL (as a subprogramme of PROMETHEUS) is to design traffic control systems using new technologies, at the functional level and from the traffic-engineering point of view. Accordingly, the industrial companies involved described more than 20 functions as a basis of further work. The PROMETHEUS Safety Group selected some functions which seemed to have a noticeable impact on road traffic safety. Under consideration of different accident databases (e.g., indepth-study data), an assessment was made of the potential accident reduction which could be gained from the designed PROMETHEUS functions. Starting from the assumption of perfect functions, some of the functions showed relatively great effectiveness in terms of accident reduction. On the other hand, some functions which seemed to be useful will have only a very small impact on road safety. If real traffic and road situations (and real drivers) are taken into account the assessed benefits will diminish considerably.

What is the Objective of PROMETHEUS?

PROMETHEUS is a European research programme aimed at elaborating the technical and administrative foundations of road traffic. The acronym stands for *Programme of a European Traffic with Highest Efficiency and Unprecedented Safety.* Its objective can be described more precisely as follows: Concepts and solutions are to be created which will make road traffic considerably:

- safer,
- more environment-friendly,
- more economic, and
- will make the traffic system more efficient and also
- increase the level of convenience for the road user.

This is to involve a departure from conventional methods. Developments in information technology accompanied by progress in microelectronics, sensor technology, telecommunications and computer science are opening up perspectives for vehicle and traffic engineering which seem likely to facilitate a breakthrough in improving all features of modern traffic.

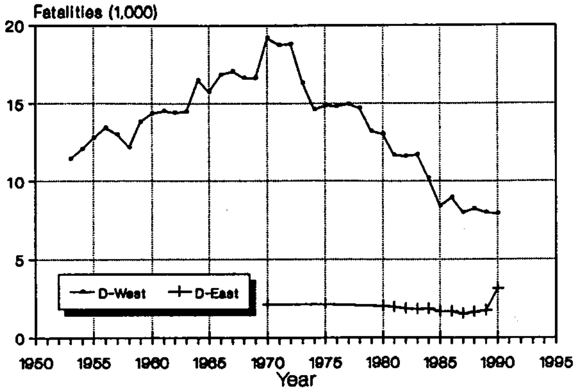
PROMETHEUS was intended to bring qualitative advances of considerable proportions and not only gradual progress. It was believed that the number of road traffic accidents can be reduced by 50%. This value was not, however, the result of sophisticated estimation of potential effects but, rather, should be interpreted as a desired target. More accurate estimates of potential effects have now been conducted for specific aspects of planned technical functions. The results obtained at the Federal Institute for Highway Research (BASt) are described below.

Traditional Approaches for Road Safety Improvement

The number of road accident fatalities in the Federal Republic of Germany has shown the same general trend as in other highly motorized nations in Europe. After an almost continuous increase in fatalities until the early seventies, a significant decline began thereafter. This decline has, however, flattened out somewhat in recent years. After peaking at a total of 19,193 fatalities in 1970, the figure had already fallen to 13,041 only ten years later. The reduction then continued, the total falling to 7,906 in 1990 (Figure 1). This corresponds to an average annual reduction of 4.3% over the twenty-year period.

In the same period, the number of motor vehicles rose from 16.78 million in 1970 to 35.55 million in 1990. This is equivalent to an annual average increase of 3.8%

In the past, this undeniable improvement in road safety was achieved with the traditional approaches (3 E's: Engineering, Education, Enforcement). The route



BASt-U1k-9107

Figure 1. Trend of Fatalitites in Road Traffic Accidents in Germany

followed was extremely arduous and not always successful; advances were often offset by setbacks and failures. As the figures show, however, the overall results were successful. This traditional approach is not to be abandoned. But PROMETHEUS does offer a considerable "short-cut." It promises the goal of achieving a dramatic reduction in accident rates solely through the use of the latest technology.

Functions, Systems and Demonstrators

In order to achieve the main PROMETHEUS objectives described, a defined set of PROMETHEUS functions (PROMETHEUS 1990) is to be employed as the backbone of the complex research work. A total of 23 functions were agreed, the majority being relevant to safety. Some functions have no direct influence on road safety and their primary purpose lies elsewhere. The description of the functions does not say anything about their type or method of technical implementation.

Systems are created by combining specific PROMETHEUS functions (Zackor 1990), while further combination produces so-called Common European Demonstrators (CEDs).

Of the 23 PROMETHEUS functions, the following were seen as having a safety effect:

Obstacle detection
Supportive driver information
Monitoring environment/road
Intelligent manoeuvring & control
Monitoring driver
Intelligent cruise control
Monitoring vehicle
Intelligent intersection control
Vision enhancement
Medium range preinformation
Safety margin detection
Emergency warning
Critical course determination
Static route guidance
Dynamic vehicle control
Dynamic route guidance

Of the total of nine Common European Demonstrators, the following six have a direct safety effect:

CED 1: Vision enhancement
CED 2: Proper vehicle operation
CED 3: Collision avoidance
CED 4: Cooperative driving
CED 5: Autonomous intelligent cruise control
CED 6: Emergency warning systems.

Conditions and Limitations

In the initial phase of the PROMETHEUS programme very far-reaching ideas were formulated in which the technical developments and concepts of recent years were boldly extrapolated into the future. Without actually knowing how to achieve practical results, those involved tended to get carried away by wishful thinking. Since then, the formulation of technical aims has become somewhat more realistic. Not everything that is theoretically technically possible can actually be produced and introduced in real life. Technical innovations which work in the laboratory are not necessarily suitable for the harsh reality of everyday road traffic situations.

Different levels of influence on the driver/vehicle system apply for the individual technical concepts. There are five categories:

- Information for the driver,
- Warning to driver,
- Binding instruction to the driver,
- Corrective intervention in driving process, and
- Automatic overtaking of control.

It is easy to see that these levels of influence will have a decisive impact on the likely safety potential. A system which merely provides the driver with information (by visual, acoustic or haptic means) in critical situations will make less of a contribution to safety than one which automatically assumes control of the vehicle in such situations, leaving the driver as a passive passenger. Nevertheless, when it comes to practical implementation, we will find it very difficult to go beyond the first three categories mentioned above. The term "product liability" is all that need be mentioned here as an explanation for this.

With regard to the safety effect of the individual PROMETHEUS functions or the CEDs, there is a further question which should not be forgotten. Is it necessary for all road users to be equipped with a particular system or does the system also operate when only individual vehicles are equipped with it? Is it enough for parts of the road network to be provided with the PROMETHEUS infrastructure or does the whole road network have to be covered? How can pedestrians, cyclists and other types of road user be included? In addition to these questions requiring technical answers, problems also arise which will have to be solved by economists, social scientists, psychologists, lawyers and perhaps even philosophers.

Potential Safety Effects

In what has been said above, it has been consistently assumed that PROMETHEUS is capable of producing a wide range of exceptional safety effects. As it is not yet possible to answer this question empirically, estimations of the potential safety effects of PROMETHEUS have been performed in Britain, France and Germany. The estimations were based on the quantitative framework of the respective national accident statistics and were conducted independently.

The estimation performed in Germany (Marburger et al. 1988) was based on three separate data sources. The effect of selected PROMETHEUS functions on accident levels was assessed on the basis of

- special evaluation of the accident data collected for official statistics (national sample),
- evaluation of accident occurrence in the state of Rhineland-Palatinate using the expanded (three-digit) accident type catalogue (regional sample), and
- evaluation of the "Accident In-Depth-Studies" of the Medical University of Hanover (local sample).

The accident locations were classified in the categories "inside built-up areas," "outside built-up areas (excluding motorways)" and "motorways." The three databases mentioned permitted three approximation tests for the assessment of efficiency.

In the course of assessment it became clear that generalized practical application of the PROMETHEUS functions in built-up areas often had to be ruled out or rated as being only partially effective in isolated cases. One reason for this was, for example, structural factors insofar as active "seeing" around buildings or through underpasses is not possible or is severely restricted. Moreover, the complexity of traffic in built-up areas and the numerous interactions with stationary vehicles or road users not equipped with PROMETHEUS systems, e.g. pedestrians, cyclists and riders of motorized two-wheelers, rule out the application of the functions in view of plausibility considerations or, at least, restrict it. In many cases, noticeable safety effects are not therefore likely.

Interestingly, the French study (Fontaine et al. 1989) and its British counterpart (Broughton 1989) both obtained results of a similar order of magnitude in terms of the estimated potential safety effects as the German study. This is shown clearly in a table of the results for all locations (Table 1) (Dryselius 1990).

Since a large number of the accidents, particularly in built-up areas, occur at intersections, it seemed worthwhile subjecting this segment of accidents to in-depth analysis in order to estimate potential safety effects.

Table 1. Estimated Potential Safety Effects of Individual PROMETHEUS Functions

	D	F	GB
Trip planning	*)	} 3%	*)
Route guidance	2%		*)
Speed guidance	*)	-	*)
Speed keeping	23%	7%	20%
Car following	3%	1%	3%
Lane keeping	3%	<1%	<1%
Overtaking	3%	1%	6%
Intersection control	20%	16%	-
Tutoring	*)	-	8%
Accident detection	<1%	1%	*)
Monitoring of driver condition	10%	5%	18%
Electric vision	<1%	7%	7%

*) not quantified, very low; - not evaluated

It is, of course, known that not only "multiple-track" motor vehicles are involved in accidents, particularly in built-up areas. If those involved in collisions are classified according to type of road use, the situation for accident injuries involving at least one "multiple-track" motor vehicle is as illustrated in Figure 2 (Otte & Schlichting 1990).

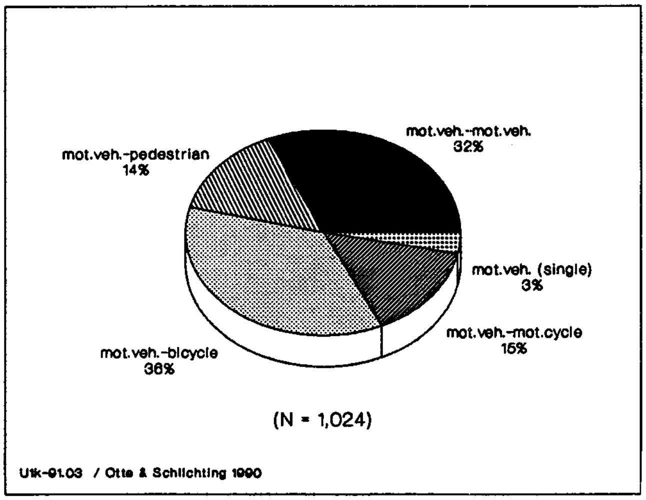


Figure 2. Injury Accidents (4-Wheeler-Involved) on Intersections in Built-up Areas

This means that at least one "unprotected" road user is involved in two-thirds of all injury accidents at intersections in built-up areas. Unless particularly utopian assumptions are made, providing these road users with PROMETHEUS systems has to be ruled out. This in itself considerably reduces the possible impact. Moreover, the question as to the level of intervention to be attributed to the PROMETHEUS functions (i.e. also: the level which society will accept) has not yet been fully discussed; in other words, should the system be restricted to giving information or should the technology be permitted to intervene actively in the driving of the vehicle? Also related to this is the problem of the man-machine interface; how can messages from the equipment be turned into human action?

For the moment, however, let us leave these reservations aside and assume that all these problems could be solved. And that all vehicles are fitted with

PROMETHEUS equipment and all intersections equipped with corresponding hardware. It is important here that not just as many as possible or almost all but, in fact, absolutely all vehicles and all intersections are accordingly equipped. If the accidents at intersections in built-up areas are analysed under these premises, it is clear that they could almost all be avoided through some kind of—still to be invented—PROMETHEUS equipment. The *Intersection control* function would be effective in 66% of cases, *Obstacle detection* in 12% and *Speed keeping* in 10%.

These effectiveness values are based, as already stated, on the assumption of 100% efficiency of the PROMETHEUS functions, an admittedly utopian assumption. The framework for the technical realisation of the PROMETHEUS functions has now been tightened considerably, as will be explained below with the example of the *Intersection control* function.

In the first approach at the start of the programme, the idea was that traffic at all intersections would be computer-controlled and would be rendered safe and efficient by automatic driving control. The function as described in the second approach (PROMETHEUS SC 1989) was considerably less ambitious: it operated only with driver information and used an in-car system in the case of low traffic volumes at intersections outside built-up areas or additional roadside equipment at intersections with higher traffic volumes. In the third approach (Zackor 1990), the scope, and also the applications framework, are presented in a more complex form again; three different possible tasks being described:

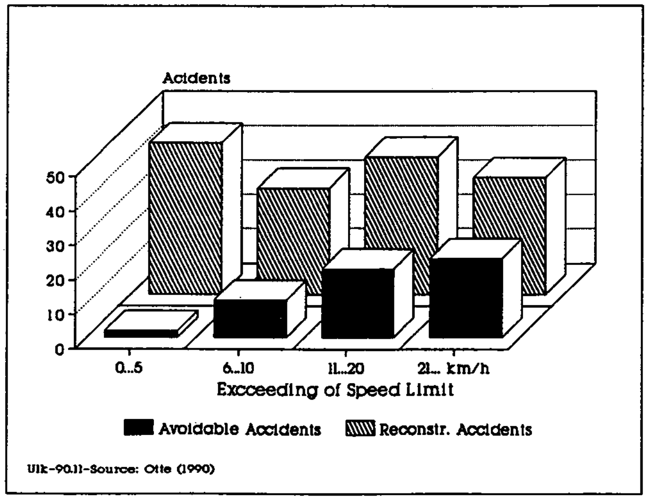
- Approaching traffic signals in convoy with automatic driving. The objective is to increase the efficiency of the intersection.
- Interaction of vehicle and traffic signals through recommendation to driver so that approaching vehicles can pass at "green." The objective is to reduce fuel consumption and pollutant emission.
- Time slot management through automatic driving at country road intersections. The objective is to increase the efficiency of the intersection.

As can be seen, the "safety" aspect is no longer a primary objective of this function. It is more or less taken for granted that there will be an implicit increase in safety or, at least, it is assumed that safety will not be diminished. An ad-hoc international assessment of individual PROMETHEUS functions by numerous experts in 1990 (Neumann & Keller 1990) rated the safety increase to be expected from *Intersection control* as being very low, i.e., in the category 0 to 2%.

It may well be said that it is justifiable to activate even such a minor safety potential in order to increase traffic safety. Without wishing to contradict this opinion, it should nevertheless be pointed out that economic considerations should not be completely ignored here. A measure which costs more than the benefit it is likely to produce in monetary units should, where possible, take second place compared to measures likely to bring greater benefit. At the same time, consideration must also be given to some fundamental legal consequences of the introduction of certain measures, as was already mentioned. The majority of experts in the ad-hoc assessment expressed legal reservations about the function *Intersection control.*

Let us now look at another PROMETHEUS function: *Speed keeping or Local speed enforcement.* This system was found to have the highest potential safety effect by the experts in the ad-hoc assessment, but many legal reservations were again expressed.

In order more accurately to determine the safety potential of such a function, injury accidents occurring at intersections in built-up areas were investigated to see whether the respective accidents could have been avoided if the relevant local speed limit had not been exceeded. These investigations were based on a group of accident statistics from the "Accident In-Depth-Studies" performed by the Medical University of Hanover, for which the speed before the initiation of accident-avoiding reactions could be ascertained on the basis of reconstructions (Otte & Schlichting 1990), see Figure 3.



Ulk-90.11-Source: Otte (1990)

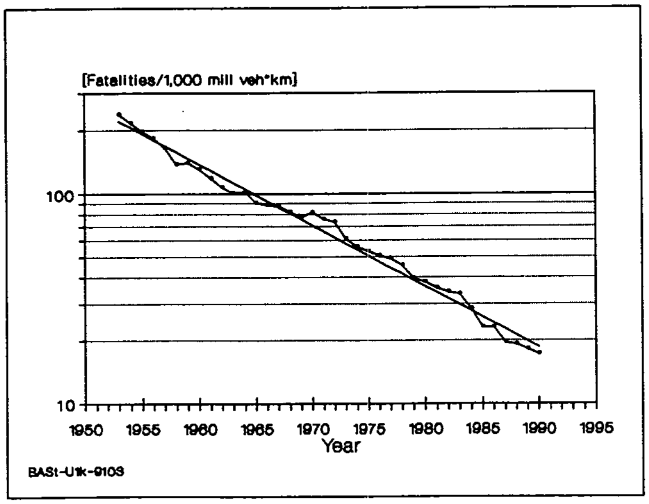
Figure 3. Exceeding of Speed Limit and Avoidable Accidents by Speed Keeping

It could be seen that 32% of the motor vehicles involved in accidents had exceeded the local speed limit. In some cases, the limit was exceeded by a quite considerable amount. It also became clear that the proportion of avoidable accidents rose in line with the level of speeding. The following general estimate can be made: if this third which are the speeding drivers had reduced their speed to the local limit, this alone could have prevented 12% of all injury accidents at intersections in built-up areas (Klöckner & Neumann 1990). Moreover, positive effects are likely even in those cases where accidents could not be avoided, this being because accident severity declines due to the lower speeds at the moment of collision. This effect does not only apply to the occupants of motor vehicles, but also especially to unprotected road users who, as already stated, are involved in 65% of accidents in built-up areas.

Perspectives

In all efforts aimed at the further development of the "motorised road traffic" system, there is one aspect which should not be forgotten: improving road traffic safety is an *important* objective but it is not the *sole* objective of further technical development. Other goals do exist, although it is not intended to start any discussion of their relative value here. Indeed, an improvement in safety is sometimes actually achieved as a welcome side-effect of the pursuit of other objectives.

Despite these reservations and not forgetting the questions already raised, the following conclusion remains: technology will continue to bring improvements in the safety of the overall road traffic system in the future. For almost four decades now, an average annual increase in overall traffic safety (expressed in terms of the reduction in the fatality risk related to mileage traveled) of 6.5% has been observed as the sum of all improvements (see Figure 4). On roads in built-up areas, the average annual reduction in the fatality risk was even around 8.5%. Technology made a major contribution here. The trend will essentially continue. A working group at the Federal Highway Research Institute which in 1986 considered the reduction in the number of road traffic fatalities (Brühning et al. 1986) believed it was justified to assume that the total number of fatalities on roads in the Federal Republic of Germany (i.e. territory at that time) would be only 5,000 in the year 2000. Technological development could be expected to play an important part here.



BASt-U1k-9103

Figure 4. Trend of Fatality Rate in Road Traffic in Germany (1953 to 1990)

Technological development does not necessarily have to be invented or introduced from scratch. Nor does it arise solely from the pursuit of high-tech international projects, whatever their title. *"It may be convenient to say that electronics make up for the shortcomings of mechanics, but that is only half the truth. With regard to the technically feasible, the question must always be whether the feasible is also sensible"* (Gülich 1990). It is entirely possible that technical components suitable for everyday use may be developed as a practical result and have positive effects on road safety. With today's level of knowledge it is not, however, likely that an exceptional qualitative advance will be achieved in the foreseeable future. Technical progress is also occurring at a much lower level with, for example, older vehicles being replaced by technically superior new vehicles. In other words, even if no more innovations were introduced in the automobile industry from today on, the next few years would still see a—gradually declining—improvement in the vehicles in use on our roads.

The generally positive assessment of technological development must not, however, detract attention from the need also to incorporate the human being. The road user himself must receive particularly careful attention for the very reason that he is the weakest link in the vehicle-man-road system. Society cannot escape responsibility by expecting technology to compensate entirely for human weaknesses and errors. Technology alone will be unable to achieve this; man still has a lot to learn about how to use the equipment which human intelligence provides for us through technology. Indeed, the following ironic conclusion can be drawn on the man-machine interface: *"New, different human beings are what is needed for our great technological advances"* (Mauz 1990).

Literature

Broughton, J.: The possible effects of future technological developments on road accidents in Great Britain. TRRL 1988.

Brühning, E. et al.: Zum Rückgang der Getötetenzahlen im Straßenverkehr: Entwicklung in der Bundesrepublik Deutschland von 1970 bis 1984. [The reduction in road traffic fatalities: Development in the Federal Republic of Germany from 1970 to 1984]. (1985). Zeitschrift für Verkehrssicherheit 32(1986)4, pp. 154-163.

Dryselius, B.: Summary report: Estimation of the potential safety effects of different possible PROMETHEUS functions. Stuttgart 1990.

Fontaine, H., Malaterre, G., Van Elslande, P.: Evaluation of the potential efficiency of driving aids. INRETS 1989.

Gülich, H.A.: Zur "Stadtverträglichkeit" von Personenwagen. [The "town compatibility" of passenger cars] AutomobilRevue (1990) 34.

Klöckner, J.H., Neumann, L.: In-depth analysis of accidents—assessment of the potential accident reduction of selected PROMETHEUS functions. Paper presented at the PROMETHEUS PROGEN Workshop held in London, Nov. 28 and 29, 1990.

Marburger, E.A., Klöckner, J.H., Stöcker, U.: Abschätzung der möglichen unfallreduzierenden Wirkungen ausgewählter PROMETHEUS-Funktionen. [Estimation of the potential accident reduction of selected PROMETHEUS functions]. BASt, 1988.

Mauz, G.: ... nicht die Technik als solche. [... not technology as such] Der Spiegel 44 (1990)4, p. 57 ff.

Neumann, L., Keller, H.: Results of the ad-hoc assessment of single-function traffic control systems. In: PROMETHEUS PROGEN, Proceedings of the Workshop held in London, Nov. 28 and 29, 1990, p. 206-216. London 1990.

Otte, D., Schlichting, K.D.: Auswertung von Erhebungen am Unfallort, PROMETHEUS II. [Evaluation of accident indepth-studies, PROMETHEUS II] Hanover 1990.

PROMETHEUS (Steering Committee): "Functions" and how to achieve PROMETHEUS "objectives." Stuttgart 1989.

Zackor, H.: PROGENERAL, Description of single-function traffic control systems. Stuttgart 1990.

S4-O-03

The NHTSA IVHS Program for Enhancing Safety Through Crash Avoidance Improvement

William A. Leasure, Jr.
National Highway Traffic Safety Administration

Abstract

Recent breakthroughs in electronics, artificial intelligence, and communications provide the basis for designing and producing the smart sensors, computers with greatly increased capacity and computational speed, and control systems needed to facilitate and augment driver performance and, ultimately, relieve the driver of most tasks, thereby achieving significant improvements in collision avoidance. In-depth crash investigation studies in the United States have consistently shown that human error is the major contributory factor in most crashes—a definite or probable cause, or severity increasing factor, approximately 90 percent of the time. Drivers need help in recognizing imminent crash situations and in making quick, correct decisions with regard to avoidance maneuvers, and, to a lesser extent, in carrying out the selected maneuver. Advanced technology provides the potential to help drivers better sense impending danger, sense and alert drivers of lapses in their judgements or skills, aid them in performing the driving task, and, ultimately, compensate for some of their errors. Since much of the non-recurring congestion on freeways in the United States results from crashes, improving the crash avoidance capability of motor vehicles will contribute to alleviating congestion. The NHTSA program outlined in this paper will provide the vehicle engineering and human factors research necessary to achieve the potential safety benefits promised by IVHS.

Background

To better understand the congestion and safety problems we face in the United States, it is instructive to review some pertinent demographic trend data.

Figure 1 provides historical data on the number of licensed drivers, the driving age population and the number of registered motor vehicles in the U.S. In 1950, 57 percent of the driving age population was licensed to drive a motor vehicle. Today, 87 percent of the driving age population is licensed to operate a motor vehicle. There were 1.26 licensed drivers for every registered motor vehicle in 1950. By 1989, this ratio had fallen to 0.87, that is 1.2 vehicles per licensed driver.

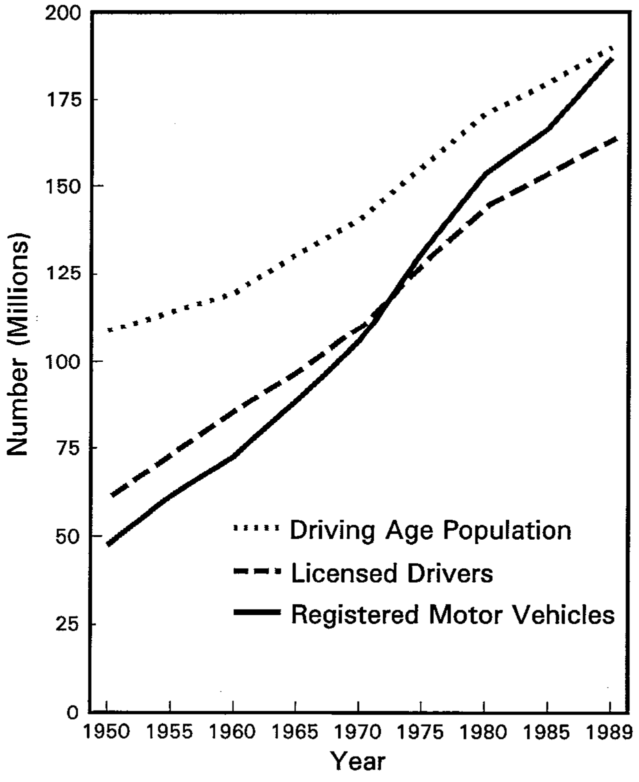


Figure 1. Trend Data on the Number of Licensed Drivers, Driving Age Population, and the Number of Registered Motor Vehicles in the United States [1]

In addition, there has been a rapid increase in vehicle miles of travel (see Figure 2). Annual travel exceeded 2 trillion vehicle miles in 1989, an increase of 4.0 percent over 1988, and an increase of 38.0 percent during the 1980's. Annual travel on roads and streets in urban areas accounted for 59.7 percent of the total, an increase of 47.1 percent in the 1980's. During this same time period, annual travel in rural areas increased by a more modest 26.3 percent.

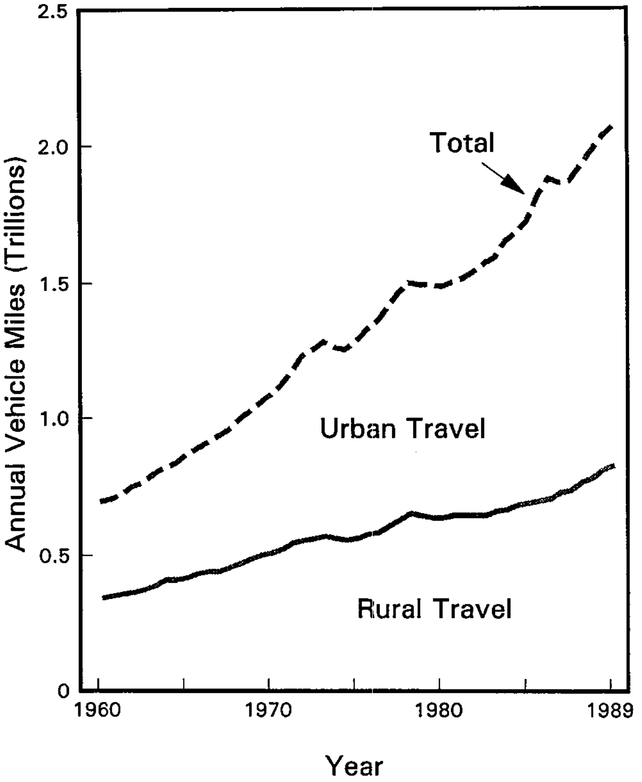


Figure 2. Growth in Annual Vehicle-Miles of Travel on the Highways in the United States [1,2]

As a result of these increases, most major U.S. cities have experienced increased congestion. In 1988, 68 percent of peak hour travel on urban Interstates occurred under congestion conditions [3]. With reserve capacity quickly being used up, additional demand will increase congestion dramatically even from current levels—a fivefold increase in delay is projected over the next two decades. Possible solutions include building new capacity, managing travel demands, increasing operational efficiency, improving safety and/or applying new technologies.

On the other hand, the fatality rate [fatalities per 100 million vehicle miles of travel (VMT)] continues to decline (see Figure 3). In 1989, the fatality rate reached 2.2—a 57 percent decrease compared to 1968. This decrease is due, in part, to the improvements in motor vehicles, many of which resulted from NHTSA's Federal Motor Vehicle Safety Standards, as well as the agency's efforts to influence behavioral changes in the driving population, i.e., campaigns to increase seat belt and child seat usage, to discourage drinking and driving, and to encourage the wearing of helmets by bicycle and motorcycle riders.

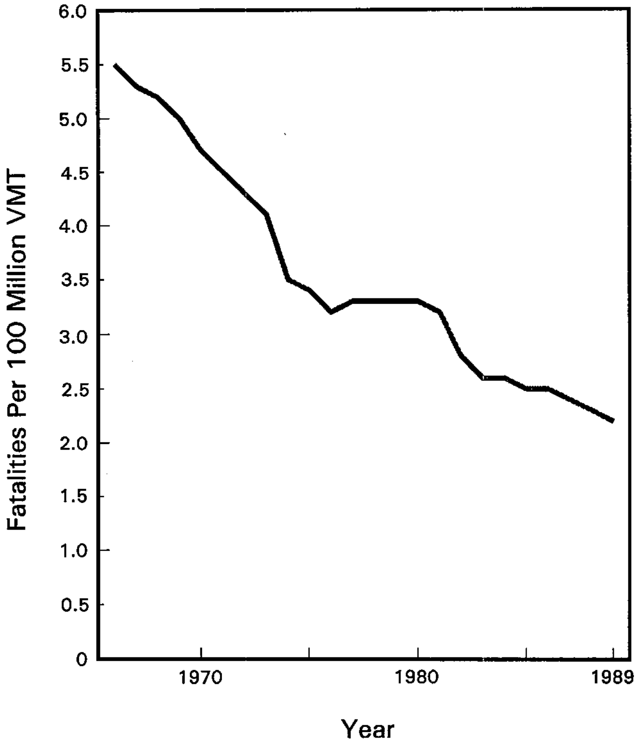


Figure 3. U.S. Traffic Fatality Rate Per 100 Million Miles Traveled [4]

Figure 4 provides data on the age of licensed drivers. In 1989, there were approximately 165,000,000 licensed drivers in the United States. Although the 20-39 age group contains the largest percentage of licensed drivers, the average age of licensed drivers is shifting upward as older drivers continue to hold licenses. Drivers age 60 and older now represent 18.4 percent of the total licensed drivers compared with 16.3 percent in 1980.

In spite of our success in steadily lowering the fatality rate, the number of crashes, fatalities, and injuries can be expected to increase as a result of continued growth in the driving age population and the number of licensed drivers and registered vehicles.

As shown by the crash involvement rate data in Figure 5 and the fatality rate data in Figure 6, younger and older drivers have the highest crash involvement rates, but older drivers, because they are more susceptible to medical complications following injuries, are more often seriously injured or killed when they are involved in a crash.

Intelligent vehicle highway systems (IVHS) offer the promise of a dramatic increase in safety. One estimate of the yearly savings by the year 2010 includes more than 11,000 lives, 442,000 injuries, and $22.2 billion in associated costs [3].

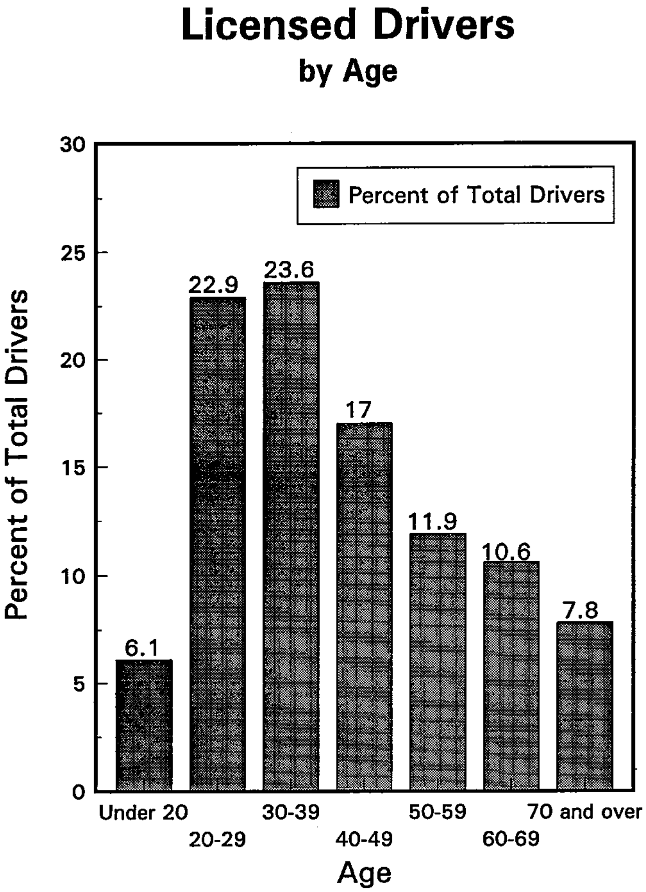


Figure 4. Distribution of U.S. Licensed Drivers by Age Group [1]

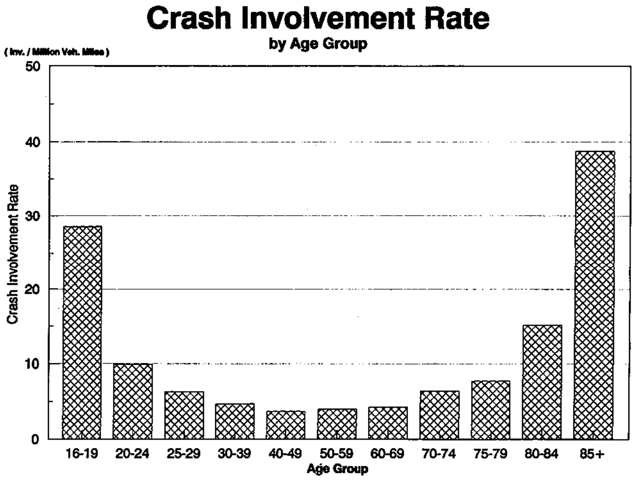


Figure 5. Crash Involvement by Age Group in the U.S. [5]

The Safety Problem

Efforts to reduce crashes and their consequences routinely focus on establishing the causes and/or contributing factors of these crashes. The relative contributions of human, vehicle and highway/environmental factors have been compared in a number of studies which have consistently shown human errors to be the leading causal or contributory agent. One of the most extensive studies of crash causes was the Indiana Tri-Level Study [6]. In that study, human errors were determined to be a definite or probable cause, or a severity increasing factor, 93 percent of the time (see Figure 7). That study also found that driver information processing errors are predominant as crash causes or contributory factors (see Figure 8). The data indicate that human errors and deficiencies which cause crashes primarily involve recognition errors (which include both perception and comprehension errors) and decision errors. Less frequently involved are instances where a driver fails to properly execute an action which he/she correctly decides is appropriate (driver maneuver performance errors). Driving is a dynamic information processing activity that encompasses mental or behavioral activities such as sensation or perception, working memory, decision-making, response execution, and attention. Each of these subsystems of information processing has limitations in terms of speed, quality of information, and types of information that can be handled reliably. In addition, there are limits to the total "mental energy" to support information processing. Stressing any one subsystem of human processing or the total system beyond its capacity may result in unreliable human performance.

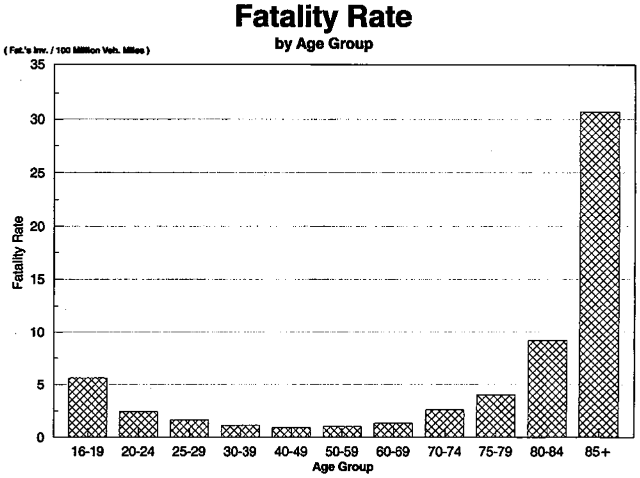


Figure 6. Fatality Rate Age Group in the U.S. [5]

Successful collision avoidance systems will generally act by enhancing one or more elements of human information processing. For example, lateral object detection devices (as might be employed to facilitate lane changing) have the potential to enhance perception by reducing the likelihood of delayed recognition of peripherally approaching vehicles, thus improving driver performance in general.

By definition, intelligent collision avoidance systems will change the way drivers perform the driving task. Such systems will enhance perception, aid working memory, support driver decision-making, augment responses, or otherwise change ways that drivers perceive, make decisions and respond. If the human factors impacts of prospective collision avoidance

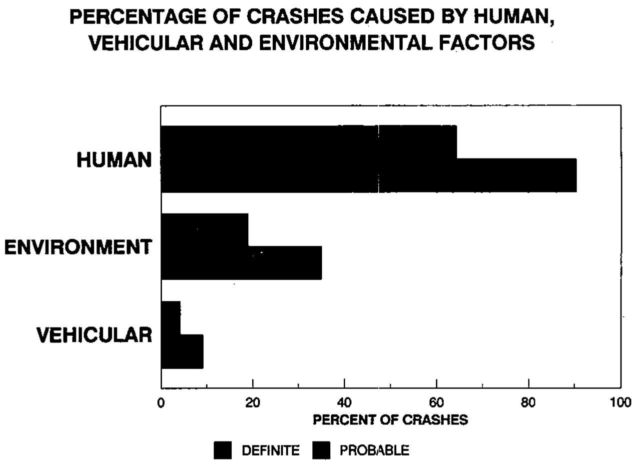


Figure 7. Percentage of Crashes Caused by Human, Vehicular, and Environmental Factors [6]

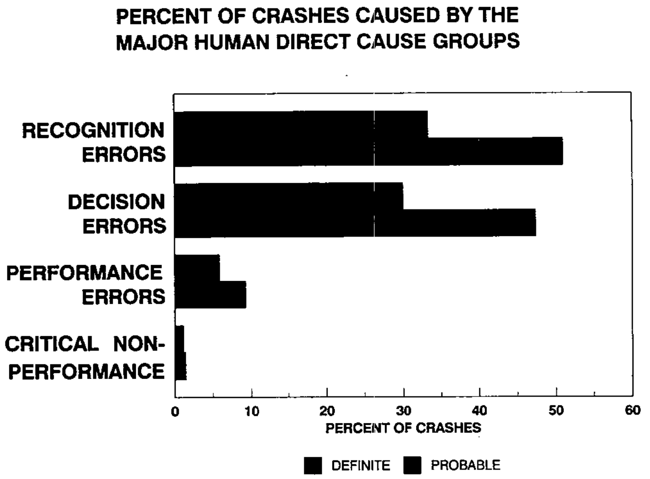


Figure 8. Percent of Crashes Caused by the Major Human Direct Cause Groups [6]

systems are not fully understood and controlled, the benefits may be nullified or, even worse, unacceptable hazards or other negative side-effects may be created. For example, an undesirable effect of the lateral object detection device alluded to earlier might be that the driver relies too heavily on the warning device, thus, failing to make full use of side mirrors or other existing visual cues. System false alarms or misses could also alter the driver's decision process in a detrimental way. For these reasons, human factors considerations must permeate research and development programs to produce and deploy safety enhancing collision avoidance products and systems.

With congestion and traffic densities increasing rapidly, margins for error, human or otherwise, are decreasing. Also, the driving population is becoming significantly older. Elderly drivers, in general, have diminished attentional-perceptual capabilities, physical abilities, and response capabilities. Motor vehicle crashes may increase, for these, if no other reasons. Traditional efforts for preventing crashes (e.g., skill development/training, public safety awareness campaigns, and traffic law enforcement as methods of influencing, modifying or controlling driver's behavior) must and will continue; but, if the potential for increasing numbers of crashes is to be reversed, additional means of preventing motor vehicle crashes must be sought, such as IVHS.

The Importance of Safety in Reducing Congestion

It has been reported [7] that 1.2 billion hours of delay occur annually on the freeways in the United States. This results in approximately 1.2 billion gallons of wasted fuel. Sixty-one percent of the delays are the result of nonrecurring congestion. Crashes, often only minor "fender benders" which do not even get reported, and disabled vehicles are the primary cause of this nonrecurring congestion.

For example, a crash blocking one lane of a three-lane freeway reduces the capacity on that roadway by 50 percent. Thus, one means of addressing the nonrecurring congestion problem is to improve the crash avoidance capabilities of vehicles.

The Potential of IVHS

There exists significant potential for improvement in traffic safety through application of IVHS technology, initially by means of collision warning and control systems that are vehicle-based, i.e., they are totally self-contained within the vehicle and do not require the existence of any roadway and/or roadside equipment to satisfactorily perform their desired function, then by means of cooperative systems which utilize vehicle-to-vehicle or roadside-to-vehicle communications to enhance the performance of the system, and finally to higher levels of control, i.e., automated roadway corridors, in which ultimate safety enhancement would be achieved since the driver would be totally removed from the control loop.

Studies [8] have shown that 50 percent of all intersection-related and rear end collisions and 30 percent of collisions with oncoming traffic could have been avoided had the driver recognized the danger 1/2 second earlier and reacted correctly. Over 90 percent of these crashes could have been avoided had the drivers taken countermeasures 1 second earlier. In some of these crash scenarios, intelligent vehicle systems have the potential to provide these additional fractions of seconds to expand the driver's margin of safety in high-risk environments.

This is not a novel concept; indeed, it has been commonplace in aircraft design for years. Modern air transports are equipped with a wide array of devices that monitor the condition of the aircraft (e.g., fire detection or hatch closure monitoring systems), the environment in which it is being operated (e.g., weather radar), as well as the way it is being operated (e.g., stall warning indicators). Collectively, these devices are intended to either warn pilots of potential dangers, aid them in performing the flying task, or, in some cases, compensate for errors. The challenge will be to introduce this design philosophy and its associated technologies into the automotive arena with high reliability at an affordable cost without overloading the driver.

A sober appraisal of the IVHS issue, however, reveals that significant safety risks may be imposed by systems that are ill-suited to the human operator. In particular, care must be taken to match in-vehicle displays and control systems to human capabilities so that drivers are not overloaded, distracted, or disoriented. Accordingly, while large safety benefits are possible, any national program in IVHS must be configured to also guard against the introduction of new safety hazards.

The expectation of large safety benefits, together with caution relative to safety down-side, argues for a deliberate safety element in the national IVHS program in the United States.

National Highway Traffic Safety Administration's (NHTSA) Role in IVHS

The Statement of National Transportation Policy (NTP) released by President Bush and Transportation Secretary Skinner in 1990 [9], reaffirms that "Safety remains the top priority of the Department." It further states that "We need to focus on innovation and technology to fulfill national transportation goals of safety. The Administration will...work...to develop intelligent vehicle/highway systems...to improve safety...." The NTP also recognized the critical role of human factors in improving safety. It stated "...any safety effort in transportation must take into account the driver or operator, the vehicle and equipment the operator is using, the infrastructure they employ, and the way the three elements interact. An intensive national program of research into human factors in transportation will lead to major breakthroughs in ... safety."

Since the mission of (NHTSA) is to improve safety on the nation's highways by reducing the yearly toll of crashes and the fatalities, injuries, and economic costs that result, NHTSA will play a key role in the U.S. IVHS program. The agency's focus is on the driver and the motor vehicle rather than the roadway. NHTSA is the primary compiler of traffic accident data upon which the safety performance of an advanced highway system will be evaluated. Also, NHTSA has a sustained concern for the human factors aspects of motor vehicle operation, an issue that will become crucial in determining the practicality and success of IVHS implementations. Thus, NHTSA efforts will complement and supplement those of the Federal Highway Administration which will focus more directly on congestion and the highway portion of the problem.

The principal focus of the agency in the past has been on occupant protection, mainly because the tools and solutions were available to make progress in that area. As noted earlier, the significant improvements in vehicle design resulted in increased structural integrity of the passenger compartment. This, coupled with improved occupant restraint systems including automatic crash protection, the passage of belt use laws, including drinking and driving, and improved emergency medical services, has been a major reason for the declining fatality rate over time. The advent of intelligent vehicle systems provides a similar opportunity for crash avoidance.

The IVHS program in NHTSA will focus on improvements to the vehicle or the interface between the driver and the vehicle that, when implemented, lead to the design and production of motor vehicles that are safer for the driving public to operate in terms of the vehicles' ability to avoid crashes completely, or to reduce the severity of crashes that do occur.

The key responsibilities of NHTSA in the U.S. IVHS program are:

- To demonstrate that improved safety can be achieved by enhancing the crash avoidance performance of motor vehicles through the application of advanced technology.
- To ensure no loss of safety as these systems are introduced into motor vehicles.
- To evaluate the safety aspects of IVH systems developed to provide congestion relief and/or mobility enhancement.

The major NHTSA focus will be on identifying targets of opportunity, i.e., workable crash problems; establishing functional goals and requirements for intelligent collision avoidance devices/systems for addressing the identified problems; evaluating developed hardware/software system performance against the established design targets; and ensuring that the developed hardware is matched to the capabilities and limitations of the drivers who will have to utilize these devices/systems.

The NHTSA IVHS Research and Development Program

NHTSA's crash avoidance research program is committed to improving motor vehicle safety by reducing the frequency of crashes and/or crash severity through the development of improved driver detection/reaction performance, driver-vehicle compatibility, and vehicle response. These programs complement the highway safety programs of other Department of Transportation administrations in continuing to reduce the yearly toll of crashes and the fatalities, injuries, and economic costs that result.

Fundamental Human Factors Research

A significant amount of driver performance data, e.g., response time, visual performance, auditory capabilities, information processing, anthropometrics and general driving behaviors, exists, however, the majority of the data were acquired in low fidelity laboratory situations

[10]. They serve as a good basis, but need to be supplemented by high fidelity driver response data acquired in dynamic, real world (or simulated) crash imminent situations. An extensive series of studies and experiments are planned to quantify critical driver sensory, perceptual, and motor capabilities and to define and measure relevant mental and decision making capabilities and their interactive role in driving safety. In addition, to support these and other program research activities, appropriate predictive and descriptive models and analytic tools will be developed.

In the human factors area, the agency has initiated three separate initiatives:

- *Driver Workload Assessment*—a program to develop standardized measurement methodologies for assessing the workload demands placed on drivers by various vehicle-based electronic aids. The measurement procedures will be used to establish baseline measurements of the current workload drivers face without these types of devices. They will then be validated in an evaluation of a production heavy truck equipped with an assortment of currently available devices/systems. The developed methodology will be applicable to all types of motor vehicles.
- *Driver Performance Capabilities With Respect to Warning Systems*—a program to develop guidelines for the presentation of real-time warning information to drivers (i.e., help determine the "best" means of eliciting collision avoidance action from the driver) and to develop measurement methodologies for assessing the appropriateness of various presentation formats used by these types of devices/systems. The needed hierarchy of warnings when there is the possibility for more than one warning signal to be presented simultaneously to the driver will also be developed.
- *Detection of Extra-Vehicular Objects/Other Vehicles (Visibility)*—a program to develop standardized measurement methodologies for assessing drivers' ability to use indirect and direct visibility systems (both conventional and advanced technology) to make them aware of objects/vehicles around their vehicle.

Future fundamental human factors research will address the following additional needs (programs the agency plans to initiate during the next 3-5 years):

- *Driver Behavior and Performance*—develop a better understanding of the behavior and performance of the driving population, i.e., the range of driver capabilities and limitations that must be accommodated in the design of various vehicle subsystems. Of particular interest would be driver characteristics that are most relevant to the safe operation of proposed intelligent vehicle highway systems. Such research would focus on: (1) driver response time as a function of workload, in-vehicle warning signal characteristics, and driver impairment, (2) driver control of the vehicle, i.e., braking and steering, and (3) driver behavior (e.g., eye scanning, braking/steering decisions, gap acceptance) during different driving tasks, such as proceeding through intersections, merging, car following, lane changing, and operating vehicle controls and displays.
- *Performance Decrements Associated with Aging*—improve our understanding of the physiological changes and related performance decrements associated with aging that are relevant to the driving task. There exists a need to better understand the crash experience of older drivers, key driver performance decrements exhibited by older drivers, and the vehicle design features needed specifically by the older driver to compensate for these decrements. Over the coming decades, as the number of older drivers and their mobility needs increase, it may be practical and economically feasible to market a special vehicle options package to older drivers.
- *Vehicle Feedback and Driver Control*—assessing the importance of cues and feedback from within the vehicle, such as kinesthetic, vestibular, and certain vehicle response cues (e.g., body roll, apparent oversteer/understeer). We need to determine which feedback cues from the vehicle most influence the driver's control response choices and gains (i.e., magnitudes and frequencies of steering and/or braking control inputs) and to develop evaluation protocols and performance specifications for technology that affects the various feedback cues that drivers use to control the vehicle.
- *Driver Compensatory Risktaking*—gather experimental data on the phenomenon of driver compensatory risk-taking, i.e., the behavioral adaptation whereby drivers drive faster or otherwise increase their risk in response to improvements in highway or vehicle safety, thereby partially, or even fully, negating the positive effect of crash countermeasures. One of the concerns in evaluating potential crash avoidance countermeasures is whether the theoretical safety benefits of the countermeasures will be achieved in the "real world." One factor influencing "real world" countermeasure effectiveness is the risk-taking behavior of the driver.
- *Systems Integration*—from a human factors point of view, the integration of various IVH subsystems is critical since information overload and/or driver confusion is inherently a problem of the totality of inputs, processes, and outputs the driver has to deal with. The study of individual IVHS-related enhancements is only a first step in evaluating their benefits within the overall system. This will be an iterative process since the ultimate "whole" system is unknown at this time.
- *Data Collection and Evaluation Protocols*—to establish a set of generally acceptable and valid method-

ologies for collecting and analyzing the required data. These evaluation protocols would establish a consistent and repeatable set of data collection and analysis techniques and requirements, as well as establish standard scenarios for given problem areas which would help ensure comparability of results among studies.

Driver Aid/Co-Pilot Development and Demonstration

The major goal of this portion of the NHTSA program is to facilitate the development and deployment of systems that improve safety by enhancing the crash avoidance performance of drivers and vehicles through the application of advanced intelligent vehicle technologies. The objectives would be to develop, test, and demonstrate vehicle and driver aid systems that will (1) improve information acquisition and decision-making by the driver, and (2) provide improved, safer driver/vehicle maneuvering performance.

The development of advanced collision avoidance systems involves transforming targets of opportunity (workable crash problems) into a set of requirements and then into an actual functioning system. Since these advanced systems involve important man-machine interactions, the development of system requirements includes an analysis of human behavioral implications.

The pre-crash scenario can be thought of as being composed of three distinct phases as shown in Figure 9. In the normal driving phase, the time and distance from any potential crash is such that the crash can easily be avoided with normal braking and/or steering inputs. The second phase would include those cases where the crash can still be avoided if the driver takes "heroic" action or automatic control functions come into play. The limit of this phase is the capabilities of the driver and/or the emergency control action. In the final phase, the crash can no longer be avoided because the limits of the adhesion between the tires and the roadway have been exceeded. Intelligent collision avoidance devices/systems which increase the time available to respond, reduce driver's response time, and/or increase a vehicle's response capabilities will minimize the number of cases where drivers get into situations where the crash can no longer be avoided.

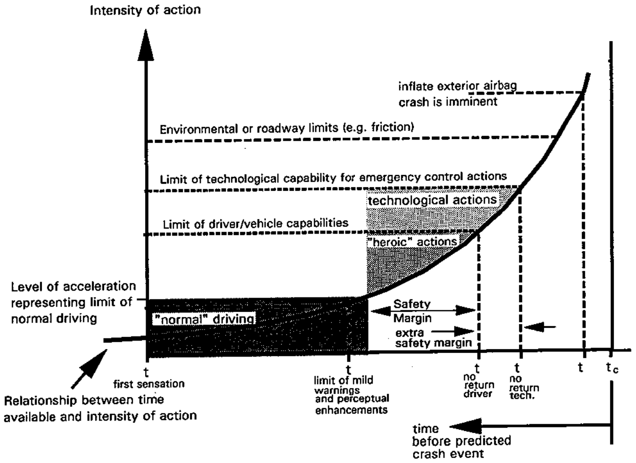


Figure 9. Generic Illustration of the Relationship Between Time Available Before a Predicted Crash Event and the Intensity of Driver Action [11]

The functional requirements (design targets) for such devices will be established on the basis of these time/intensity-of-action functions in order to maximize the potential for initiating proper collision avoidance action in a timely fashion. Crash scenarios will be modeled and the vehicle's response to the control action will be analyzed on the basis of a knowledge of typical braking distances or lateral displacement as a function of time characteristics for the particular vehicle of interest. Closing speeds for the situation will be estimated. Existing data on driver reaction time will then be used to estimate the time and distance consumed before the driver needs to initiate control action.

NHTSA is currently engaged in the initial phases of collision avoidance problem definition/countermeasure technology assessments to:

- Define, describe and quantify crash problems amenable to advanced technology based countermeasures.
- Assess countermeasure technologies, capabilities, and mechanisms of action so as to identify candidate vehicle-based solutions to these crash problems.
- Assess and describe relevant roadway, environmental, vehicle, and human factors that may affect countermeasure effectiveness.
- Model target crash scenarios and countermeasure action to predict countermeasure effectiveness and identify critical functional requirements to ensure effective performance.
- Estimate benefits based on the potential effectiveness of identified countermeasures in preventing and/or reducing the severity of target crashes.
- Identify specific priority technological, human factors, or other R&D topics/issues to be resolved to ensure that the countermeasure's potential is reached.

This phase will provide extensive and systematic assessments of crash avoidance countermeasure potential and will be the basis for the specification of functional requirements for the intelligent collision avoidance systems.

Table 1 provides a listing of collision avoidance countermeasures (target products) that are likely to be developed and deployed, the function of the specific product, and a qualitative assessment of the benefits such a product would provide. The recently initiated research will serve as the basis for making quantitative benefits assessments in the future. The sequence of hardware development program activities (assumed to be carried out in conjunction with the private sector) would be initiated with efforts to define system technology concepts meeting the functional requirements established.

This would be followed by system development testing, and finally, fabrication and installation of in-vehicle models. System development activities would be supported with system specific human factors research to optimize the interface between the driver and the vehicle.

Table 1. Intelligent Collision Avoidance Technologies

FUNCTION	TECHNOLOGY	BENEFIT
Provide driver with a warning indicating that braking or steering action should be taken to avoid hitting an obstacle	Obstacle detector for warning of objects in front of the vehicle	Reduce frequency and/or severity of front-end crashes
Provide driver with a warning if an intended vehicle action (e.g., lane change) will place the vehicle in the path of an adjacent object or vehicle or if an object is in the path of a vehicle backing up	Near field proximity (blind spot monitor/backup warning	Reduce frequency and/or severity of lane change, blind spot and backing crashes
Provide driver with a warning if lapses in driver attention or vigilance are detected	Driver vigilance behavior and status monitoring system	Reduce frequency and/or severity of crashes involving drugs, alcohol, fatigue, or falling asleep at the wheel
Provide driver with a warning if any of his vehicle components or systems are malfunctioning, operating with decreased performance or failed	Vehicle status/diagnostic system	Reduce frequency and/or severity of crashes resulting from vehicle system/component failure
Provide driver with a warning that the vehicle is approaching its rollover threshold so that appropriate action can be taken to prevent rollover	Rollover threshold warning system	Reduce frequency and/or severity of rollover crashes, particularly trucks and utility vehicles
Provide driver with a warning that the vehicle is leaving the roadway or the travel lane	Lane departure/roadway edge detection system	Reduce frequency and/or severity of run off road or lane departure crashes
Provide driver with a warning of adverse environmental conditions, e.g., ice, fog	Visibility and traction warning system	Reduce frequency and/or severity of fog and reduced traction crashes
Provide drivers with a warning that it is not safe to continue through the intersection	Intersection hazard warning system	Reduce frequency and/or severity of intersection crashes
Do not allow further operation of vehicle if vehicle status is not acceptable	Vehicle performance shut-down system	Reduce frequency of crashes resulting from malfunctioning or failed vehicle components/systems
Do not allow further operation of vehicle if driver status or behavior is not acceptable	Driver performance shut-down system	Reduce frequency of crashes resulting from impaired or inattentive drivers
Provide driver with an enhanced image of the roadway ahead under adverse visibility conditions at night	Night vision enhancement system	Reduce frequency and/or severity of cahes involving a lack of ability to see/detect objects at night
Supplement driver control with capability to automatically maintain minimum headway while cruise control is operational	Adaptive cruise control system	Reduce frequency and/or severity of crashes involving failure to disengage cruise control
Supplement driver control with capability to automatically apply brakes if there is a potential for collision	Automatic braking system	Reduce frequency and/or severity of crashes involving failure to brake in time
Supplement driver control with capability to automatically maintain lane position	Automatic lane keeping control system	Reduce frequency of crashes involving failure to stay in lane
Supplement driver control with capability to automatically determine when it is safe to traverse the intersection	Intersection safety management systems	Reduce frequency of intersection crashes

Early projects will include the following:

- Early warning of potentially dangerous driver, vehicle, road, and environmental conditions, e.g., proximity warning (blindspot to the side or rear of the vehicle), rollover threshold warning, collision warning (to the front of the vehicle), driver inattention/driver impairment warning, and intersection collision management.
- Perceptual enhancement, e.g., enhanced night vision systems.
- Vehicle control, e.g., adaptive cruise control, automatic braking, and electronic steering, braking and throttle control.

The final product of this portion of the NHTSA program will be vehicles equipped with the developed systems and demonstration of the capabilities and potential safety advantages of the systems. Field operational tests of sufficient numbers of systems will be carried out to assess the performance of the developed technology relative to the established functional requirements, as well as the reliability, maintainability, costs, and failure modes/consequences of the design.

Safety Performance Evaluation

Standardized measures and test procedures will be developed to evaluate the effectiveness of the new systems as they are developed. Additional protocols would be developed to assess the safety impact of new systems whether introduced as safety systems or for other purposes such as congestion relief (route guidance and navigation) or mobility enhancement.

It is expected that the evaluations will consider traditional safety benefits (i.e., number of lives saved, injury levels reduced, etc.), as well as the crash avoidance benefits of the congestion relief that is promised by IVHS. For example, we want to answer the question whether the introduction of navigation and route guidance systems improve safety as a result of the relieved stress on the driver, or whether the display/message transmission is distracting to the driver and, therefore, is a safety hazard [12].

Summary

The NHTSA program outlined in this paper will provide the vehicle engineering and human factors research necessary to achieve the potential safety benefits promised by IVHS. Mobility 2000 [3] estimated that the widespread usage of intelligent collision avoidance systems would yield a yearly savings of over 11,000 lives, 442,000 injuries, and $22.2 billion in associated costs.

Intelligent collision avoidance systems are now feasible. The enabling technologies to develop products and/or systems to assist drivers in avoiding crashes are either already available or under development. These include:

- *Sensors* to measure driver and vehicle performance; obstacles around the vehicle; the edge of the roadway (or lane); the friction of the roadway; the absolute location of vehicles; and the distance (ranging) to other vehicles/objects, and their velocity and acceleration.
- *Other Electronics* such as high speed computation and vehicle-to-vehicle and roadway-to-vehicle communications.
- *Mechanical Actuation Systems* such as antilock brakes, traction control, electronic braking steering and throttle control, adaptive suspension and 4-wheel steering.
- *Software Technology* including artificial intelligence, pattern recognition, neural networks, diagnostics (fault detection, accommodation, fault tolerant design, "threat" analysis, nonlinear and adaptive control design, human interface design, reliability engineering, software verification/validation for safety.

Vehicles produced in the next couple of decades could be equipped with systems to instruct drivers to take action to avoid impending danger (lane departure; front, side and rear collision; environmental conditions such as rear collision; environmental conditions such as ice or fog; rollover, vehicle condition; and intersection hazards), to sense lapses in their judgements or skills (driver performance monitor); to augment their capabilities (night vision enhancement), and to even compensate for some of their errors by providing control assistance (vehicle and driver performance shut-down, adaptive cruise control, automatic braking, automatic lane holding and intersection collision avoidance safety management).

Such systems, if properly matched to the capabilities and limitations of the drivers who must use them, will provide the extra fractions of seconds drivers need to be able to successfully execute collision avoidance maneuvers.

Although extensive research, development, test, and evaluation programs will be necessary to produce reliable, cost-effective intelligent collision avoidance systems, no major technological breakthroughs are required. Major cultural, legal, and institutional barriers, however, need to be removed if widespread deployment of such systems is to be achieved. Foremost among these are product liability and public acceptance.

References

[1] Our Nation's Highways, Selected Facts and Figures, Publication Number FHWA-PL-90-024, Federal Highway Administration, Washington, D.C., 1990.

[2] Highway Statistics, Federal Highway Administration, Washington, D.C., 1989.

[3] Advanced Vehicle Control Systems, Proceedings of a National Workshop on IVHS Sponsored by Mobility 2000, Texas Transportation Institute, College Station, TX, March 19-21, 1990.

[4] Fatal Accident Reporting System 1989, A Decade of Progress, DOT HS 807 693, National Highway Traffic Safety Administration, Washington, D.C., March 1991.

[5] Cerrelli, E., Older Drivers: The Age Factor in Traffic Safety, DOT HS 807 402, National Highway Traffic Safety Administration, Washington, D.C., February 1989.

[6] Treat, J.R., et al, Tri-Level Study of the Causes of Traffic Accidents: Final Report - Volume 1: Causal Factor Tabulations and Assessments, DOT HS 805 085, Institute for Research in Public Safety, Indiana University, Bloomington, IN, May 1979.

[7] Lindley, J., Urban Freeway Congestion: Quantification of the Problem and Effectiveness of Potential Solutions, Institute of Transportation Journal, January 1987.

[8] Enke, Kurt, Possibilities for Improving Safety Within the Driver-Vehicle-Environment Control Loop, Proceedings of the Seventh International Technical Conference on Experimental Safety Vehicles, Paris, France, June 5-8, 1979.

[9] Moving America: New Directions, New Opportunities, A Statement of National Transportation Policy, U.S. Department of Transportation, Washington, D.C., February 1990.

[10] Henderson, Robert L., editor, NHTSA Driver Performance Data Book, DOT HS 807 121, National Highway Traffic Safety Administration, Washington, D.C., June 1987.

[11] Personal Communication from Paul S. Fancher, University of Michigan Transportation Research Institute, Ann Arbor, MI, August 1991.

[12] Burgett, August, Safety Evaluation of TravTek, presented at The International Conference on Vehicle Navigation and Information Systems, Dearborn, MI, October 1991.

S4-O-04

Opportunities in Automotive Safety: A Public Health Perspective

David C. Viano
Biomedical Science Department
General Motors Research Laboratories
Richard F. Davis
Industry Government Relations
General Motors Corporation
Milford R. Bennett, Robert L. LeFevre
Environmental Activities Staff
General Motors Corporation
Richard E. Rasmussen,
Mitchel C. Scherba
Current Product Engineering
General Motors Corporation

Abstract

Although considerable progress has been made in reducing the highway fatality rate throughout the U.S., the relative risk of a driving fatality varies by more than 1,000-to-1, depending on the way one chooses to drive. Such factors as alcohol and drugs, failure to use safety belts, excessive speed and aggressive driving substantially increase fatality risk. This is particularly true for young people, as vehicle crashes pose the greatest risk of fatality from all causes for those aged 1-34. Vehicle-related crashes are therefore a major health problem for the nation, and the most significant reason for lost years of productive life.

This paper describes the advances being made by the automotive safety community in the U.S. to further improve the design and performance of motor vehicles to avoid a crash and prevent injury. It also discusses the need for careful evaluation of opportunities for further safety gains. These gains include not only the "hard technologies" of vehicle crashworthiness and crash avoidance hardware, but also the "soft technologies" of modifying driving techniques and risk-taking behavior to avoid crashes. That is, if a person has been taught proper driving techniques, exercises safe driving behavior, and has avoided crashes as a result, these "soft technologies" can take on equal importance in preventing injury as the "hard technologies" of crash avoidance by ABS, heads-up display, or obstacle-detection radar.

As part of national health promotion, HHS Secretary Sullivan has asked the medical profession to encourage the public to take responsibility for their own health. In much the same way, there needs to be a national program by the government and industry to encourage drivers to take responsibility for their own behavior and protection. Perhaps this could be an ancillary program to the current research on causes and control of crash injury to the nation's citizens. It could help form a national strategy to determine the most effective ways in which driving behavior might be modified, and the principles developed could be employed to reduce risk-taking behavior, particularly in young people.

Introduction

The highway safety record in the U.S. has never been better. But a review of the statistics and their public health implications causes all observers, expert and lay person alike, to demand continuous improvement. Automotive safety is a public health issue; and, the safe use of motor vehicles requires a comprehensive program involving as many individuals and institutions as possible. While in the past such issues were addressed by specialists who developed the strategies and conducted the work for safer highways, vehicles, and driving behavior, today individual members of the public are accepting more responsibility for meaningful resolution of health problems, both personal and societal.

National media reporting confirms that the public is more interested than ever in improving individual "wellness." The challenge for automotive safety leadership is to leverage that developing attitude through national and institutional strategies that result in true behavior modification and courteous road use. Such efforts, in combination with continuing engineering improvements in roadway and motor vehicles, offer the best opportunity for improved highway safety.

Recent scientific analyses, engineering developments, increasing safety awareness, and heightened attention by public health officials offer guidance and suggest opportunities to further improve the nation's already impressive highway safety record. The following analyzes these areas.

Automotive Crash Injuries

The United States has experienced a continuous drop in fatal injury risk from motor vehicle crashes. Using the number of fatalities per 100 million miles traveled, the current rate is 2.1 in the U.S (MVMA 1990). This represents an 86% reduction from the 15.6 rate in the 1930s and a 60% reduction from the 5.3 rate in 1960 (Table 1). The drop is related to continuous improvement in vehicle design, restraint use, highway engineering, and driving experience. The 1990 rate represents an unprecedented level of safety as indicated by one fatality on average for every 47.6 million miles traveled. This shows how rare fatal crashes are, based on vehicle travel.

However, the average fatality rate does not adequately describe the risk factors that contribute to fatal crashes. There are many driver, vehicle and environmental factors that contribute substantial variability to the rates for fatal automotive crashes. In a recent study, Evans et al. (1990)

Table 1. Motor Vehicle Accident Facts

Year	All Deaths	Occupant Deaths	Fatalities per 100,000,000 Miles	Fatalities per 10,000 Vehicles	Fatalities per 100,000 Population
1930	31,050	5,700	15.60	12.10	25.30
1940	33,549	9,500	11.49	10.41	25.40
1950	34,763	11,650	7.59	7.07	23.00
1960	38,137	14,800	5.31	5.12	21.20
1970	54,633	23,200	4.88	4.92	26.80
1980	53,172	23,000	3.50	3.28	23.40
1990(est)	48,000	21,500	2.10	2.60	19.90

quantified differences in relative risk for fatal crashes. Figure 1 is a logarithmic plot showing fatality risk differences related to several factors: driver age, alcohol intoxication, safety belt use, vehicle weight, and road type.

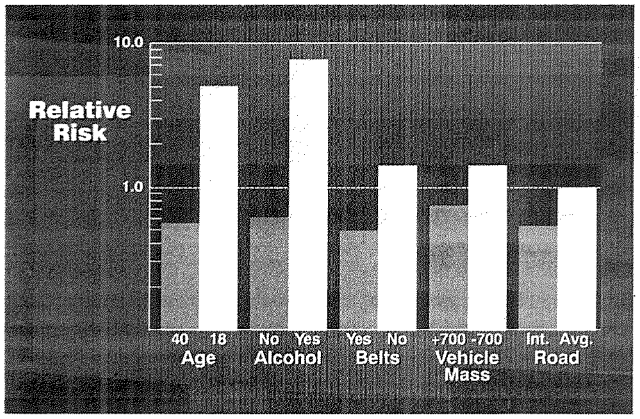


Figure 1. Relative Risk Difference for Fatal Crashes (developed from Evans et al., 1990)

For example, there is nearly a ten-to-one difference in fatality risk between an 18 year old and 40 year old driver, a fifteen-to-one difference with alcohol intoxication, and a three-to-one difference in relative risk with safety belt use. Safety belt use has two influences, one because of the intrinsic effectiveness of belt use which is 42% for the driver, and another because of selectivity since belted drivers have a lower crash involvement rate than non-users. Vehicle mass also influences fatality risks. A weight difference of +700 lbs. above and below the average vehicle, actually has a greater effect than the intrinsic safety of lap-shoulder belts. Lastly, travel on interstate highways is safer than other roads.

Since the many factors which influence relative risk of a fatal crash are independent, their overall effect is cumulative. For example, Figure 2 shows the average fatality rate for passenger vehicle drivers at 1.2 deaths per 100 million miles traveled. Fatality risk increases for an 18 year old male driver, and if the young driver is intoxicated, unbelted, in a 700 lb. lighter than average vehicle, and on a two-lane road, the relative risk has increased to 93.1/100 million miles, almost 100 times greater than the average fatal crash. On the other hand, a 40 year old, sober driver who is belted in a 700 lb. heavier than average vehicle, and on an interstate highway, has a rate of 0.080/100 million miles, greater than a tenth of the average risk. This represents a spread of nearly 1200-to-1 in relative risk about the average fatality rate. Clearly, alcohol use, failure to buckle up, excessive speed, and aggressive driving substantially increase the risks of a fatal crash. Obviously, opposite behavior increases the safety of motor vehicle use.

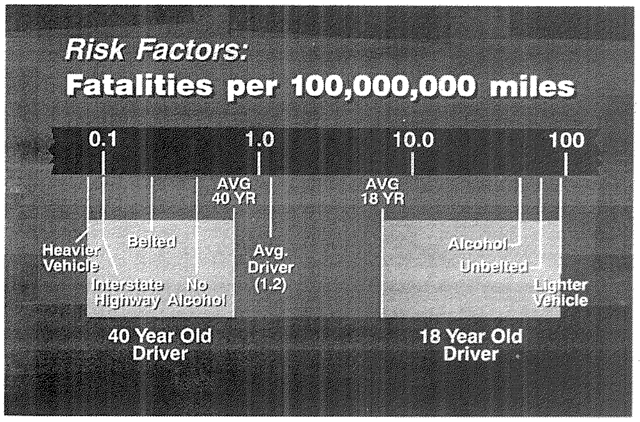


Figure 2. Cumulative Effect of Various Factors on the Driver Fatality Rate (developed from Evans et al., 1990)

There are over 180 million vehicles in operation on U.S. roads, nearly one for every licensed driver. Based on incidence per 10,000 licensed vehicles, crash fatalities have declined over the past 60 years by a similar amount as on a per mile basis. In contrast, the population-based risk of a fatal crash has actually remained quite constant at about 20 per 100,000. Population-based rates are most frequently used in public health discussions of disease and injury. It is on this basis that motor vehicle crashes stand out as a significant public health problem. This is particularly true of youth in America, as vehicle crashes pose the greatest risk of fatality from all causes for people aged 1-34.

Figure 3 shows the fraction of fatalities related to motor vehicle crashes in relation to the age of the

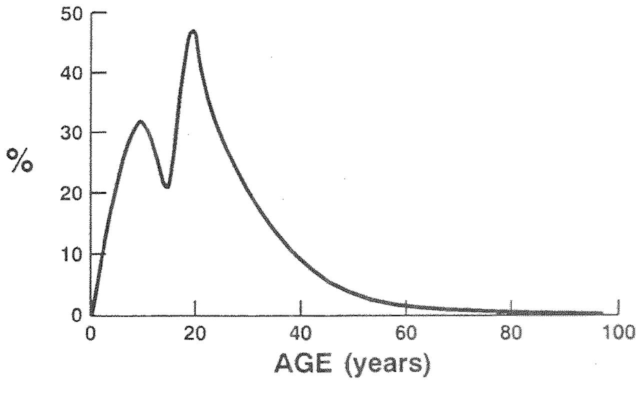


Figure 3. Probability That a Fatality is Related to a Motor Vehicle Crash (derived from Evans 1991, with permission)

victims (Evans 1991). Traffic fatalities increase to nearly 50% of the cause of death for individuals 20 years old. After 20, the proportion of motor vehicle related fatalities decreases. Beyond age 50, traffic fatalities represent a small fraction of U.S. fatalities since other disease processes dominate as the principal causes of death.

The fatal crash risk varies by a factor of four with driver age (NSÇ 1990). The highest rate is for the youngest drivers, and averages 79 fatalities per 100,000 licensed drivers under 20 years of age (Table 2). The rate remains high until age 34 and is associated with the highest reported rates of alcohol involvement in fatal crashes. The licensed driver rate again increases for those over 75, the oldest age cohort.

Table 2. Age-Related Motor Vehicle Fatality Rates

Age	Licensed Drivers mill.(%)	Fatals Thous.(%)	Fatals/ 100,000 Drivers	Alcohol Involvement (%)
<15	--	--	--	6.1
16-20	10.1(6.1)	8.0(12.9)	79	20.8
21-24	17.2(10.4)	9.3(15.1)	54	34.7
25-29	41.1(24.9)	17.3(28.0)	42	33.5
30-34	"	"	"	30.6
35-39	34.1(20.7)	10.8(17.5)	32	27.4
40-44	"	"	"	22.0
45-49	22.5(13.7)	6.3(10.2)	28	19.1
50-54	"	"	"	16.4
55-64	18.9(11.5)	4.7(7.6)	25	13.7
65-74	14.7(8.9)	2.8(4.5)	19	6.8
75+	6.3(3.8)	2.6(4.2)	41	"

Motor Vehicle Injuries: A Public Health Problem

As a public health problem, injuries (primarily motor vehicle crashes) are a major cause of death in the U.S. (Figure 4). They are the fourth leading cause of death following heart disease, cancer and stroke. However, motor vehicle fatalities are comparable to cancer and heart disease on the basis of lost years of productive life. This considers work life lost by premature death before 65 years of age. Since motor vehicle crashes disproportionately involve youth, it is a health problem that affects the productivity and competitiveness of Americans.

However, statistics like 48,000 deaths and 1,600,000 lost years of productive worklife annually do not convey the full significance of motor vehicle crashes. Survivable injury and disability are equally important consequences. There are over 5 million automotive-related injuries annually, with nearly 2 million requiring medical treatment and 150,000 serious enough to require hospital admission (Rice and Mackenzie 1989). Although the incidence of permanent impairment is not accurately known, there are 50,000-70,000 cases of serious disability related to brain, spinal cord or orthopedic injury. The lifetime cost of death, injury, and disability constitutes 67% of the $72 billion annual loss due to motor vehicle crashes. This represents an average lifetime cost of $9,062 per injured person, $43,409 per hospitalized person, and $352,042 per fatality.

The importance of motor vehicle injuries as a major public health problem has resulted in a partnership between the U.S. Department of Transportation and Centers for Disease Control (CDC) in the Public Health Service to conduct injury control research, prevention programs, and public education. The coordinated federal effort was initiated by Public Law 90-190 (Congressional Record 1985) and has involved the private sector and citizens in a concerted program to reduce injuries by developing safer behavior, habits, and products. CDC is currently developing a national strategy to increase prevention of motor vehicle injury. This will involve a broad-based collaboration by many groups and organizations with an interest and programs related to safer vehicle use.

The trends for the 1990's along with a greater health consciousness have increased public interest in automotive safety. As a result, there is a greater demand for safety features, such as airbags and anti-lock brake systems. This provides a marketing opportunity for manufacturers, and prompts public interest in comparative shopping since safety is a determinant of vehicle choice. The supposed perspective of the 1950s that "safety doesn't sell" has been replaced by growing customer interest in safety information, features and performance of current vehicles. Safety is now a more competitive attribute of marketing with fuel economy, quality, styling, acceleration, durability, and cost. This marks a major shift in the public attitude about automotive safety.

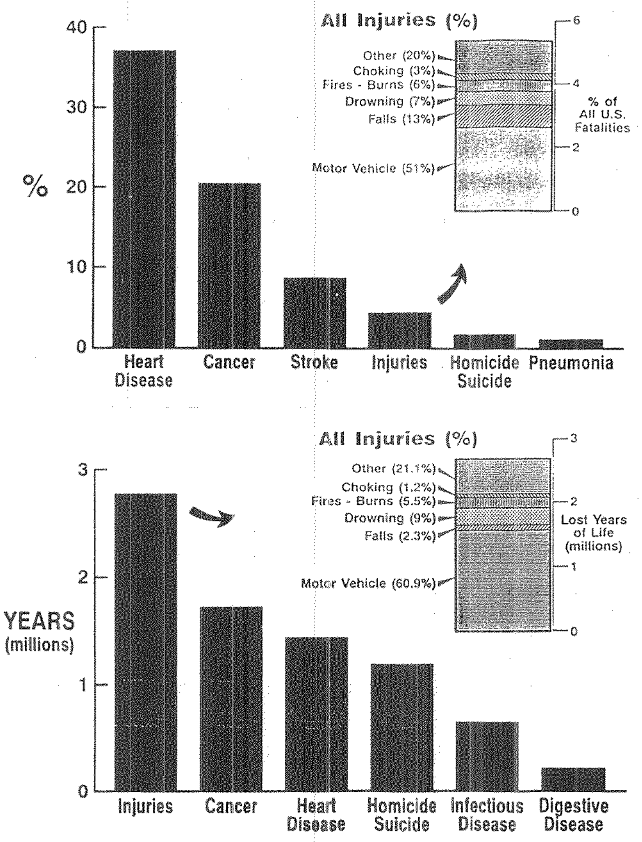


Figure 4. Proportion of Injury-related Fatalities and Lost Years of Productive Life in Relation to Other Health-Related Causes of Death (from Viano 1989 with permission)

Current Situation in Road Safety

There are many factors that enhance the safety of vehicle use and others that increase the risks of motor vehicle crashes (Table 3). Vehicles are now sold with historically unprecedented safety content for occupant restraint, crashworthiness, and crash avoidance. More comprehensive crash testing, improved test dummies, more relevant injury criteria, and in-depth crash investigation have significantly advanced vehicle safety. Safety belt use, the addition of air bags or supplemental inflatable restraints, and routine testing at both 30 and 35 mph by some manufacturers now help assure that vehicles of all weight provide a high degree of crash protection. Recent efforts to improve fuel system integrity, residual occupant space after rear-end crashes, and structural and interior padding changes to reduce side-impact injuries add to crash survivability and injury prevention. In addition, the national interstate highway system is nearing completion. This network provides one of the safest road systems in the world.

Table 3. Factors Influencing Automotive Safety

FACTORS IMPROVING SAFETY	FACTORS DECREASING SAFETY
*Safety Belt Use	*Aggressive Driving/Maneuvering
*Supplemental Airbags	*Increased Travel Speeds
*Crashworthiness Enhancement	*Urban Congestion
*Crash Avoidance Features	*Heavier Commercial Trucks
*Decreased Alcohol Use	*Deteriorating Highways/Bridges
*Experienced Drivers	*Older Occupants/Lower Tolerances
*EMS Systems/Trauma Centers	*Vehicle Downsizing

However, the positive effects of these advances are being mitigated by trends that increase crash injury risks. Higher speeds of road travel, aggressiveness in vehicle use and maneuvers, turning and merging in congested urban streets, and a greater number of older occupants with lower injury tolerances all act to counteract the built-in safety advances of new vehicles. There is also an emerging concern that pressure for substantial increases in fuel economy will cause dramatic downsizing of vehicles and inherently poorer safety in not only multi-vehicle crashes but also single vehicle crashes. There is over a four-to-one increase in fatality risk in the smallest to largest passenger vehicle equally equipped with safety features, just due to mass differences (Frost and Viano, 1991). These factors offset the benefits of further safety improvements, even as new safety features are included in a larger fraction of the vehicle fleet.

Most of the factors that detract from road safety involve driver behavior and attitudes about vehicle use. Table 4 shows improper driving in fatal, injury-producing, and all accidents (NSC 1990). Speeding, pulling in front of traffic, disobeying traffic rules, and violating right-of-way occur frequently. With such evidence about driving, significant advances in traffic safety will require not only a combination of vehicle features and restraint use, but also the adoption of a "courtesy on the road" philosophy and safer driving habits. These aspects require more concerted attention to youth education and formation of good behavior, risk aversion, and avoidance of aggressive habits.

Table 4. Police-Reported Cases of Improper Driving

REPORTED CONDITIONS	TYPE OF CRASH		
	FATAL	INJURY	ALL
IMPROPER DRIVING	61.9%	73.7%	72.7%
Speeding	26.7	23.1	18.9
Right-of-Way	12.2	25.4	23.4
Failure-to-yield	8.4	18.2	17.8
Passed Stop Sign	2.1	2.0	1.6
Disregard Signal	1.7	5.2	4.0
Drove Left of Center	4.5	1.5	1.7
Improper Overtake	6.2	2.0	2.4
Improper Turn	0.4	1.5	2.6
Followed too Close	0.7	6.1	6.4
Other Improper Actions	11.2	14.1	17.3
NO IMPROPER ACTIONS STATED	38.1%	26.3%	27.3%

Safety benefits will accrue even without major new vehicle safety innovations because of the gradual phase-in of airbags and increased use of safety belts. There have been substantial increases in safety belt wearing as reported from observational studies. Reported usage has increased from around 10% in the late 1970s to about 50% in recent studies (NHTSA 1990). However, the increase is occurring for the safest drivers: those least likely to engage in the unsafe practices of drinking and driving, aggressive vehicle use, speeding, and unreasonable risk-taking. Since belt wearing in fatal crashes is only in the range of 10-20% (Table 5), more focused programs are needed to not only pass state use laws, but also improve belt wearing by occupants most likely to

Table 5. Belt Use in Crashes and Normal Driving

	States with Use Laws		States without Use Laws	
	Fatalities	(%)	Fatalities	(%)
Fatal Crashes				
Used	3,842	19.8%	948	9.4%
Not Used	12,813	65.9%	8,184	80.9%
Unknown	2,774	14.3%	985	9.7%
Observed Use	--	49.8%	--	29.7%

Estimate of Lives Saved with Belt Use

1987 Fatalities Without Belt Use		Potential Lives Saved		
In States with Use Laws	In States without Laws	All States with Laws	70% Use	100% Use
15,587 80.2%	9,169 90.6%	2,059	7,278	10,398

engage in risky behavior, as well as to modify this behavior.

Safety belt wearing is much lower in fatal crashes than in observation of normal driving. Even in countries with belt use in the 90 + % range, nearly a third of fatalities are unbelted at the time of the crash. This indicates that passive protection of unbelted occupants will be a strategy which may yield continuous improvement in crash protection. This includes airbags, but also friendly interiors which absorb impact energies of an occupant either by supplementing belt restraint or as primary protection for unrestrained occupants.

Worldwide, vehicle crash testing emphasizes safety performance with the restraint system in use. For years, GM has pursued dual development of crash safety by evaluating the protection of belted and unrestrained front-seat occupants. This is a complementary approach to developing the overall safety of the vehicle. It also promotes the use of a wider range of occupant protection features. It not only assures the performance of the restraint system, but also emphasizes the safety built into the occupant compartment. Interior surfaces act as a complement to belt restraints by adding back-up protection in very severe crashes and also act as primary safety for unbelted occupants. The assessment of safety systems is made more effective by using the Hybrid III for frontal and BioSID for side impact testing, and advanced injury criteria, such as the Viscous and compression criteria (Viano et al., 1989).

As the complexity of safety systems increases, testing and performance evaluation become more difficult. For example, the supplemental inflatable restraint is more than just an airbag. It is a complex system comprised of crash-severity sensors, electronic modules for processing mathematical algorithms, and pyrotechnic devices to inflate the bag. This hardware, when combined with the vehicle's restraint system, unique front structure, steering column, instrument panel, and seating position, constitutes the "total vehicle system."

Vehicle airbag hardware and software must be evaluated to assure that the airbag deploys at the proper level of crash severity and that it does not deploy unnecessarily. Extensive evaluation begins with "analytically testing" sensing algorithms against an extensive envelope of criteria using crash simulations. A matrix of simulated vehicle tests is performed to map out locations on the front structure of the vehicle, determining where sensors should be placed to reflect multiple impact conditions. Finally, a series of vehicles undergo a uniquely designed combination of rough-road impacts and vehicle-crash configurations representing severe customer usage to validate the overall system performance. Since variously sized and equipped vehicles behave differently, each system needs to be subjected to this rigorous development and evaluation procedure.

As the automotive safety community further improves the design and performance of motor vehicles to avoid a crash and prevent injury, there is a need for careful evaluation of opportunities for safety gains. This should include the analysis of injury mechanisms and the types of accidents causing serious injury to lap-shoulder belted, belt and airbag restrained, and unbelted occupants. The crash types are likely to be different for the various conditions and may involve different opportunities to enhance safety by vehicle structure, restraint features, and energy-absorbing interiors.

Crashworthiness Issues

It is important to determine the crash fatalities that may be preventable by reasonable engineering changes of the vehicle. In a study of unbelted occupants, Huelke (1979) found that about 50% of fatalities were unpreventable by the use of belt restraints, airbags or other engineering changes that modify the vehicle. In a more recent study of belted occupant fatalities, Viano and Ridella, (1991) found that 63% of belted fatalities were unpreventable by practical engineering changes in the vehicle or restraint systems. This leads to a similar 50% level of unpreventable deaths based on the mix of belt use (Figure 5). The analysis is important since the opportunities for reasonable improvement in safety are limited, assuming a belt-restrained occupant.

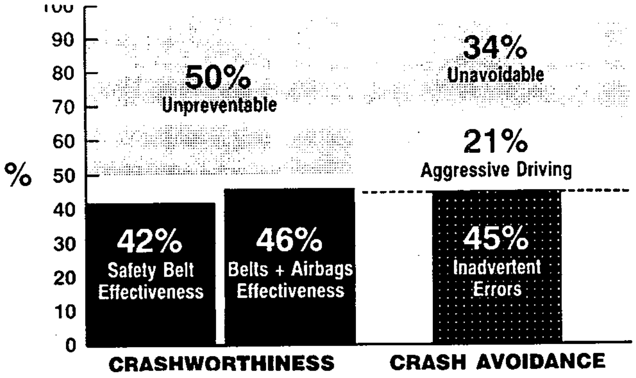


Figure 5. Fraction of Motor-Vehicle Fatalities Preventable by Restraint Use in Relation to Unpreventable Deaths and Fraction of Crashes Related to Driving Errors Possibly Avoidable, to Aggressive Driving, and Unavoidable (from Viano and Ridella 1991 with permission)

Figure 6 shows a 46% safety benefit for the combination of belts and supplemental airbag. Since 50% of fatalities are unpreventable, the difference of 4% represents the opportunity to enhance safety. The margin is considerably larger at 32% when unbelted safety is considered, since "airbag-only" effectiveness is 18% (Evans 1991). This represents an opportunity to consider different features than for belted occupant safety. For example, other measures could be considered to minimize ejection, to help protect the body from impact with pillars, rails and vehicle structures, and to better contain unbelted occupants in the seating area.

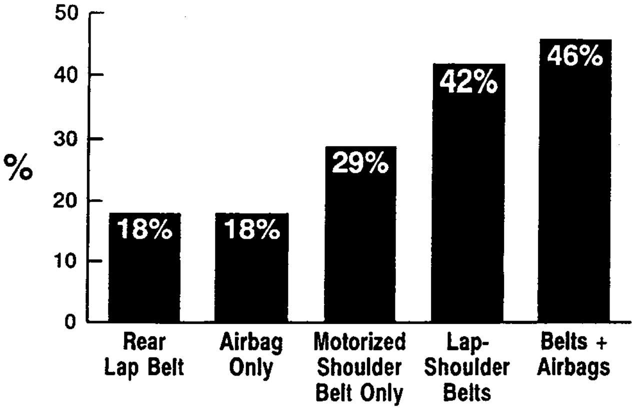


Figure 6. Life-Saving Effectiveness of Occupant Restraint Use. The Data are for a Vehicle Driver Except for Lap-belt Use by Rear Seat Occupants (from Viano 1989 based on research of Evans 1991)

Table 6. Fatalities and Lives Saved by Driver Restraint Use

Belt Use (%)	Fatalities by Restraint Used					Fatalities Avoided			
	None	Belts	Airbag Only	Airbag &Belts	Total	Total	% Avoided	by Airbag	by Belts
0	22,500	0	2,050	0	24,550	450	1.8	1.8	0.0
10	20,250	1,305	1,845	135	23,535	1,465	5.9	1.7	4.2
20	18,000	2,610	1,640	270	22,520	2,480	9.9	1.5	8.4
30	15,750	3,915	1,435	405	21,505	3,495	14.0	1.4	12.6
40	13,500	5,220	1,230	540	20,490	4,510	18.0	1.2	16.8
50	11,250	6,525	1,025	675	19,475	5,525	22.1	1.1	21.0
60	9,000	7,830	820	810	18,460	6,540	26.2	1.0	25.2
70	6,750	9,135	615	945	17,445	7,555	30.2	0.8	29.4
80	4,500	10,440	410	1,080	16,430	8,570	34.3	0.7	33.6
90	2,250	11,745	205	1,215	15,415	9,585	38.3	0.5	37.8
100	0	13,050	0	1,350	14,440	10,600	42.4	0.4	42.0

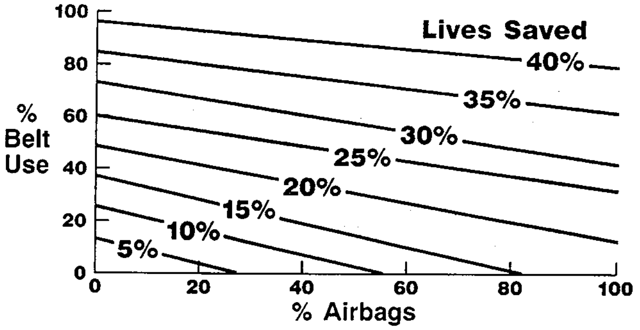


Figure 7. Fraction of Driver Fatalities Avoided by Belts and Airbags as Safety Belt Use Increases and Driver Airbags Phase into the Vehicle Fleet (from Viano 1991)

Interestingly, "airbag-only" effectiveness is similar to that of lap belt use by rear seated passengers. The airbag enhances safety by distributing loads, and the lap belt by reducing ejection risks. Use of a motorized shoulder belt by front seat occupants is 29% effective when the lap belt is not used (Evans 1991). While these data represent the inherent safety of each restraint system, they do not include the influence of availability and utilization on actual lives saved in motor vehicle crashes.

Table 6 provides a projection of the annual driver fatalities and fatalities avoided by restraint availability and use. It assumes a baseline of 25,000 driver fatalities and determines the number of fatalities avoided by various levels of belt use, given 10% of the vehicle fleet or 20,000,000 vehicles are equipped with driver airbags. This level of airbag penetration will occur in the mid-1990's. This analysis merges the effectiveness estimates from Figure 6 with use and availability of safety systems (Viano 1991). Thirty percent safety belt use results in 3,495 fatalities avoided. This represents 90% of the fatality prevention, as the airbag avoids 350 fatalities. Because of the severity of many crashes, fatalities will occur even though safety belts are worn and airbags deploy. 405 deaths will occur to properly belted drivers in airbag deployment crashes. Obviously, the maximum leverage in saving lives is achieved with safety belt use, as 10,600 (42.4%) fatalities are prevented by 100% safety belt use. Figure 7 extends the projection of fatality prevention as airbags become more available and safety belt use increases.

Efforts must continue to improve safety belt use. In addition to good crash performance, safety belts must be conveniently located to facilitate buckling up and they must be comfortable to avoid irritation. Since customer satisfaction is determined largely by what they receive through their senses, touch and feel become important discriminators. In addition to the seat (and steering wheel for the driver), the component that "touches" the occupant at all times is the safety belt. Therefore, in the customer's mind, the difference between a good belt system and a poor system is often judged on comfort and convenience of buckling up and wearing belts. Good comfort and convenience should reinforce the habit of belt usage.

However, comfort presents a significant design challenge since occupant sizes and their corresponding seating positions—front and rear—vary widely. To foster improved comfort, devices such as adjustable belt anchors, belt anchors that are attached and move with the seat, intentionally-set comfort features, as well as child restraints, may play a role in improving performance and comfort of safety belts.

The safety of belted occupants may be enhanced by improved side impact protection, energy-absorbing restraints, and limiting intrusion in partial loading of the vehicle structure. In terms of occupant restraints, the safety of older occupants provides a potential area of improvement. With age, the tolerance of the skeletal system decreases. The high loads of belts, even properly worn, can result in injury to the rib cage and bones. As currently designed, belts impose restraint loads irrespective of the tolerance of the occupant. Energy-absorbing and load-limiting restraints may improve restraint effectiveness in preventing moderate-to-severe belt-induced injury for this special group of occupants.

Belt-restrained occupants are exposed to serious injury risk in crashes involving intrusion in the vicinity of the restrained occupant. Evans (1991) has found that intrusion is a key factor in unbelted fatalities also. Baumann et al. (1990) consider intrusion a key factor in serious-to-fatal injury of belted occupants. These crash circumstances are different from the typical frontal barrier crash, and can involve high-speed loading of a portion of the struck vehicle. The offset frontal crash test provides concentrated asymmetric loading and the potential for intrusion of the occupant compartment. This provides a new challenge for vehicle structure and occupant protection that may be relevant to the safety of an increasing number of belt-restrained occupants.

Side impacts can also involve high-speed intrusion and impact of the occupant adjacent to the struck side. The relative importance of multi-vehicle side impacts increases with driver age (Figure 8) and frequently involves an inadvertent driving error at an intersection (Viano et al., 1990). The error is one of judgment, perception or attention while crossing or turning. The speed of approaching traffic which has the right-of-way is a critical factor in crash severity and the risk of serious or fatal injury. Single vehicle side impacts typically involve a young driver who loses control of the vehicle and impacts a tree, pole, or fixed object. The crash is frequently associated with aggressive driving and speeding. While current engineering focuses on side structure and padding to reduce risks during the crash, the opportunities are limited by the high speed of impact and tolerance of occupants (Viano 1989). Although the side impact crash situations are different for young and old drivers, injury-related crashes are severe enough that crash avoidance provides a particularly important and complementary approach to crashworthiness improvements.

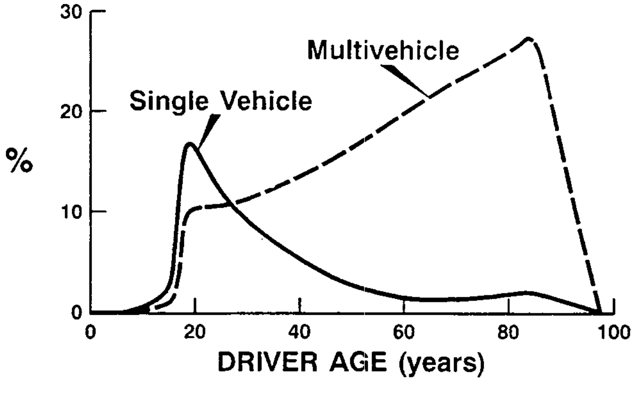


Figure 8. Probability that a Serious Injury is Related to a Single Vehicle and Multivehicle Side Impact Crash (derived from Viano et al., 1989)

While current engineering practices that assess crash safety performance have evolved during the past 60 years, the safety research field has matured sufficiently to allow the emergence of a more refined scientific basis for safety engineering. This type of approach represents the next logical step in automotive safety, and it represents a long term goal that takes us beyond the current regulatory approach of setting tolerance limits for a dummy subjected to a specified crash.

The current approach in FMVSS 208 sets a limit of 1000 on the head HIC, 60g on chest acceleration and 10kN on femur load in a 30mph frontal barrier impact. An immediate regulatory change from the Part 572 to the Hybrid III dummy is warranted (GM 1990). The next generation approach would require analysis of safety performance over a range in crash severities where the integrated effect of the distribution in human tolerance and frequency of crash exposure are considered in establishing overall safety. Such an approach would be a Safety analysis (Safety being an expression combining crash severity, exposure frequency and the distribution in human tolerance to assess societal benefit).

The concept of a Safety analysis as a more refined scientific basis for safety engineering has been presented by Horsch (1987), and used to assess padding benefits for side impact protection. A Safety-type analysis was first proposed by researchers in the United Kingdom, and has been refined by GM into a helpful PC-based computer program. This approach identified a different optimum padding than would be selected from a single side-impact crash test. The approach would provide a larger societal benefit. Yet, this design of padding would actually provide a higher (less desirable) score in the single side impact test than the "best" design for that single test. A Safety-based analysis approach would substantially improve safety, yet it could conflict with the strategy of focusing principally on passing the traditional regulatory test.

In addition to new ways to assess safety, there are a number of other areas of automotive safety. Pedestrian impact protection and roll-over crash safety are two issues that are under investigation. Injury and fatality of pedestrians may be the worldwide safety issue of the 1990s. More lives are lost as pedestrians than as occupants of vehicles internationally. There have been numerous studies on approaches to reduce injury risks by front-end design for pedestrian protection. The wrap-around concept of pedestrian impact has shown that the areas of head contact on the hood and windshield depend on the height of the occupant and geometry of the vehicle. Knowing likely contacts, there may be ways to provide energy absorption for head impacts without compromising vehicle structure that is integral to crashworthiness.

Rollover crash safety has gained more attention in the U.S. with publicity regarding several specific sport utility vehicles. The role of the vehicle design in resisting rollover for severe maneuvers has been obscured for sport utility vehicles that are frequently driven by young, impaired, and aggressive drivers in western mountain states with unforgiving terrain. Some of the most criticized models are also found to be frequently modified by their owners so they no longer represent the intent of the manufacturer. Rollover crashes also have a higher incidence of ejection because of low rates of safety belt use and vehicles without structural tops and doors.

Rollover resistance and occupant protection in rollover accidents do not presently benefit from accepted international procedures for full scale testing or analysis, although there are many proposals being considered and a few regulations in place. Extensive testing has shown that the unrestrained occupant can be injured by impacts almost anywhere in the car or outside for high speed and high severity rollover accidents (Orlowski et al., 1985). Restrained occupants may benefit from localized padding during rollovers; however, extrapolation of benefits to the complexities of the real world is uncertain since entrapment of the head may be potentiated by padding leading to neck injury.

Crash Avoidance Issues

The analysis of fatal crashes of belted occupants indicates that a practical limit of crash protection is being approached with the availability of safety belts, airbags and crashworthy vehicle structures. While pursuit of improvements in occupant restraints and vehicle structure will continue, major gains in vehicle safety will occur only through attention to crash avoidance by an understanding of the causes and prevention of motor vehicle crashes.

A systematic approach to analyzing accident causation has been attempted recently by Viano and Ridella (1991). This effort provides a classification of crashes by common scenario based on pre-crash factors and driving circumstances. The approach differs from others by considering crashes in two general categories (Figure 5). One category involves aggressive driving and vehicle use with the driver "out looking for trouble and finding it." Aggressive, risk-taking behavior is a root cause of many crashes. The other category involves "good drivers exercising caution but getting into trouble" by inadvertent error of judgment, cognition, recognition, perception or motor functions. With the former group, driver training, education and the development of more prudent driving behavior are practical approaches to avoiding a crash. Most vehicle-related changes may not prevent crashes associated with aggressive driving, except technologies that limit access to vehicle use by impaired drivers or limit vehicle speed for the road conditions (Table 7).

Table 7. Accident Avoidance Approaches

GOOD DRIVERS	AGGRESSIVE DRIVERS
*Improved Daytime Conspicuity	*Alcohol Impairment Interlock
*Wet/Icy Road Detection	*Speed Governing
*Obstacle Detection	*Controlling Risk Factors
*Intersection Control Detection	*Road Shoulder Geometrics
*Public Education	*Judicial Action
*Vehicle Emergency Handling	*Traffic Law Enforcement
*Human Factor Analysis	
*Self-Assessment of Prescription Drug Effects	

Approaches that prevent aggressive and risk-taking vehicle use are needed. Such behavior turns a vehicle into a weapon rather than a mode of transportation. However, aggressive behavior is difficult to change. It may be more effective to influence it by education focused on youth during the formative pre-teen years of behavior development. Peer pressure to show-off and act out-of-the-norm is a critical factor in youth behavior, so there needs to be a strong focus on young drivers experiencing the first years of vehicle use. This may include a zero limit on Blood Alcohol Concentrations (BAC), curfew on night driving, and more comprehensive driver training during the teenage years. Stricter enforcement of traffic laws and more effective programs to curb recidivism by substance abusers and repeat offenders may also help.

The greatest opportunity for vehicle-based crash avoidance may be by assisting good drivers in avoiding crashes related to inadvertent error. This class of accident typically occurs in daylight hours on urban roads. Errors are frequently at intersections and are caused by a violation of right-of-way subsequent to improperly starting or turning at an intersection. There are other relevant crashes that may be avoidable. Wet-road accidents associated with loss-of-control, primarily by female drivers inexperienced in vehicle handling in emergency conditions, represent an area in which driver training may improve the emergency reactions of drivers inexperienced in loss-of-vehicle control. There may be other approaches to aiding novice drivers to safely develop vehicle and road experience. This area represents an opportunity to provide interventions that aid safe driving. Such aids may provide welcome assistance.

A great number of driving aids are under development around the world, and several, such as anti-lock brake systems (ABS) and traction control systems (TCS), are being applied in production vehicles at an increasing rate. ABS and TCS provide direct closed-loop control of critical crash avoidance elements with performance that exceeds driver capabilities. Available, but less broadly applied, are sophisticated schemes for control of the distribution of driving forces in high performance all-wheel drive vehicles, and a number of systems for modifying vehicle directional dynamics through rear steering, steer-by-wire, and stability augmentation accomplished with motion transducer feedback. Much of this technology has been applied in the aerospace industry for some years. There are also a number of devices on the threshold of broad application to improve driver perception of hazardous situations. Among these are heads-up displays, vision enhancement, and a variety of obstacle-detection systems.

Most of these systems have been proven feasible but await likely future reductions in cost and proof of reliability and practicality of the technology for broader application. More difficult and less predictable is the problem of determining the actual value of these systems to crash avoidance performance in the real world. It is becoming traditional in many parts of the world to promote crash avoidance devices on the basis of advertising claims and benefits that are claimed should result from their application.

Much less attention is being devoted to careful measurement of crash avoidance benefit when the systems are installed on a volume of vehicles. ABS has been applied in North America at significant volumes for more than five years with almost no hard facts on its contribution to crash avoidance. Government agencies that collect accident data, the vehicle manufacturing industry and the insurance industry need to coordinate their large data bases and most sophisticated analysis efforts to provide the engineering community, regulatory community, and general public with technical information on system effectiveness.

Safety in the Context of a Total Vehicle

The current approach to developing regulation on the automobile is fragmented and deals with various vehicle attributes separately. There are three major areas of regulation: automotive safety, vehicle emissions, and fuel economy. Each deals with an aspect of the societal responsibility of the product. However, handling the items separately can lead to troublesome trade-offs. For example, the discussion on stricter fuel economy standards only recently included the potential negative impact on automotive safety. Lighter vehicles would be required to meet the higher fuel economy proposals without shifting to vehicles which are potentially underpowered. Consideration should be given to a balance of performance which may be achieved by a combined index of performance which simultaneously considers safety, emissions, and fuel economy. A single index of societal benefit may not only be appropriate, but may allow a manufacturer the opportunity to trade-off one aspect for another as part of a marketing strategy.

Achieving a societal index for motor vehicles would benefit national effectiveness, efficiency, and the economy; but, it represents an enormous political and scientific challenge. Fuel economy and emissions requirements are locked into Congressional law while safety is regulated by an agency required to develop and apply minimum performance standards. The current science is imprecise in projecting potential health effects of proposed technological initiatives in either emissions or safety. Despite these challenges, the opportunities for societal benefit from a more comprehensive and interrelated approach to national "risk management" begs for the beginning of debate and dialogue within the safety, environmental, and political communities.

There may be a value in a focused federal research program or a National Academy of Sciences (NAS) study under the umbrella objective of "societal risk management" related to these vehicle attributes. This could lead to the next generation of ESV—Experimental Societal Vehicle.

Organizing for Public Health Protection

The U.S. Department of Health and Human Services recently set-out public health goals for the nation (DHHS 1990). The objectives include health protection with motor vehicle use. Personal responsibility for health promotion is a critical aspect of the "Year 2000 Goals." An infrastructure of health education will be directed at youth to promote risk avoidance and the development of safer habits. There is also a set of objectives for older Americans to minimize disabling injuries related to falls and other accidents.

The Year 2000 Goals set objectives for increased safety belt and child seat use, alcohol avoidance before driving, bicycle and motorcycle helmet use, and specific reductions in survivable-but-disabling brain and spinal cord injuries. While the Public Health Service will provide leadership in monitoring progress toward the health promotion goals, corporate America, private citizens, advocacy groups and federal agencies have a role in achieving injury prevention. The issue of "Injury Control in America" is being better focused in an attempt to achieve safer motor vehicle use (NAS 1985). Better driving behavior by the motoring public would take advantage of the built-in crash avoidance and crashworthiness features of modern vehicles.

Public Involvement

While the issues of auto safety have frequently focused on vehicle crashworthiness, airbags and safety belt use, avoidance of a crash should be just as important to a driver or passenger as crashworthiness—and perhaps even more important to society. That is, if a member of the public has avoided a crash because he or she somewhere along the line has been taught proper driving techniques such as:

- Avoidance of risk-taking behavior (speeding, improper passing, tailgating, road discourtesy)
- Avoidance of drinking/driving situations
- Evasive driving techniques
- Use of safety belts to remain in place during these evasive maneuvers

then all of these "soft technologies" take on as much importance in preventing injury as the "hard technologies" in crash avoidance, such as anti-lock brakes, head-up display or radar-enhanced obstacle detection.

DHHS Secretary Louis Sullivan has encouraged the medical profession—as community authority figures—to educate all members of the public to take responsibility for their own health. Similarly, it behooves the nation, the safety community and auto manufacturers to educate the public to take responsibility for its own safety and protection. The challenge is to find effective ways to change the national psyche regarding avoiding crashes and risk-taking. Efforts need to target the age and socioeconomic groups of highest accident incidence, and then to study and apply the most effective ways to influence the behavior of these groups, especially our nation's youth.

The best way to achieve an appropriate mindset in young people about risk-taking may be to give the message during the pre-adolescent stages, between 8-14 years of age. Adult messages and guidance presented to them after this age are frequently rejected by adolescents, as a natural part of the growing-up process. GM's Medical Committee for Automotive Safety and the American Medical Association developed several creative videos relating to safety belt use and the risks of drinking/driving or riding with a driver who has been drinking, directed at the pre-adolescent student. The videos were sent to every elementary and junior high school in the U.S., with accompanying teachers' guides to help institutionalize the message in the continuing education system.

In addition, adolescents of driving age typically have low self-esteem and a strong desire to be popular with their peers. Therefore, it is reasoned, a message about drinking/driving and other risk-taking behavior that might also risk *sacrificing the lives of friends* might penetrate this natural resistance of adolescents. That is, if teaching techniques focused on such behavior as indifferent to the health and safety of friends rather than self, then the drinking driver would risk a loss of popularity and a poor reputation among his or her peers. In a sense, this is attempting to create a "reverse macho" among young drivers by showing how their behavior is stupid and inconsiderate to friends, rather than "brave risk-taking" to self.

There is the need to study the most effective behavior modification techniques used to date (Geller 1990), and attempt to institutionalize such techniques in the U.S. educational system and relate it to risk-taking behavior. The GM Medical Committee has discussed, with DHHS Secretary Louis Sullivan and other top health officials (such as the current and past Surgeons General), the fact that (1) injury is a national health issue of significant proportions since it is the main killer of young people 1-34; (2) that there is the need to improve society's understanding about risk-taking behavior; and (3) that there is a need to change educational techniques to achieve a different mindset among young people. Secretary Sullivan, Asst. Secretary James Mason, and Surgeon General Antonia Novello have asked for more ideas and information.

There is also the need to create a supportive and continuing infrastructure such as innovative public service announcements (delivered by peer-heroes and heroines of young people), reinforcing messages for school systems to use related techniques for driver education course instructors, and possibly pointed messages and role-modeling woven into TV shows and movies directed at young people. Surely the knowledge and pressure of the DHHS, DOT and the Department of Education can move these programs forward, and elevate some of these resulting techniques to a science.

Such techniques would be just as important in avoiding crashes as would the "hard technologies" designed to reduce the number of crashes, injuries and permanent disability. Even if only moderately successful, these programs could go a long way toward getting today's youth to take responsibility for their own health and safety, and should extend into other phases of their life. Indeed, there should be a significant gain for society in reducing health care costs, adding years of productive life, and reducing risks to prudent drivers or innocent victims who are often inadvertently involved in crashes caused by the risk-taking and aggressive behavior of young people.

Progress toward the Year 2000 health goals may be best made by the involvement, cooperation, and coordination of the many organizations and groups working on road safety, including:

- Legislative action at the state and federal levels to promote wider use of safety belts, child restraints, and helmets.
- Police to increase enforcement of restraint system use by adults and children and traffic laws.
- Schools and advocacy groups to direct regular and effective education at pre-teens and teens to develop responsible behavior and motor vehicle use by inexperienced drivers.
- Schools also to provide education for professionals on injury control.
- Corporate America and labor unions to promote safer habits by the U.S. workforce, and include injury prevention as part of a comprehensive program for health promotion.
- The motor vehicle and insurance industries to coordinate programs with federal agencies to advance product safety, testing and use for public safety.
- The health industry to increase its focus on primary safety and injury prevention to develop an organized system of emergency and acute medical care for injury victims.

Individual responsibility for behavior and action is primary to America's making further in-roads in safe motor vehicle use. Table 8 provides helpful advice for family motoring safety. Achieving the desired goals of "courtesy on the road" will not only promote transportation safety, but increase driving enjoyment.

The objectives of the U.S. Intelligent Vehicle-Highway Systems (IVHS) program are to alleviate road congestion and increase traffic information. This should help reduce the frustration of traffic congestion and improve highway travel. IVHS may help a national effort for courteous vehicle use. However, individuals and individual vehicle use are the building blocks for the future. Accountability for personal action is critical, and public outcry is needed to dissuade inappropriate and unacceptable behavior by drivers on public roads. This provides a balanced approach to the triad of automotive safety by attention to the aspects affecting normal driving (pre-crash), the crash, and post-crash. Table 9 presents a list of ABC's for each phase. These are building blocks for a coordinated national program.

Table 8. Advice for Family Motoring Safety

*Use "Courtesy on the Road," maintain control of the vehicle, and look out for trouble.

*Develop the habits of personal protection by use of safety belts, motorcycle helmets, child safety seats, and protective clothing.

*Avoid impaired driving caused by alcohol and substance abuse.

*Control risk-taking and aggressive behavior including excessive speeding, improper traffic stops and maneuvers, discourteous actions, disobeying traffic laws, and wet/icy road conditions.

*Recognize the potential for inadvertent errors and mistakes related to decreased vision, perception, cognition and reactions, and functional impairments.

Table 9. ABC's of Automotive Safety

DRIVING/PRE-CRASH		CRASH	POST-CRASH
HABITS	VEHICLE	PROTECTION	EMS-EXTRICATION
*Aggressive Driving	*Acceleration	*Airbags	*Access Occupants
*Behavior	*Braking	*Belt Use	*Board Injured
*Courtesy on the Road	*Control	*Crush Zones	*Control Vital Functions
		Compartment Integrity	
ERRORS	RISK FACTORS	RESEARCH	EMS-RESUSCITATION
*Attention Lapse	*Alcohol/Drugs	*Acute Care	*Airway Open
*Basic Motor Function	*By Speeding	*Biomechanics	*Breathing
*Cognition of Risk	*Carelessness	*Crash Causation	*Cardiac Function

While a coordinated national program for safer motor vehicle use is being implemented, there are competing factors that may detract from progress, including unreasonable advocacy, product liability claims, and unreasonable or excessive demands for individual freedom. There is a need to carefully scrutinize these factors and weigh the national good (Babcock 1988, WLF 1990). The U.S. needs to pursue those opportunities that clearly advance the safety of all individuals without inappropriately compromising legitimate individual rights. Reason, balance, and responsible action are needed, while legal and public manipulation are curbed.

References

Babcock, C.W., "Could we alone have this? Comparative legal analysis of product liability law and the case for modest reform." *Loyola of Los Angeles International and Comparative Law Journal*, pp. 321-359, 1988.

Baumann, K.H., Groesch, L., Holtze, H., and Schwede W., "Frontal offset crash testing for approximately 15 years: results, experiences, and consequences." In *Vehicle Crashworthiness and Occupant Protection in Frontal Collisions (SP-807)*, pp. 29-41. SAE Technical Paper #900413, Society of Automotive Engineers, Warrendale, PA, 1990.

Department of Health and Human Services, Public Health Service. *Healthy People 2000: National Health Promotion and Disease Prevention Objectives.* Washington, DC, Government Printing Office, 1990.

Evans, L., *Traffic Safety and the Driver.* Van Nostrand Reinhold, 1991.

Evans, L., Frick, M.C., and Schwing, R.C. "Is it Safer to Fly or Drive?" Risk Analysis 10(2):239-245, 1990.

Frost, L.L. and Viano, D.C., "Automotive safety and CAFE: proposed changes in standards have 'weighty' implications for vehicle occupants." GM Research Laboratories SEARCH 26(3):1-6, August, 1991.

Geller, E. Scott, "Applications of behavior analysis to prevent injuries from vehicle crashes." In *Progress in Behavioral Studies,* Volume 3, S. Glenn (ed), Cambridge, 1A:Cambridge Center for Behavioral Studies.

General Motors Corporation, *General Motors Corporation Comments and Petition to Amend FMVSS 208 in Response to Docket 74-14: Notice 66. Occupant Crasn Protection.* USG 2842, November 13, 1990.

General Motors Research Laboratories, "GMR's viscous criterion impacts safety research." GM Research Laboratories SEARCH 26(2):1-8, May, 1991.

Horsch, J.D., "Evaluation of occupant protection from responses measured in laboratory tests." Society of Automotive Engineers Technical Paper #870222. Society of Automotive Engineers, Warrendale, PA, 1987.

Huelke, D.F., Sherman, H.W., Murphy, M.J. "Effectiveness of current and future restraint systems in fatal and serious injury automobile crashes." Society of Automotive Engineers Technical Paper #790323. Society of Automotive Engineers, Warrendale, PA, 1979. 27

Motor Vehicle Manufacturers Association, *MVMA Facts Book.* Motor Vehicle Manufacturers Association of the United States Inc., Detroit, MI, 1990.

National Academy of Science, *Injury in America.* National Academy Press, Washington, DC, 1985.

National Safety Council, *Accident Facts,* National Safety Council, Chicago, IL, 1990.

National Highway Traffic Safety Administration, *Safety Belt Wearing Rates.* Washington, DC 1990.

National Highway Traffic Safety Administration, *FMVSS 208 Regulatory Impact Analysis.* Department of Transportation, Washington, DC 1984.

Orlowski, K.F. and Bundorf, R.T., "Rollover crash tests—the influence of roof strength on injury mechanics." In *Proceedings of the 29th Stapp Car Crash Conference*, pp. 181-204, SAE Technical Paper #851734, Society of Automotive Engineers, Warrendale, PA, 1985.

Rice, D.P. and MacKenzie, E.J., *Cost of Injury in the United States: A Report to Congress 1989*. San Francisco, CA: Institute for Health & Aging, University of California and Injury Prevention Center, The Johns Hopkins University, 1989.

U.S. House of Representatives, Public Law 99-190. Congressional Record, p. HI 2868, 1985.

Viano, D.C., "Limits and challenges of crash protection." *Accident Analysis and Prevention*, 20(6):421-429, 1988.

Viano, D.C., "Cause and control of automotive trauma." *Bulletin of the NY Academy of Medicine*, Second Series, 64(5):376-421,1988.

Viano, D.C., "Estimates of fatal chest and abdominal injury prevention in side impact crashes." *Journal of Safety Research*, 20(4):145-152, 1989.

Viano, D.C., King, A.I., Melvin, J.W., and Weber, K., "Injury biomechanics research: an essential element in the prevention of trauma." *Journal of Biomechanics* 22(5):403-417, 1989.

Viano, D.C., "A blueprint for injury control in the United States." *Public Health Reports*, 105(4):329-333, 1990.

Viano, D.C., Culver, C.C., Evans, L., Frick, M., and Scott, R., "Involvement of older drivers in multi-vehicle side impact crashes." *Accident Analysis and Prevention*, 22(2):177-188, 1990.

Viano, D.C. and Ridella, S.A., "Crash causation: a case study of fatal accident circumstances and configurations." In *Proceedings of the 1991 AAAM Conference*, October 1991 and submitted to *Accident Analysis and Prevention*, 1991.

Viano, D.C., "Restraint Effectiveness, Availability and Use in Fatal Crashes: Implications to Injury Control." For submission to *Public Health Reports*, March, 1991.

Viano, D.C., "Effectiveness of Safety Belts and Airbags in Preventing Fatal Injury." In *Frontal Crash Safety Technologies for the 90's (SP-852)*, pp. 159-171. SAE Technical Paper #910901, Society of Automotive Engineers, Warrendale, PA, 1991.

Washington Legal Foundation, Critical Legal Issues, Working Paper Series No. 43, *The Negative Impact of Product Liability on U.S. Competitiveness: Liability Law Reform Reinforced by New Studies*, 1990.

S4-O-05

Safety Aspects of Driving with Intelligent Vehicles and Intelligent Traffic Systems

Dr.-Ing. Thomas Scharnhorst
Volkswagen AG

Introduction

All over the world, unprecedented efforts are being devoted to researching new ways to improve the efficiency of road traffic flows whilst simultaneously increasing road safety. The main research programmes in question are PROMETHEUS and DRIVE in Europe, IVHS in the USA and AMTICS, RACS and VICS in Japan. The problem is there for all to see: there can be no doubt that the traffic situation has seriously worsened throughout the world, and in some regions the sheer volume of traffic inevitably provokes traffic jams, often caused by otherwise minor road accidents. The waste of time and energy caused by traffic congestion was estimated by Deutsche Straßenliga (DSL) to have cost a total of 26 billion DM in 1989 alone in the former West Germany.

The initial phase of PROMETHEUS was launched with the vision that the quantum leap in improved efficiency and safety would be provided by the increased use of electronics in the car, for example with the goal of automatic driving on motorways. However, events on our streets have rapidly overtaken this dream, especially in cities. Today, there is general agreement that in the short term the control of traffic congestion will require a cooperative approach to traffic management, whereby governments, local authorities and the car industry will have to work together to devise highly individual solutions for the particular areas that suffer the worst problems of traffic flow and safety.

Independently of this urgent need for short-term solutions, there are hopes that we will be able to derive the benefits of the most important technical evolution of these closing years of the 20th century, namely the increasing capacity of electronic applications. This evolution has for example meant that every 2 or 3 years computers double in capacity for half the price.

This article views the contributions of electronic applications both to the actual vehicles and to traffic management under the heading of "Preventive Safety." The aim is to achieve a safer and thus more efficient traffic flow by exerting a positive influence on the behaviour of vehicle drivers.

Accident Statistics

The overall mileage driven in Germany has increased every year, but, encouragingly, the number of people killed in road accidents has constantly decreased, see Figure 1. However, for 1989, this figure still stands at more than 8000 people, of which roughly a half were car drivers or passengers, roughly a quarter were pedestrians and the remaining quarter were riders of 2-wheeled vehicles.

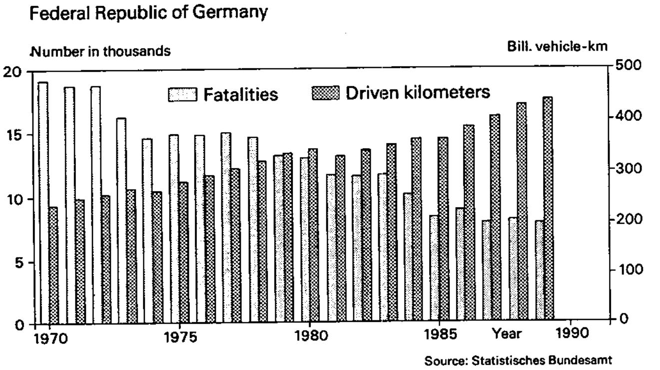
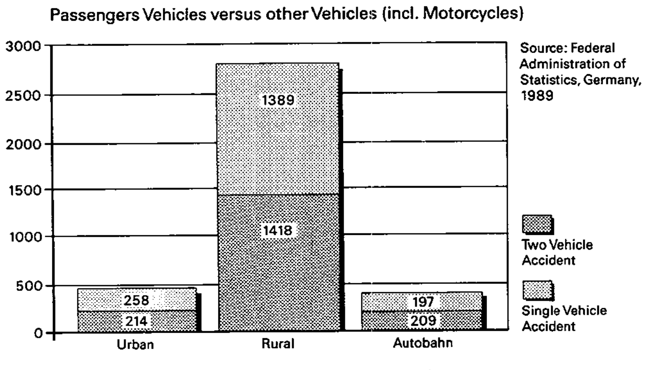


Figure 1. Fatalities and Driven Vehicle-Kilometers

Between 1970 and 1989, there has been an overall improvement of 25% in these figures, weighted by mileage. Over the years, without claiming to be exhaustive, the following three contributory factors have played a key role in this improving trend: car drivers are now, on average, more skilful and experienced; the infrastructure, in the form of roads and road signs, has been improved and, last but by no means least, cars themselves have become safer. In this last respect, advances in "active" safety have now been matched by improved "passive" safety precautions, in particular structural improvements to vehicle bodies and optimal restraining systems that soften the brutal deceleration forces unleashed on the occupants of the car in the event of a collision, thereby minimizing the severity of injuries. However, the most decisive advance has been the legal obligation to wear seat belts, which led to a marked reduction in road deaths from 1985 (see Figure 1).

The causes of accidents involving personal injury are almost entirely traceable to human (driver) error. The German Office of Statistics cites a figure of only 1.2% for technical faults in the vehicles, and even here the ultimate cause could be negligent maintenance. The vast majority of fatal accidents involving cars occur on ordinary country roads, as shown in Figure 2.



Source: Federal Administration of Statistics, Germany, 1989

Figure 2. Fatalities in Passenger Vehicles

The Human Factor

Humans, as vehicle drivers, are responsible for both closed-loop and open-loop control of their vehicles, so that they are in effect the most important component of the vehicle on the road. Basically, the capacity of the human driver is comprehensive, but instead of operating on fixed algorithms this capacity is expressed in individual spontaneous decisions based on experience. For all drivers, the driving process can be resumed as follows once they have completed their initial learning phase:

> "Receive information - Process information - Decide changes to manipulated variables - Execute decided action. It should be noted that this process is entirely subconscious, which is a sign that driving is not experienced as hard work but as a pleasant occupation that leaves room for other thoughts" (Forster).

However, there are situations in which humans make mistakes due to errors of judgement. Obvious examples include the visibility range in fog, tyre adhesion in the wet or on ice and the braking distance at different speeds, to name but three.

Frequently, these situations could be improved by better information.

One section of Volkswagen's research work in the PROMETHEUS programme is devoted to the theme of "Preventive Safety," i.e. all activities designed to prevent critical safety situations occurring in the first place. The starting points are better pre-processed information, accurate predictions and the provision of semi-active and active supports for the driver. These measures apply to the infrastructure, vehicle technology and driver training.

Expectations of Vehicle Electronics

Humans are able to learn and adapt, but their performance is subject to a variety of inner and outer influences. By various driver support measures, and by alleviating the consequences of mistakes on the road, the aim is to maintain the driver's performance at an optimum level for as long as possible. Electronics can often be used as a positive aid in this respect, as can be seen from the variety of functions currently at various stages of research or already available as optional extras for customers (see Figure 3).

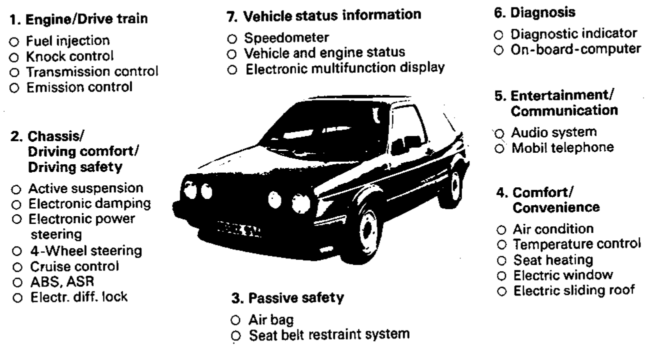


Figure 3. Options of Car Electronics Today

Another equally important criterion is the question of road safety. Here, the fundamental principle is that the use of electronics inside the vehicle or as part of the traffic system must have either a neutral or enhancing effect on safety. If a new application is estimated to have a negative effect on road safety, it must not even be considered for use in traffic. However, it is not easy to separate the wheat from the chaff in advance: at the very least, the selection process must be based on strictly controlled field tests. Large-scale research projects such as PROMETHEUS are ideal for this task.

Safety by Information from the Wider Environment

In future, "intelligent roads" are expected to make a major contribution to road safety. "Intelligent roads" are roads with road signs that adapt to the actual hazard conditions: in addition to giving appropriate warning, these signs arouse a higher driver response than conventional non-dynamic road signs. For example, warnings of "Ice on the Road" that remain fixed in place all year round tend to be useless when actually needed, because drivers who take the same road every day will no longer register the warning. The same applies to fixed speed limits. Here, as shown in Figure 4, "intelligent" systems have proved able to ensure fast and safe traffic flow on motorways, initially by means of purely visual signals.

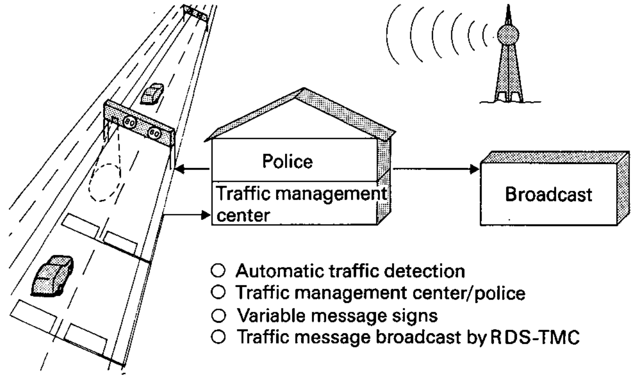


Figure 4. Interurban Traffic Management on Motorways

The use of intelligent (i.e. adaptable) systems can be extended to warnings of incipient traffic jams, accidents and fog. To ensure that the warnings are appropriately switched according to the actual situation, measurements are required to determine the flow rate (speed) and density of traffic. At present, these measurements are taken by induction loops in the road Audible information is also provided to drivers by means of traffic news on the radio, and it will soon also be possible to transmit and store coded data via the RDSTMC system. Drivers will then be able to call up the relevant data for their chosen journey. As a whole, traffic guidance systems on motorways should help prevent minor shunting accidents which can easily degenerate into massive pile-ups or simply provoke extremely long tailbacks. According to results so far, accident figures can be reduced by 20% in these areas.

In cities, positive effects on both the environment and road safety can be achieved by a coordinated urban traffic management system designed to prevent unnecessary traffic, such as cars looking for non-existent parking spaces (Figure 5). Here again, the driver can simply be directed by visual signals installed in the infrastructure. Figure 6 shows an autonomous navigation system built into the car to help the driver find the desired destination, albeit with relative imprecision. Navigation systems based on position-finding data from satellites or from information beacons on the side of the road have adequate precision but are extremely expensive. These beacons permit 2-way communication with the vehicle, and if coupled with up-to-the-minute traffic data and connected to a traffic guidance computer, they can help determine the current best route to a given destination, thus sparing the driver the unnecessary fatigue and exasperation of route finding or long traffic jams. The responsibility for traffic information, traffic communication and traffic guidance systems lies with the state. The task of PROMETHEUS is to work out and implement the necessary agreements for future standards and interfaces.

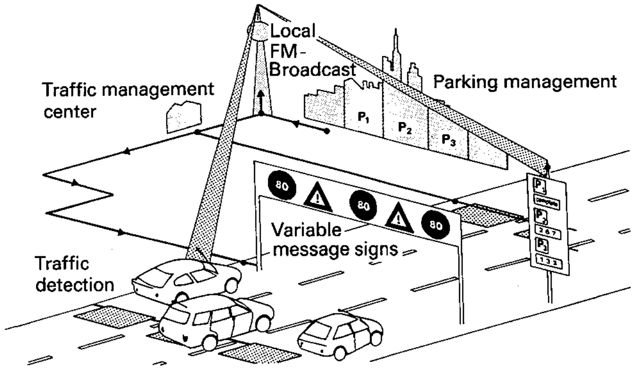


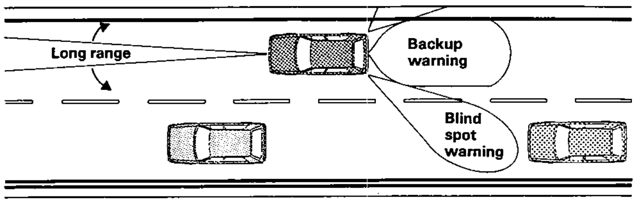
Figure 5. Urban Traffic and Parking Management with RDS-TMC

Figure 6. Navigation with Bosch Travelpilot—Static Route Information

Safety by Information from the Immediate Environment

Information from the immediate environment is mainly supplied by systems installed inside the vehicle. One of the projects in this area aims to warn the driver of obstacles ahead. Surveys have shown that 50% of rear-end collisions could have been avoided if the driver of the second car had braked half a second earlier.

Figure 7 shows the system and the problems to be solved. A sensor is needed to measure the distance from an obstacle in front of the vehicle. Depending on the width of the sensor light beam, the space in front of the vehicle must be covered by several beams or scanned by a single beam. Infrared pulse lasers or microwave sensors seem best suited to this task. To avoid overburdening the driver with a surfeit of information, a collision warning is considered preferable to a distance warning.



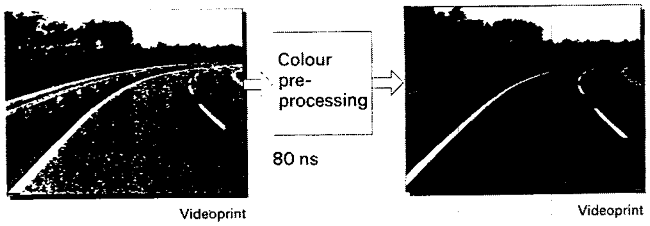
Technologies under investigation:

Long range	Short range
○ Infrared puls laser	○ Laser
○ Radar	○ Ultra sonic
○ Computer vision	○ Computer vision
○ Infrared camera	

Figure 7. Distance and Collision Warning Systems

To prevent oncoming vehicles being signalled as obstacles when cornering, the system must detect the lane (track) of its own vehicle and reject all reflections from outside this lane as erroneous.

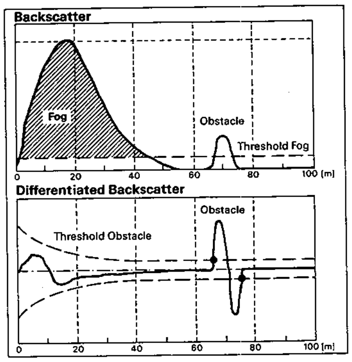
For this purpose, automatic image processing is required in addition to the laser. The vehicle is therefore also equipped with an electronic camera and a multiprocessor in which the various features that characterize a vehicle's track are analyzed. Figure 8 shows an example of track detection based on the white lines on the road. An on-board computer can then correlate the track and sensed distance data. The driver is only warned if obstacles are detected in the vehicle's own lane.



Filtering of the lane marking's colour

Figure 8. Lane Detection by Computer Vision

Figure 9 outlines a further potential application of the collision warning system by using the contrast of the emitted and reflected laser signals as a key to determining visibility conditions.



- ○ Sensing fog density by pulse-shape and duration of backscatter
- ○ Determination of fog density by pulse-integration or pulse-amplitude
- ○ Sensing obstacles using the differentiated signal
- ○ Determination of obstacles distance by exceeding a positive and a negative threshold in a given time space
- ○ Threshold fog density fixed
- ○ Threshold levels obstacles a function of signal to noise

Ref: H. Spies, M DE 3640449, MBB-Deutsche Aerospace

Figure 9. IR—Distance—Visibility—System

Ideally, all information relating to road safety should be displayed in the driver's direct field of view, so that the driver never has to look away from the road. Figure 10 shows an example of a "head-up display" (HUD) of this type. In this system, the received signal is converted into a visual symbol in a liquid crystal display, and this symbol is projected into the lower half of the driver's field of view by a mirror system. This projection is made possible by a partially transparent (two-way) mirror, which is made of holographically processed film and embedded in the windscreen.

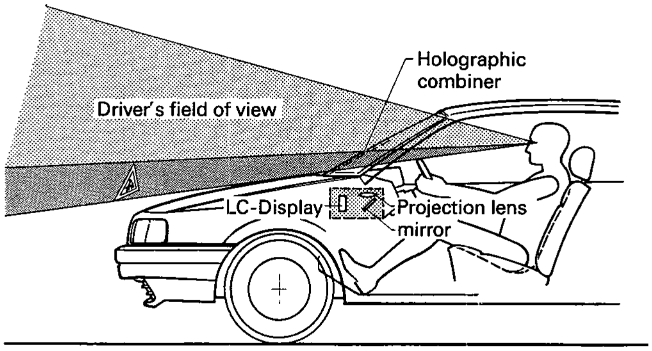


Figure 10. Head-Up Display

Hazards resulting from changed road surface conditions, e.g. ice or loose chippings, can be estimated as reduced adhesion and displayed to the driver in the form of a skid danger warning in the HUD. It is important to give this warning while the vehicle is still on the straight, so that there is time to reduce speed before the next bend. The vehicle is equipped with special wheel-slip computers that use the ABS sensors to compare and evaluate the wheel-slip signals from the driven and undriven wheels (see Figure 11).

Safety by Power-Assist Systems

All the above systems are designed to give the driver early warning of dangers, including dangers outside the driver's normal range of perception, e.g. icy roads. Servo and power-assist systems go one step further, in that they

Tyre/Road friction monitoring

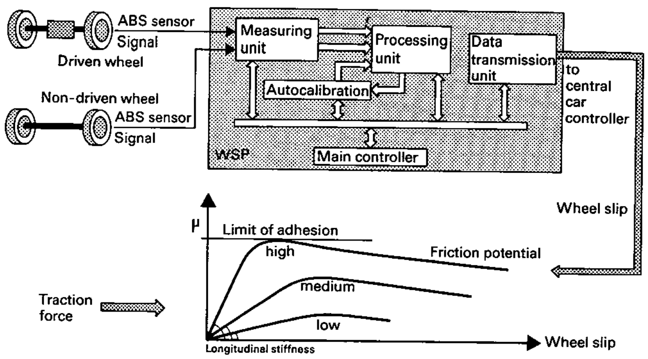


Figure 11. Vehicle On-Board Diagnostic

Intelligent cruise control with smooth automatic braking
Intelligent lane control with support in the driver's steering task

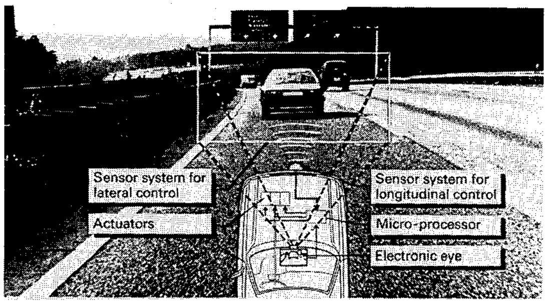


Figure 12. Driver Assistant Systems

boost the driver's strength in possible weak points, thereby giving the driver added power to control the vehicle reliably.

In critical situations—frequently when the driver has misjudged a situation or allowed attention to slip from the road—the vehicle is required to behave correctly of its own accord. As well as the technical basis, which is by no means simple, given that all conceivable situations have to be checked for plausibility within a fraction of a second, there are legal questions of road safety legislation that still remain unanswered. Nevertheless, research into the possibilities of electronics in this field is rewarding. One example would be to couple the collision warning system described above with a system that automatically takes action if the driver fails to apply the brakes, either by means of a haptic effect on the accelerator pedal or a slight automatic braking if the cruise control is in use (see Figure 12). In the same way as the car can be prevented from running into the back of another vehicle, it is also theoretically possible to prevent it leaving the road. Here, after correctly anticipating vehicle movement in relation to the desired line of travel, it would be necessary to intervene automatically on the steering system. For reasons of safety, for example on country roads, this system is not easily conceivable in practice.

Chances and Risks of Improving Safety by IVHS

Publications aimed at enhancing safety on European roads speak of the possibility of reducing the number of deaths by some thousands. The risk is that-this vision may still fail to live up to its full potential, due to the inexperience, indecisiveness, fallibility, restricted visibility and limited information-processing capacity of humans: despite extensive safety systems, these human failings may still conspire to cause accidents.

Nevertheless, it is important to avoid simply compensating for the weaknesses or irregularities of humans. Safety research must interact with the human driver, especially in the power-assist systems. If even part of the control is taken out of the hands of the human driver, questions of acceptance, testing and familiarization must be considered.

The purpose of perfecting the electronic facilities in the car must therefore be to give humans added calmness and serenity in controlling the vehicle safely, by means of systematically good information on the road and unambiguous assistance in emergency situations.

There are also question-marks over the financing of intelligent vehicles and intelligent roads in their final implementation and gradual introduction by field tests. Public authorities or private investors are required to put up the capital, whilst manufacturers will be dealing with a new market that will initially be difficult to estimate. All initiatives in this domain will share the common aim of achieving a good cost/benefit ratio through the introduction of new technology. This question will have to be thoroughly analyzed.

However, technical developments have always been ahead of safety requirements, and all major legislative initiatives on road safety have been led by industrial initiatives. Safety initiatives for traffic management will therefore be derived from technical improvements to the traffic infrastructure, improved hazard warning systems in the vehicle and finally—remembering that the human driver remains the key to improved traffic behaviour—the use of driving simulators supplied by the car industry for road safety programmes (see Figure 13), including, for example, the traffic safety programme of the German Automobile Manufacturers Association (VDA), which offers free safety training to all young buyers of new cars.

Literature

1. Walzer P., Zimdahl W.; European Concepts for Vehicle Safety, Communication and Guidance, SAE Conference 1988, October 17-18, Detroit.
2. Förster H.J.; Automobiltechnik, Technik nach menschlichem Maß [Automotive technology, technology on a human scale], VDI Bericht 595, 1986.
3. Praxenthaler H.; Elektronik im Straßenverkehr—Erfahrung und Ausblick [Electronics in road traffic—experience and outlook], VDI Bericht No. 819, 1990.

Figure 13. Training with Driving Simulator

4. Maretzke J., Dreyer W., Hoppe P. and Jacob U.; Systems for Driver Support in the Longitudinal and Lateral Control of Motor Vehicles, ESV 905165
5. Bücher T, Höfflinger B., Schwederski T. and Maretzke J.; WSF-A Processor for real-time wheel-slip measurement in vehicles, IEEE Vehicular Technology Society Conference, St. Louis, 1991.
6. Dreyer W., Hoppe P., Jacob U. and Maretzke J: ICAD-Intelligent Computer Aided Driving. Automobil-Industrie 35, 1990, Vol. 2 pp 147-151.

S4-O-06

PSA Project "For A Safer Road"

J.P. Faidy, J. Hamon
PSA

Abstract

In Europe, from 1972 to 1985, the number of killed people was reduced by 37% whilst the number of vehicles increased by 56%. But, since 1985, progress has stagnated.

The PSA research plan "PSA For a Safer Road" aims at reducing by half, between now and the year 2000, the number of road accident victims by taking a global, rigorous, innovative, voluntary and concerted approach, bringing together the driver, the highway infrastructure and the vehicle.

This approach comprises 4 sectors entitled:

- **KNOWLEDGE** to better understand the causes and consequences of accidents as well as the driver's physiological and psychological behaviour;
- **PREVENTION** to eliminate as far as possible risk situations by having a safe infrastructure and properly trained drivers, and by adopting a convivial driving style with safe, comfortable vehicles in good condition;
- **AVOIDANCE** to ensure that in a risk situation the accident does not occur. This avoidance is based on driver assistance programmes and dialogue between the vehicles and the infrastructure;
- **PROTECTION** to ensure maximum limitation, in the event of an accident, of consequences to the people involved by better protecting vehicle occupants and reducing the aggressive nature of the road environment and that of vehicles towards pedestrians and bicycle users.

Introduction

In France, the number of killed people decreased by 37% (figure 1) between 1972 (16,600 deaths) and 1985 (10,446), whilst the number of automobiles increased from 16 to 25 million (+56%) and the traffic index increased by about 35%.

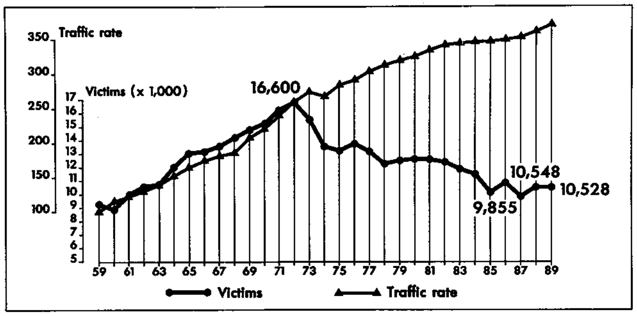


Figure 1. Evolution Since 1959 of the Number of Victims on the Road Compared to the Traffic Rate on the National Road Network

However, these very encouraging results have not improved since 1985, thus showing that the steps taken to achieve them have reached their limit.

More precisely, a survey conducted by ONSER highlights that, whilst the number of human accidents continues to decline, the number of deaths on our roads is stagnant (10,000 deaths per annum) thus leading to a major accident rate of 6.3 deaths per 100 human accidents or 4.4 deaths per 100 victims (deaths + injuries) in 1990.

For this reason PSA has equipped itself to carry out a programme on road safety research with the aim of pursuing from now until the year 2000 the same rate of reduction of road deaths per annum as achieved between 1972 and 1985.

Such a large scale road safety initiative can only succeed if account is taken of the three road participants i.e. the driver, the vehicle and the infrastructure and their interaction is understood.

Furthermore, the research effort is directed towards the implementation of new concepts and technologies. It is cohesive with the already established large scale European programmes such as PROMETHEUS and DRIVE.

Finally, it enables links to be activated between a fair number of outside partners who are also associated with the same activity (suppliers, universities, laboratories).

Overall Presentation

The programme "PSA For a Safer Road" is the fruit of an approach which intends to be, at the same time, global, rigorous, innovative, voluntary and concerted:

- a global approach consisting, not only of analysing the three elements of road safety—driver, vehicle, infrastructure—in an independent way but as a system in which the separate elements can and must interact with each other.
- a rigorous approach enabling solutions to be selected, with due account taken of costs, which offer optimum returns in terms of human lives saved. The approach must take into consideration scientific analysis of the various accident configurations, their frequency, the conditions in which they can occur as well as the evaluation of measures which would enable the accidents to be avoided and the use that motorists would make of these measures.
- an innovative approach founded on the considerable potential offered by new technologies in the fields of electronics and telecommunications.
- a voluntary and concerted approach because the proposed solutions bring into play numerous partners and some of the solutions have wider implications for the whole of Europe.

The programme has four sectors:

- Knowledge: know the reality of accidents (causes and effects) as well as the behaviour of road users;
- Prevention: with the aim of not allowing critical situations to occur;
- Avoidance: in critical situations, stop the accident from happening;
- Protection: as soon as an accident has occurred, minimise the effects on the people involved.

The table shown in figure 2 shows the synthetic ways in which the safety actions are distributed respecting the four sectors and according to the players mentioned above.

ACTOR ACTION	DRIVER	VEHICLE	INFRASTRUCTURE
KNOWLEDGE	STUDY OF THE ACCIDENTS (case studies)	→ ANALYSIS OF THE CAUSES → ANALYSIS OF THE CONSEQUENCES	
PREVENTION	DRIVERS EDUCATION	- DYNAMIC BEHAVIOR - EASY INFORMATION CAPTION	INFRASTRUCTURE PLANNING
AVOIDANCE	DETECTING OF THE INAPTITUDE TO DRIVE (state of drunkness, hypovigilence)	- DETECTION OF MOVING OR FIXED OBSTACLES - CO-PILOTING	- COOPERATIVE MANAGEMENT OF ROAD NETWORK - SPREADING OF ADAPTED INFORMATIONS
PROTECTION	INCITATING TO THE FASTEN OF THE SAFETY BELTS	- CRASH WORTHINESS - PROTECTION DEVICES	- AUTOMATIC ALARM IN CASE OF ACCIDENT - EASIER INTERVENTIONS OF THE SAFETY TEAMS

Figure 2. Classification of the Action Fields to Improve Road Safety

Knowledge

Making oneself aware of events is the prelude to any research. It is a question of "Knowing better to heal better;" to understand the reality of the facts to be able then to better focus the research's direction.

It is also a way of debating the technical options and of evaluating the stakes in play (number of human lives saved, injuries avoided) which will then enable the most efficient solutions to be proposed, taking due account of the investment that they will represent.

This research is, in the main, carried out at the joint PSA and Renault Accidentology and Biomechanical Laboratory (LAB).

It is split into two main activities:

- accidentology or research into the causes and effects of accidents,
- biomechanics or research into understanding human tolerance of physiological stress in the event of an accident.

Accidentology

"Accident surveys" are systematically carried out in test areas by the Laboratory teams, assisted by the Police and the Gendarmerie as well as the medical institutes. The result is a computerised file index covering more than 8,000 vehicles and 13,000 people involved in accidents. Furthermore, for more than a year, the Gendarmerie and the National Police force send the Laboratory a copy of every report on fatal accidents in France and this has developed into a library of more than 7,500 reports.

Finally, the Gendarmerie Nationale and the SETRA (Road and Motorway Technical Department) supply additional computerised information.

More recently the Laboratory has focussed its attention on a better understanding of the causes of accidents. It is a question of re-enacting the pre-collision phase and of understanding the cause of the accident. To achieve this, the Laboratory, assisted by INRETS which has already worked on this subject, has perfected a methodology which is broken down into two phases:

Data Collection Phase: The concern here is to collect the maximum amount of data relative to the driver, the vehicle and the environment. In particular, the aim is to take statements from the people involved in the moments following the accident. This is done, wherever possible with the person's agreement and professional secrecy is guaranteed.

Analysis Phase: Using the previously collected data this phase involves:

- describing, in a qualitative manner, the way in which the accident occurred.
- splitting the events into cinematic sequences
- creating a model for each sequence, using mechanical equations, starting from the moment of impact and retracing the steps in time. Examination of the way in which the vehicle(s) is/are deformed enables deductions to be made in relation to the impact forces involved and for calculations to be computed.
- imagining the type of counter-measure which would have avoided the accident.

Biomechanics

Research into the behaviour of the human body in the event of impact and the injuries sustained lead to dummies being produced at a very early stage. These dummies are still widely used and continue, thanks to constant improvements in their characteristics, to serve in developing restraint systems.

However, their limitations stem from their own characteristics:

- "Bio-reality" limitations (In the event of impact there are no injuries. An over-complex dummy would be too fragile)
- Limitations in terms of the number of accessible measurement points

For these reasons mathematic modeling has been developed thanks to models such as PRAKIMOD (2D) or MADYMO (3D) which enable easy simulation and a large number of parametric studies.

Simulation does not stop here, as we are seeking to describe the human body and its dynamics using complete elements.

The aim is to arrive at a complete model of the car and the dummy inside by using the RADIOSS calculation code.

Prevention

It is a question of developing measures which prevent a critical situation from arising.

The measures cover, at the same time, the drivers who must acquire appropriate training, the vehicle which must be comfortable and have reassuring road holding characteristics and the infrastructure which must have the necessary equipment.

Driver Training

Driving license holders of less than two years have on average 2.5 times more accidents of all types than those drivers who have had their licenses for ten years, (source: Groupement des Assurances). This underlines the importance of training.

But the drivers must also behave in a responsible manner. We should remember that in France, 40% of those drivers presumed responsible for a fatal accident have a blood/alcohol level above the authorised level of 0.8 9/1 of blood. This represents 4,000 human lives. It is also a requirement to obey safety warnings, especially speed limits, and to wear a safety belt: the statistics shows that seat belts divide the number of deaths by three.

The vehicle manufacturers are well aware of the role they have to play in this area, by increasing information campaigns, avoiding aggressive images in their models and taking care to improve the comfort and driving pleasure of their vehicles.

The Vehicle

The vehicle manufacturers are working to bring to market products which are the result of ever improving studies in the fields of road holding and controlling the vehicle in emergency situations.

Power units are improving both in terms of performance at emission pollution. The car is taking on the aspect more and more of a highly integrated functions system, managed by computers which determine instructions for the mechanical organs in an optimum manner. PSA has already introduced the DYNACTIVE concept which illustrates active computer control of the suspension (softening the ride, filtering out road bumps and potholes, controlling body roll), of the 4 wheel drive system (controlling power transmission to the wheels in relation to adhesion) as well as wheel/ground contact (anti-spin, antiblock brakes) and the wheel geometry settings (controlling induced micro-steering).

Research is underway to improve also one's vision of the environment. Discharge bulbs are being studied by VALEO which offer a significant improvement in the field of vision.

Against dazzling, PSA has developed the technique of infra- red cameras which replicate on a screen in the dashboard an image of the road far greater than that which the human eye, which does not perceive infrared rays, is capable of detecting.

Against the effects of rain, PSA is working with the major French glass manufacturers on developing hydrophobic glass.

Technical research is also preoccupied with driver and passenger comfort aiming at reducing fatigue. Passenger compartment design is directed towards easy use of the controls, efficient heating/ventilation systems, seat quality and their adjustment capabilities to take account of many varied human body shapes.

The Infrastructure

The REAGIR surveys reveal that almost half of all fatal accidents involve a factor linked to the infrastructure.

Motorways are the safest form of highway: for every 100 million kilometres covered there are 0.9 deaths on the motorways and 4 on the rest of the network. In 1990, 672 deaths were counted on the motorways, whereas on the rest of the network 9,774 deaths were recorded.

We should remember that for frontal impacts there are as many deaths during accidents with car against car as there are with car against fixed obstacles.

It is a question of working on the infrastructure to improve driving safety, not only by reshaping certain zones (lane widening, building up the verges, lane separation, etc..), but also of equipping the network with dynamic information systems (as opposed to static ones, i.e. present day signs). For its ISIS system, which is explained in detail later on, PSA recommends interactive systems for distributing information between the vehicle and the infrastructure by using infrared beacons along the roadside, especially in critical areas. For example, INRETS has shown that the cooperative management of road junctions would enable, if it were perfect, 16% of injuries to be eliminated. This evaluation, carried out in a similar fashion in Germany within the PROMETHEUS programme ("PROMETHEUS estimate of the potential effects on safety of different possible functions") shows a homogeneous estimate of 20%.

Avoidance

The aim of the "avoidance" activity is to develop devices which contribute to the accident not occurring when a critical situation is created. This field is directly linked to the study of the causes of accidents listed above under "knowledge."

About 90% of accidents at road junctions or by frontal collision could have been avoided if the driver was informed of the situation one second earlier.

Therefore, it is a matter of developing systems which, not only inform the driver, but also warn him or even act for him in an emergency situation by assistance in the form of orders given directly by the on-board computer to the mechanical elements (co-piloting).

Thus two main research axes have been formed:

- Autonomous systems
- Systems which activate infrastructure devices and on-vehicle devices.

Autonomous Systems

PSA has patented a telemetric system of the LIDAR type with static sweeping enabling obstacles to be detected and the vehicle to be brought to a halt if the object is static or for a safe travelling distance to be maintained if the object is mobile (e.g. cars following each other on the motorway).

With the aid of an on-board CCD camera and image processing software an experimental vehicle can be automatically driven to follow white lines. Furthermore, this system will be linked to a hypovigilance detector as the measurement of directional variations in relation to the road axis can be a telltale warning of decreasing driver concentration. Naturally, to be capable of being co-piloted the experimental vehicles also are fitted with braking circuits, fuel supply systems and steering systems which can be piloted by an on-board computer. Furthermore, at any moment, the driver can regain manual control of his vehicle if he deems it necessary, by cancelling the automatic systems (e.g. for following the white lines, by activating the direction indicators).

Vehicle-Infrastructure Interactive Systems

This is the ISIS system (Interactive Signs System). "Intelligent" infrared beacons communicate messages to any vehicle cutting their beam and give information on the road surface condition, traffic jams, accidents, fog, etc. They can be used also to simply show up on a roadside sign (dangerous bend, recommended speed, stop at 150m, etc.) with or without a warning noise, in relation to the vehicle's speed. A co-piloting activity can arise from this. PSA has already produced prototypes with the road speed automatically adjusting to that recommended by the beacon on entering a bend and which stop automatically at a Stop sign. PSA has also developed a beacon system which signals, as soon as the vehicle enters the bend, potential hazards due to the presence of a hidden vehicle or vehicles on the inner bend. In this case, the beacons situated at the bend entry and exit "communicate" with each other by high frequency waves and inform each entering vehicle of the nature of the hazard (vehicle coming the other way, vehicle going the same way, stationary vehicle). To improve night safety in open country (e.g. at a crossroads), PSA envisages a remote controlled lighting system activated by the vehicle passing a beacon set a hundred or so metres before the crossing.

In order to reduce the number of vehicles especially on urban roads and, at the same time improve traffic flow and safety, an information system about the nearest parking and the number of available spaces has been produced. The information, again from infrared beacons, appears on a screen inside the vehicle.

Naturally, PSA has to conduct further research to prove the feasibility of these concepts. It is a question, before offering these devices to the market, of evaluating the level of acceptability by the drivers themselves. For this reason PSA has already established contacts with the medical professions to test these concepts in the context of human behaviour.

Protection

When an accident occurs, the effects on the people involved must be minimised.

Here again, these actions are based on co-operation between the infrastructure and the vehicle manufacturers.

Infrastructure

A few examples will suffice to illustrate the nature of the actions to be taken: in open country, during 1988, in accidents involving a vehicle and not a pedestrian, 841 people died by their vehicle hitting a tree, 194 people died by their vehicle hitting a telephone post, 225 people died by their vehicle hitting a concrete structure: the accident rate from impact with fixed obstacles (in open country) is 16 deaths per 100 accidents (source SETRA). This is much higher than the figure mentioned above for all accident causes: 6.3 in 1990; in 1988 the figure was 6.0 (ONSER figures).

The infrastructure must also ensure traffic management which limits the hazards created from the wide variety in vehicle sizes. On the same highway, a heavy truck represents a real danger for a small car.

The Vehicle

More and more, vehicle behaviour on impact is taken into account at the design stage. Secondary safety has even become a major preoccupation and its realisation is the fruit of exceptional design effort. In this field the directions for action are as follows:

Research into suitably adapted engine compartment design and structure to absorb, as it crushes on impact, the shock energy to create a sustained, progressive collapse (optimising the laws of deceleration). This research is based on measured vehicle impact testing against a wall. (PSA: 200 runs per year on average), and on mathematical modelling. The action is also aimed at a better understanding of material behaviour under rapid dynamics and postbuckling, the influence of assembly parameters (gluing, riveting, welding, etc.), the combining of materials (filling hollow profile sections). All this is aimed at finding the right part design having, at the same time, the role of working structures in everyday use and of energy absorbers in the event of impact. With the Ecole Centrale de Paris, PSA has recently created an Automotive Safety Research Laboratory (LRSA) which is specialising in modelling work in this field.

Optimising means of restraint: with the view to having the passengers in the vehicle benefit from the deceleration caused by its deformation. It is the research into coupling the passengers and the vehicle. It is achieved by more and more sophisticated restraint systems (seat belt locking, pretensioners). Perfecting such systems means understanding physical phenomena, evaluating the importance of the parameters (e.g. flexibility or play: anchor points, the seat, the buckle, etc.) carrying out numerous tests (on the vehicle, on a test trolley) and numeric simulation.

It is also a question of producing impact prevention devices to avoid injury: the steering wheel mounted air bag is one such device. As well as this the passenger compartment materials are selected to be energy absorbing.

PSA is working on optimising a seat which is already the subject of several patents and which offers, at the same time, safety functions (restraint system integral with the seat) and ergonomics (better seat adjustment).

Conclusion

The PSA group, with Automobiles Peugeot and Automobiles Citroen has decided to make Road Safety a priority theme in its research. Within the Peugeot and Citroen companies goals have been set for concrete achievements over the years to come.

These efforts, to arrive at the challenge that we have set ourselves to cut by half the number of victims by the year 2000, must be developed in synergy with improvements and innovation in the infrastructure, with renewed training and with driver education.

It is by the global approach, already underway in France and which we hope to see extend to the European Community, that we can hope to build Road Safety in Europe, whilst retaining the basic characteristics of road transport in terms of cost, time and freedom.

References

Primary safety priorities which determine feasibility limits in automotive secondary safety (Communication XXIII Congress FISITA - TURIN - 7/11 May 90). PSA RENAULT Accidentology and Biomechanical Laboratory (Laboratoire d'Accidentologie et de Biomécanique PSA/RENAULT). C. Thomas, S. Koltchakia, C. Tarriere. Accidentology and Biomechanical Research Institute (Institut de Recherche en Accidentologie et Biomécanique). B. Tarriere, C. Got. Orthopedic Research Institute (Institut de Recherche Orthopédique), A. Patel.

Groupement des Assurances (GTA) 1987; CDIA, Volume 89-90 page 45.

Rapport statistique sur l'évolution des accidents de la route en 1988. (Statistical report on the evolution of road accidents in 1988) (European Conference of Ministers of Transport.)

National Road Safety Observatory. Annual statistical report and comments. Year 1990.

S4-O-07

Automated Vehicle/Highway System

Norio Komoda, Keiji Aoki, Takaharu Saito, Takashi Shigematsu, Hidetoshi Ichikawa
Toyota Motor Corporation

Abstract

This presents TOYOTA's concept, experiments and future scope of AVHS (Automated Vehicle/Highway System) which could contribute to a possible solution to automobile traffic/transportation issues in the 21st century.

Concept: This system enables smooth, automated cruising on highways by keeping the distance to the leading vehicle and avoiding obstacles. Compact, lightweight actuators are designed from a practical viewpoint. The system is intended to have broad benefits for vehicles with add-on devices as well as for automated vehicles.

Findings: The prototype runs smoothly over 100 km/h satisfying the above requirements with simple control algorithm. CCD lane sensor with compensation to disturbances can detect the lane except under severe weather conditions. The improvement of road structure and lane would make the sensor more robust. To make the system more reliable, misperception of vague lane is corrected by the onboard memory of 3-D road curvature as a backup. Onboard laser radar is feasible for obstacle or distance sensing and obstacle avoidance control with assist of road side TV camera with computer image analyzer, which can detect smaller obstacles and is a key solution. This forms a cooperative intelligent vehicle/infrastructure. With some compensation laser radar can detect the leading vehicle except under severe conditions such as small road curvature, bad weather, etc.

Scope: AVHS is expected to penetrate effectively because intelligent infrastructure can widely provide beneficial information for vehicles with telecommunication receivers as well as sure backup for automated vehicles. Further studies and discussions are necessary to obtain system reliability and social consensus.

Background

In Japan as well as in American and European countries, automobile traffic/transportation issues in the 21 C have been focused on in recent years in pursuit of effective and efficient ways to improve safety, congestion and environmental protection. In the following the related backgrounds are overviewed concerning Japanese traffic/transportation issues, the trend of AVCS (Advanced Vehicle Control System) and the historical overview of automated vehicle control systems. Our idea stands on the basis of this overview.

Automobile Traffic/Transportation in Japan

The following is our future prospect for Japanese automobile traffic/transportation (Fig. 1-4): The construction of highways should be eagerly pursued because of their much lower accident rate than that of normal roads. However, the future construction plans in Japan will not provide enough capacity to absorb the predicted increase of VKT (Vehicle Kilometers of Travel) if the future highway remains in its traditional form.

The accident statistics show that for the effective accident avoidance on normal roads, measures should be taken for rear end, head-on and side collision with vehicles, and collision with road side constructions. On highways, collision with road side construction and rear end collision are the major issues. The increase of aged drivers and pedestrians should not be neglected either.

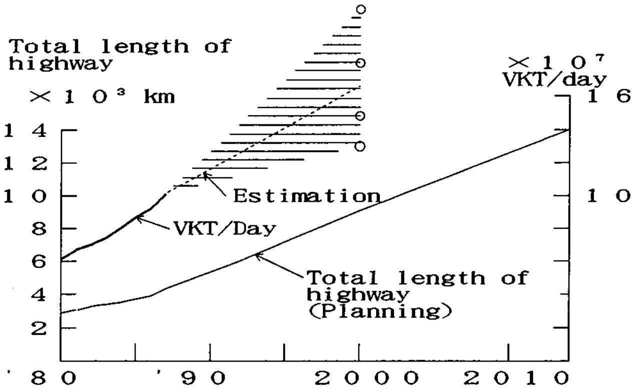


Figure 1. Total Length of Highway and VKT/day in Japan

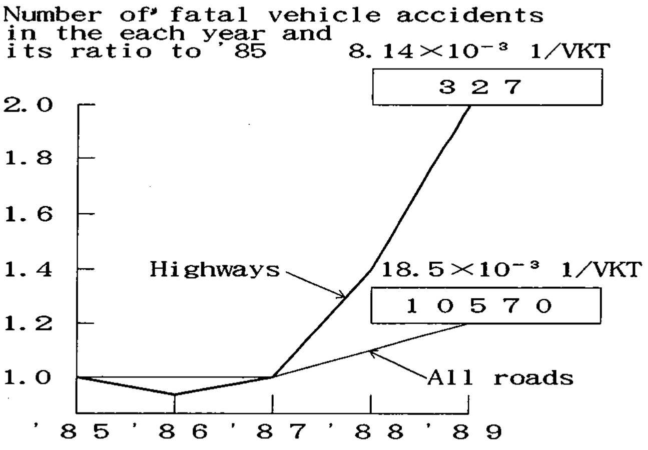
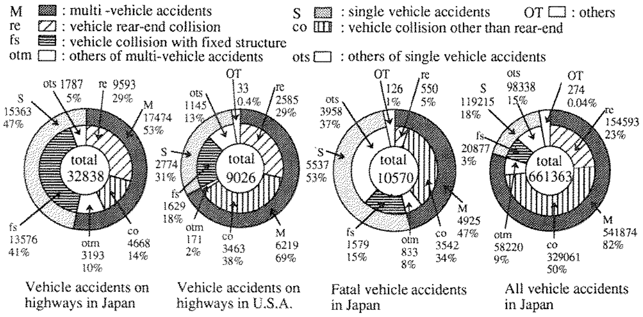


Figure 2. Number of Fatal Vehicle Accidents in Japan

The future congestion issue should seriously be considered both for highways and normal roads.

Thus the cooperative intelligent vehicle/infrastructure should possibly provide a key solution for the traffic/



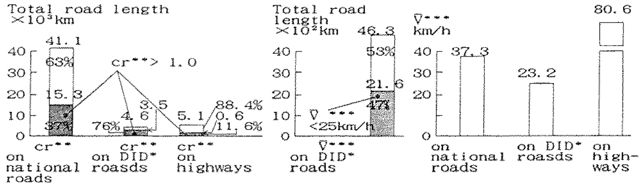
Vehicle accidents on highways in Japan

Vehicle accidents on highways in U.S.A.

Fatal vehicle accidents in Japan

All vehicle accidents in Japan

Figure 3. 1989 Accidents Statics (Number of Accidents)



Note :

- DID* :Densely inhabited district : A district of adjacent cities, towns and villages with high density of population (more than 4000 / km²) and more than 5000 inhabitants.
- Cr** : Congestion ratio = (traffic volume of the road / day) / (standard of traffic capacity of the road / day).
- V̄ *** : Mean velocity at the time of maximum traffic volume / day.
- The road's width on these statistics is over 5.5m.

Figure 4. 1990 Congestion Statistics in Japan

transportation issues in the 21 C. While it would be effective both for highways and normal roads, from the viewpoint of technical feasibility the first plan should be for highways.

Overview on AVCS Technology

The trend is best understood when it is divided into 3 phases based on the typical evolutional features as shown in Fig 5.

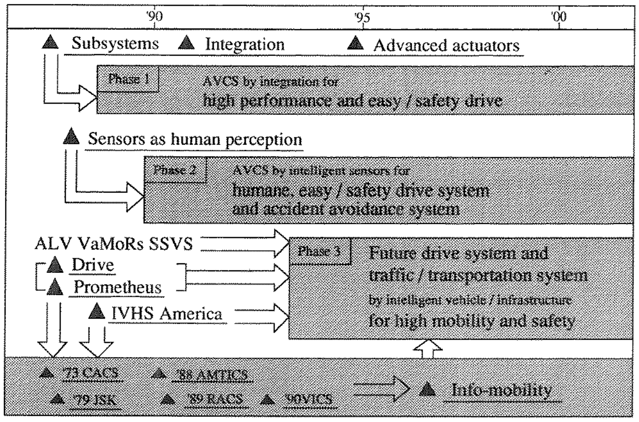


Figure 5. Overview of Trend on AVCS

Phase 1: The current AVCS Technology is going to cover almost all kinds of vehicle control subsystems and integrate them for smooth and high vehicle dynamic performance to the maximum of the tire friction circle as shown in Fig 6. The main subsystems including ABS, TRC, 4WS, 4WD and Active Suspension are currently being developed amidst tough competition. They could be more effective if equipped with more advanced active actuators. They are considered as fundamental factors for the so-called active safety system that provides the safety margin for accident avoidance maneuvers, although that margin depends on human factors.

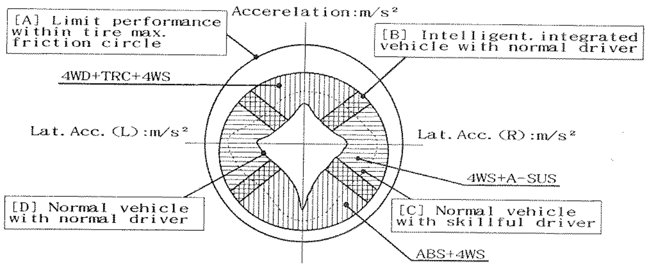


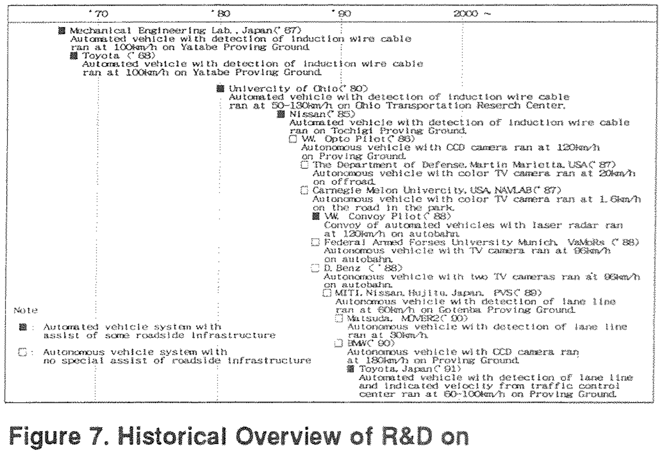
Figure 6. Effects of AVCS by Integration of Vehicle Intelligent Control Subsystems for High Performance, Easy and Safety Drive

Phase 2: Phase 2 systems are now moving from the research phase to the development phase. The important technical evolution in this phase is to substitute human perception and reaction with sensors and advanced active actuators. This could bring about a revolutionary change to the future of automobile safety and mobility. Various types of AVCS products could be introduced such as the rear end collision warning or avoiding system, lateral warning or control system, etc.

Phase 3: In addition to the AVCS in Phase 2, a more advanced and wide spread application of Info-Mobility System (intelligent traffic management system and vehicle-road telecommunication system) would make a great contribution to automobile traffic/transportation in the 21 C. This paper treats AVHS based on this background.

Historical Overview of Automated Vehicle Control System

As shown in Fig. 7, over 20 years many papers have been contributed mainly from technical interests in the most advanced technology at that time. We studied on these previous contributions thoroughly and selected carefully compact, light weight, cost-effective and reliable control devices to construct the best cooperative intelligent vehicle/infrastructure system available at this point.



▩ Mechanical Engineering Lab., Japan('67)
Automated vehicle with detection of induction wire cable ran at 100km/h on Yatabe Proving Ground

▩ Toyota ('68)
Automated vehicle with detection of induction wire cable ran at 100km/h on Yatabe Proving Ground.

▩ Univercity of Ohio('80)
Automated vehicle with detection of induction wire cable ran at 50-130km/h on Ohio Transportation Reserch Center.

▩ Nissan('85)
Automated vehicle with detection of induction wire cable ran on Tochigi Proving Ground.

☐ VW. Opto Pilot('86)
Autonomous vehicle with CCD camera ran at 120km/h on Proving Ground.

☐ The Department of Defense, Martin Marietta, USA('87)
Autonomous vehicle with color TV camera ran at 20km/h on offroad.

☐ Carnegie Melon Univercity, USA, NAVLAB('87)
Autonomous vehicle with color TV camera ran at 1.6km/h on the road in the park.

▩ VW. Convoy Pilot('88)
Convoy of automated vehicles with laser radar ran at 120km/h on autobahn.

☐ Federal Armed Forses University Munich. VaMoRs ('88)
Autonomous vehicle with TV camera ran at 96km/h on autobahn.

☐ D. Benz ('88)
Autonomous vehicle with two TV cameras ran at 96km/h on autobahn.

☐ MITI, Nissan, Hujitu, Japan. PVS('89)
Autonomous vehicle with detection of lane line ran at 60km/h on Gotenba Proving Ground.

☐ Matsuda. MOVER2('90)
Autonomous vehicle with detection of lane line ran at 30km/h.

☐ BMW('90)
Autonomous vehicle with CCD camera ran at 180km/h on Proving Ground.

▩ Toyota, Japan('91)
Automated vehicle with detection of lane line and indicated velocity from traffic control center ran at 60-100km/h on Proving Ground.

Note

▩ : Automated vehicle system with assist of some roadside infrastructure

☐ : Autonomous vehicle system with no special assist of roadside infrastructure

Figure 7. Historical Overview of R&D on Automated/Autonomous Vehicle Control System

System Concept

The R&D project of AVHS gives challenging chances to R&D engineers in this field to accelerate the progress in the system development itself and to look for feasible technical byproducts in this time of emerging new technology.

This system is planned to enable the automated vehicle with lane and obstacle sensors to run automatically between ICs over 100 km/h on the cooperative intelligent highway lanes. It runs on the 2 lanes with intelligent infrastructure of the 2.6 km 3- (partly 4-) lane circuit with the parking lot or the IC. The presence of any other normal or automated vehicles on these 2 lanes is allowed.

The system provides smooth lane trace control, safe distance control, cruise control, obstacle avoidance by stopping or lane changing control and exit/entrance control using extremely simple control algorithms.

The onboard system has the following:

- Compact, lightweight and cost-effective actuators for the steering, brake and throttle systems.
- Cost-effective lane sensor and obstacle sensor (that senses only four-wheel vehicles and motorcycles) that cooperatively work with the intelligent infrastructure system, which provides backup for both onboard sensors. Onboard 3-D road curvature memory is also provided for the backup of onboard lane sensor.
- ECU and vehicle-road telecommunication system.

The intelligent infrastructure system has the following:

- White lane line for cruise and red lane line for exit/entrance, which are easy to see even under bad weather conditions.
- Obstacle detecting system which serves as a redundant system for the onboard detector, but also as a more robust, precise detector of smaller obstacles under severe disturbances.
- Traffic control center with the vehicle-road telecommunication system which provides (a) information to assist the automated vehicle to run smoothly and (b) information for traffic control.

Cooperative Vehicle/Infrastructure Concept:

- The investment should be reasonable and efficient compared to the broad benefit not only for automated vehicles but also for normal vehicles equipped with only some subsystems and/or the telecommunication receivers that make effective warning systems and/or semi-automated systems for accident avoidance.
- The investment would be relatively small compared to the much greater investment for highway construction in Japan even if the most advanced technologies are deployed for the cooperative intelligent vehicle/infrastructure. However, it would not be reasonable to pursue perfect backup under very severe disturbances.

Plan and Design of AVHS

The following are the special features of the prototype. The basic model is 1990 Toyota Camry (Fig. 8 and 9).

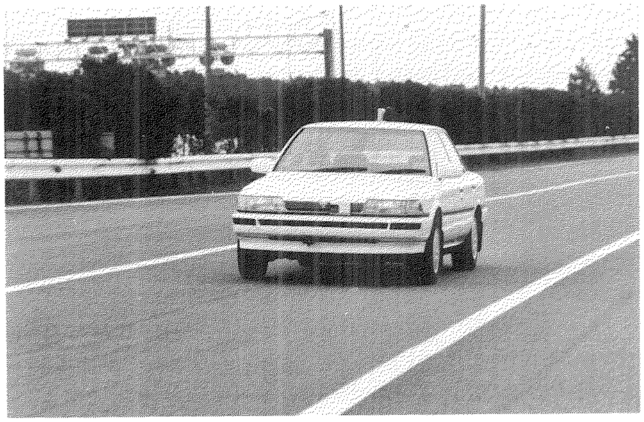


Figure 8. The Prototype Running Over 100km/h

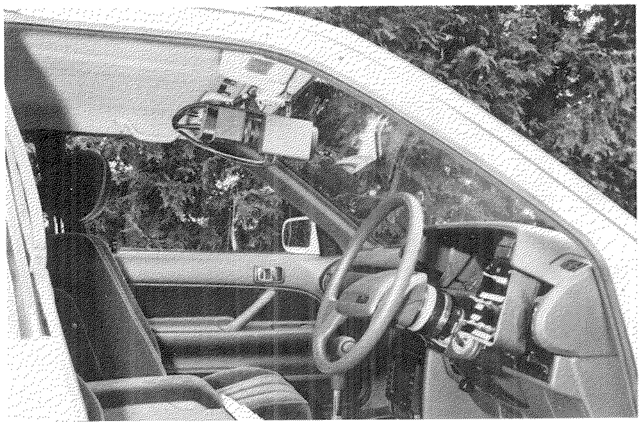


Figure 9. Steering Actuator and Color CCD Lane Sensing System

Onboard Systems

Actuators. The steering actuator is a lightweight, compact and high powered brushless DC motor which is installed coaxially with the steering main shaft of the hydraulic power assisted steering, as shown in Fig. 9 and 11. The specification of the motor is shown in Table 1. The driver can take over the steering wheel at any time.

Table 1. Actuator Specification

	Steering	Brake	Throttle
Type	brushless DC motor	spool valve and solenoid with high responce moving core	direct drive pulse motor
Spec.	voltage : 12 V torque : 3.5 N*m at 60 rpm current : 16 A at 3.5 N*m size : ⌀100 × 45 mm	voltage : 12 V max. oil pressure: 14 MPa at 3.8 A size : ⌀100 × 125 mm	voltage : 12 V torque : 0.25 N*m at 1350 pps current : 3.5 A step angle : 0.9 ° size : ⌀60 × 60 mm

The brake actuator is driven by a hydro-electronic valve powered by the ABS pump and a lightweight, high-response solenoid with moving core, which are so installed in parallel to the master cylinder of the foot brake that the driver can actuate at any time. The specification is shown in Table 1.

The throttle actuator is a direct drive pulse motor (Fig. 12 and Table 1).

Sensors. The lane sensor is a color CCD sensor (TV camera) mounted at the inside rear view mirror immediately behind the top of the windshield glass as shown in Fig. 9. It watches for the lane line from 10 to 20 m ahead. The specification is shown in Table 2. The 3-D course curvature memory provides instantaneous backup in case of any failure of the lane sensor with assist from the vehicle position information from the roadside beacon.

The obstacle detector is a scanning laser radar mounted at the front radiator grill, as shown in Fig. 10. It watches mainly for vehicles and motorcycles from S to 120 m ahead. The specification is shown in Table 2. The detection of smaller obstacles depends on the intelligent infrastructure.

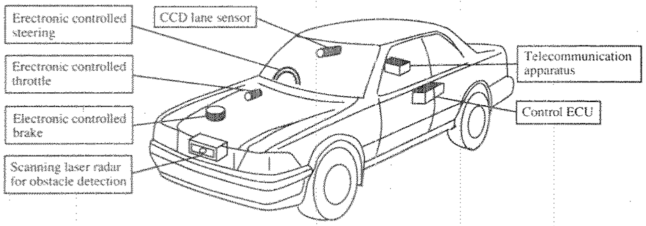


Figure 10. Onboard System

Table 2. Onboard Sensor Specification

	Lane sensor	Laser radar for obstacle detecting
Type	2 dimensional color CCD	scanning laser radar
Spec.	high resolution RGB output : 756 pixels × 485 lines electronic shutter : 1/125 ~ 1/10000 sec	detectable range : 5 ~ 120m scanning angle : ±15° beam vertical angle : ±1.5 ° scanning speed : 120 ms

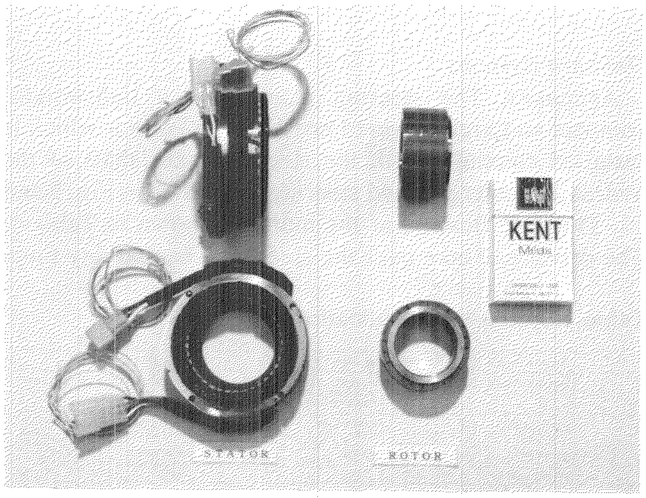


Figure 11. Electronic Controlled Steering Actuator

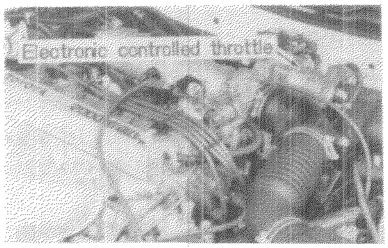


Figure 12. Electronic Controlled Throttle

The onboard traffic monitoring system is installed in the center instrument panel (Fig. 25).

ECU and telecommunication systems are installed in the luggage compartment.

Infrastructure System

Intelligent proving ground (Fig. 13). (1) The proving ground is 2.6 km-long oval circuit. The central 2 lanes of the 3-(partly 4-)lanes are used for AVHS, with the parking lot assumed as the IC for exit/entrance control. The specially painted bright lane line with many small spherical asphalt spots is perceptible in bad weather. (2) Ten beacons and a TV camera are implemented on the course. (3) The traffic control center is located at the assumed IC.

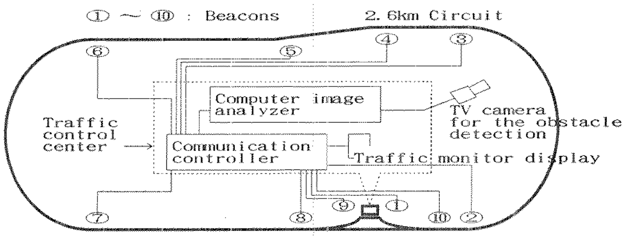


Figure 13. Intelligent Infrastructure System

The vehicle-road telecommunication is done between the antenna on the roof of the prototype and the 10 beacons located along the test track through the traffic control center. The information exchanged is used for traffic control and for smooth and safe drive control as shown in Fig. 14. The communication protocol is also shown in Fig. 14.

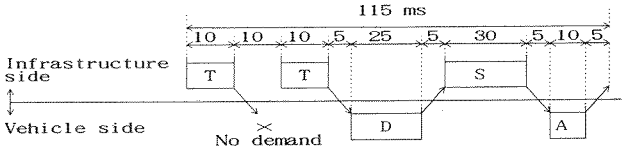
Road side TV camera and computer image analyzer for obstacle detection: The TV camera is implemented on a pole of 8.8 m-height to detect obstacles on the road from 10 to 30 m ahead or from 100 to 500 m ahead. The TV camera and the computer image analyzer in the control center function as a redundant backup system as well as a reliable obstacle detector for smaller obstacles. The specification is shown in Table 3.

The traffic monitor display is in the control center as shown in Fig. 26.

Findings

Lane Sensing and Steering Control

The prototype succeeds in running along the lane over 100 km/h using a simple steering control algorithm to detect the lane of 10 to 20 m ahead (Fig. 15-17). In this test, the detection range is set to 10 to 20 m ahead in order to eliminate the influence of vehicle pitching phenomenon, the minimum road curvature of 50 m R on Japanese motorways, the distance to the leading vehicle, the reach of the head lamp at night, etc.



T : Trigger
D : Demand text : Traffic control center to vehicle
S : Service Text : Vehicle to traffic control center
A : Acknowledgement reception

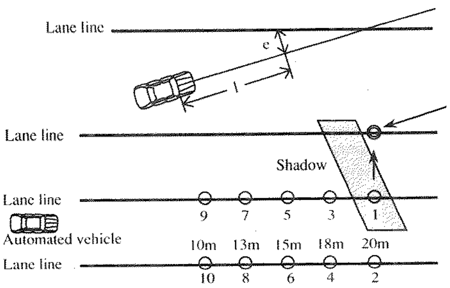
	Service text
1	beacon position
2	travel mode
3	velocity
4	distance between vehicles
5	weather
6	temperature
7	direction of the wind
8	velocity of the wind

	Demand text
1	vehicle number
2	travel mode
3	obstacle information
4	velocity
5	distance between vehicles

Figure 14. Telecommunication Protocol and Information

Table 3. Road Side Obstacle Detection System

	TV camera for obstacle detection	Obstacle detection system
Type	CCD camera	
Spec.	resolution : 38 × 10⁴ pixels 570 lines electronic shutter : 1/125 ~ 1/10000 sec body size without lens : 70 × 70 × 170 mm	detectable range: ① 8m width × (10 ~ 30m) ahead ② 8m width × (100 ~ 500m) ahead minimum obstacle size : ① 0.3m wide × 0.3m long × 0.05m high ② 2m wide × 2m long × 0.3m hign information : position. number and velocity of obstacles



$\delta = f_1(l,v) \times e + f_2(l,v) \times \dot{e} + a \times \bar{e}$
$\bar{e}$: target of lateral displacement
v : velocity
f_1, f_2 : functions of l and v
a : constant

misdetected point due to the shadow, found from comparison with the detected other points or the past detected memory.

Figure 15. Lane Sensing Algorithm and Steering Control Algorithm

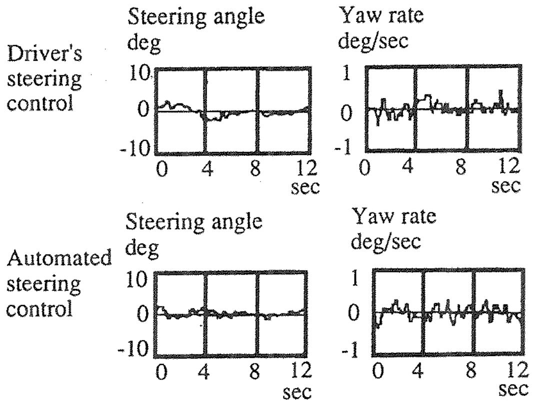


Figure 16. Stability and Control of the Prototype: Steering Correction and Yaw Rate on Straight Line

The course lane detecting algorithm for the CCD sensor is quite sensitive to the change of the sun shine due to the influence of the shadows from road side trees or constructions and the brightness of the sun itself owing to the change in clouds, etc. (Fig. 18-20). The feedback control of the CCD sensor using illuminance meter output of the road surface brightness is an effective way to make the lane sensing system robust to changes in brightness.

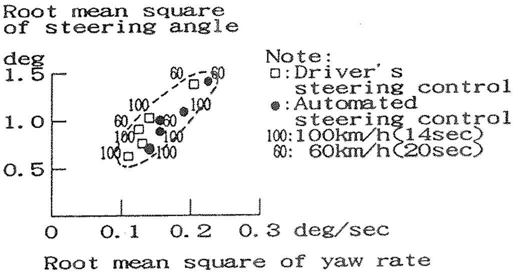


Figure 17. Stability and Control of the Prototype: Root Mean Square of Steering Angle and Yaw Rate on Straight Line

Figure 18. Perceptibility of the Lane Under the Shadow of Trees

Figure 19. Perceptibility of the Improved Lane Under Rainy Weather

Figure 20. Perceptibility of the Improved Lane at Night

It is also sensitive to the influence of the wet road that interferes with lane detection by the CCD sensor. Many small convex spots on the pavement and/or bright paint on the lane line improve the detectability to a considerable extent (Fig. 19) as well as the application of a polarizing filter on the lens.

An effective way to eliminate the influence of disturbances to the lane sensor is to reproduce the lane outline by the smoothing method using the past memory of the 10 points detected at a period of 1/30 sec, as shown in Fig. 15. If the automated highway has only one lane, it is most practical to place the lane marker on the side wall of the road side construction to avoid disturbances by bad weather conditions as mentioned above.

Exceptionally difficult cases are during sunset or sunrise, etc., when the sunshine beams directly into the lens. For such exceptional cases the memory of the road curvature and the present location of the vehicle informed from the telecommunication through the beacons are effective as a redundant backup to the lane sensor system. However, since the current system does not provide information on the lateral position of the vehicle, this backup system is effective only for the short period necessary to stop the vehicle safely.

Obstacle Detection and Obstacle Avoidance Control

The onboard scanning laser radar can detect vehicles from 5 to 120 m ahead as shown in Table 2. Although it sometimes misdetects in the case of severe pitching or severe curvature of the course, errors can be compensated by the memory of the past detection to some extent. Even on a tight curvature or in the fog the leading vehicle can be detected at shorter distances. However, since the passengers might feel unsafe at very close distances, the system would need the integration of 2 kinds of sensing systems and would cost more unless the road side detector could form a reliable backup.

The road side TV camera can detect obstacles of 0.3 m x 0.3 m x 0.05 m on the road at a distance of 10 to 30 m ahead or of 2 m x 2 m x 0.3 m on the road at a distance of 100 to 500 m ahead by means of image analysis at every 1/30 sec as shown in Fig. 22 and Table 3. This method would be one of the most effective ways to detect obstacles on the road and probably be a reliable backup system for the onboard obstacle detector.

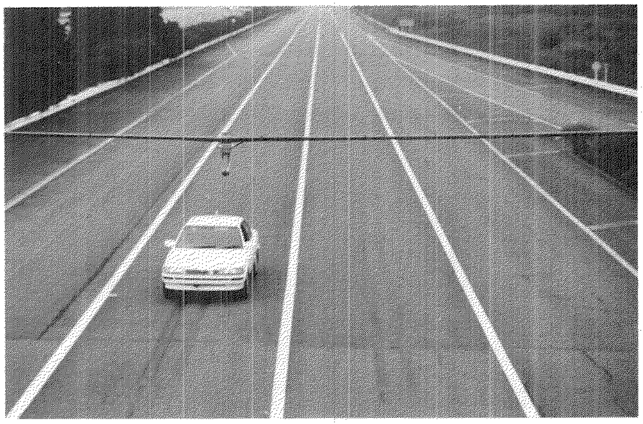


Figure 21. Beacon on the Test Truck

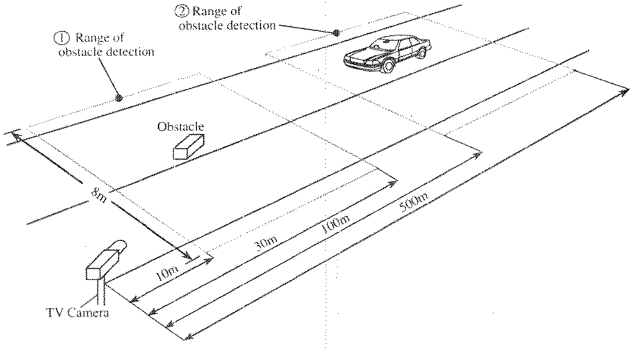


Figure 22. Range of Obstacle Detection on the Road

When an obstacle is detected either by the onboard or the road side detector, the vehicle can be controlled for straight stopping or lane change under instructions from the traffic control center (Fig. 23 and 24).

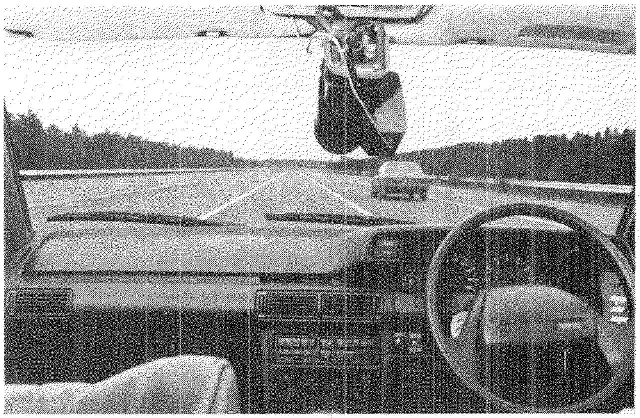


Figure 23. Detection of a Standing Vehicle Ahead and Lane Change

Traffic Control

The traffic monitoring display is shown in Fig. 25 and 26.

Informations and instructions for exit/entrance control, emergency stop, lane change, speed limit and distance control can be exchanged through beacons by the vehicle-road telecommunication system (Fig. 14 and 21).

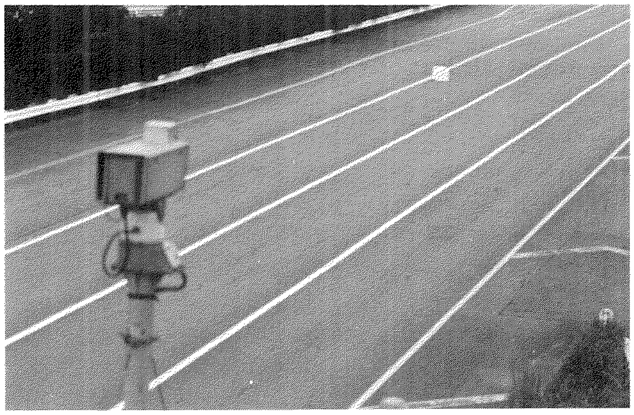


Figure 24. Detection of an Obstacle by Road Side TV Camera

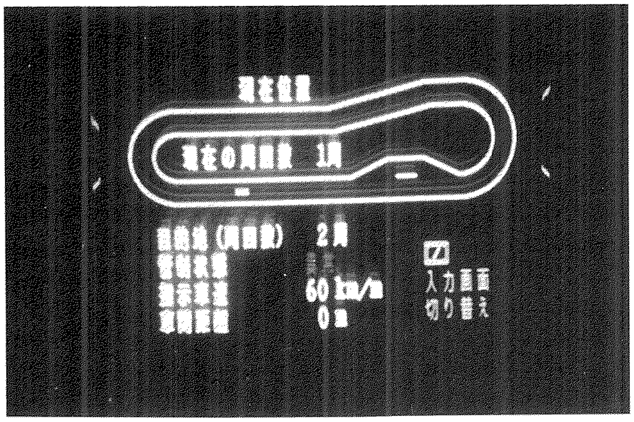


Figure 25. Onboard Traffic Monitoring Display

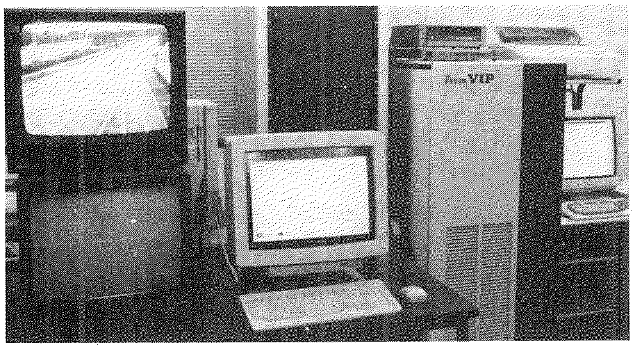


Figure 26. Traffic Monitor and Computer Image Analyzer

Concluding Remarks and Discussions

Lane Sensing and Steering Control

The CCD sensing system with the illuminance feedback and the simple steering control algorithm can make successful test runs over 100 km/h. Hereafter further efforts should be given to extend its sensing ability.

The lane sensing ability would become almost complete if an improved road infrastructure is set up. Then the total cooperative system would be more reliable, cost-effective and redundant. For example if the automated vehicle is limited to one lane, the lane line could be on the side wall and less prone to the disturbances of severe weather, etc. Since the actuator system is more responsive than the human driver, the distance of detection could be shortened, reducing the influence of thick fog, heavy rain, pitching phenomenon, etc. on the onboard lane sensor. It would be practical to apply the HOV lane at the 1st step. When the highway has 2 lanes or more, the lane line should be set up so that it can be detected under bad weather conditions by the use of such means as convex reflecting markers on the lane line. The backup system can be more complete if it is combined with another sensing system like a lateral position sensor, the vehicle position information and 3-D road curvature memory. Since the automated vehicle looks at 20 m ahead at most, other leading vehicles do not disturb the lane sensor of the automated vehicle, allowing even normal vehicles to run on the same lane.

The following are possible alternative or backup methods for CCD lane sensor. Each of them has advantages and disadvantages compared to the CCD lane sensor:

The underground cable and the coil sensor system have the advantage that it is robust to the weather disturbances, but has the disadvantages of vulnerability to any magnetized material or the electric wires around the road structure, and the difficulty of its maintenance. Even though the lane detection is done right under the vehicle it can control the prototype to run at a speed of 100 km/h.

The laser radar to sense the distance to the side wall would work as a backup system when combined with the onboard memory of the road curvature with the vehicle position information provided that the application is limited to the one lane system.

The laser radar and the road lane marker with reflectors would be more robust to weather disturbances than the CCD sensor system, but would cost more.

The above methods would be feasible to some extent. However the most important point is that any attempt to build a reliable system with onboard sensors alone would probably cost too much and not be practical. From this viewpoint the cooperative intelligent vehicle/infrastructure system is preferred, and the CCD sensor system would probably be the most practical and efficient way for lane sensing.

Obstacle Detection and Obstacle Avoidance Control

The onboard scanning laser radar has to overcome some difficulty to get a reliable detection performance under the influence of road curvature, etc. It is vulnerable to foggy weather, too. If the system is limited to one lane, on onboard scanning laser radar with the assistance of CCD lane sensor system would be more reliable. Among other onboard sensor systems now under R&D, a simple image analyzer combined with the CCD sensor might have the possibility of an effective solution in the future.

Road side TV camera would be the most sturdy and reliable way to detect smaller obstacles on the road, since it detects them on a stationary background, eliminating the influence of weather. The investment for the system per unit road length would be relatively small as compared to the huge investment for the highway construction even including the cost of maintenance for the system.

Practical Approach

An exclusive lane for automated vehicles might be possible in the distant future, but would not be practical during the process of the penetration of AVHS. The automated lane should provide broad benefits even for normal vehicles that only have sensor systems and/or telecommunication receivers to get information from the traffic control center.

The detection of other vehicles on the two or more lanes is not easy from the vehicle side alone. It needs assistance from the road side detection system. Although its possibility was proved by the use of the road side TV camera and computer image analyzer, traffic control on two or more lanes would be the 2nd step after the penetration of the single lane automated highway.

Other Issues

It is necessary to proceed to further studies to establish sufficient reliability as the cooperative vehicle/highway system. Ample discussions and field tests to get social consensus on the institutional and legal issues concerning any possible failure are also required before their deployment.

Acknowledgment

This project has been proceeded by the engineering staffs of the special project team including the staffs in charge of the intelligent proving ground. The contributions in this field over the past 20 years were quite instructive as well as advice and support from the related supervisors and colleagues. The authors would like to thank all of them.

References

[1] Y. Ohshima, E. Kikuchi, M. Kimura, S. Matsumoto, Control System for Automatic Automobile Driving, Proc. IFAC Tokyo Symposium on Systems Engineering for Control System Design, '65.

[2] K. Miki, T. Makino, M. Nagai, K. Hasegawa, Research on Automatic Vehicle Operation, Toyota Gijyutsu No. 20-1, '68, June.

[3] H. M. Morrison, A. F. Welch, E. A. Hanysz, Automated Highway and Driver Aid Developments, SAE preprint, '60, March.

[4] T. Ito, M. Furumata, F. Harashima, H. Inaba, S. Matsumoto, An Automatic Driving System of Automobiles by Guidance Cables, SAE Paper 730127, '73, Jan.

[5] T. Hirose: Study on Machine Vision of Intelligent Vehicle, Report of Mechanical Engineering Lab. No. 152 '90, Nov.

[6] S. Takaba, N. Hashimoto, K. Sakai, N. Nakamura, K. Sugimoto: Development of the Traffic Flow Analysis System Using The VTR, The 16th Joint Conference on Image Technology, Tokyo, '85, Dec.

[7] K. Sasaki et al: In Tunnel Traffic Volume Measuring System Using an ITV Camera, Sumitomo Denki No. 134, '89, March.

[8] Express Highway Research Foundation of Japan, SE-2000: Report on Basic Study of Automated Vehicle System, '84, Feb.

[9] Ministry of Construction, RACS, '90, May.

[10] I. Muramoto, S. Okabayashi, M. Sakata, M. Tsuji, Application Technology of Cooperative Laser Radar System for Automobiles on Expressways, EEE Tokyo Section, No. 26, '87.

[11] V. Graefe, K. D. Kuhnert, A High Speed Processing System Utilized in Autonomous Vehicle Guidance, IAPR Workshop CV, Tokyo, '88, Oct.

[12] V. Graefe, Robot Vision and Autonomous Vehicles, Institute of Measurement Science, Faculty of Aeronautical and Space Engineering, Federal Armed Forces University Munich, '91.

[13] M. A. Turk, D. G. Morgenthaler, K. D. Gremban, M. Marra, VITS—A Vision System for Autonomous Land Vehicle Navigation, IEEE Transactions on Pattern Analysis and Machine Intelligence, Vol. 10, No. 3, '88, May.

[14] C. Thorpe, M. H. Hebert, T. Kanade, S. A. Shafer, Vision and Navigation for the Carnegie-Mellon Navlab, EEE Transactions on Pattern Analysis and Machine Intelligence, Vol. 10, No. 3, '88, May.

[15] R. Stengel, A. Niehaus, Intelligent Guidance for Headway and Lane Control, Engineering Applications of Artificial Intelligence, Vol. 2, No. 4, '89, Dec.

[16] S.E. Shladover: Advanced Vehicle Control System (AVCS), SAE Paper 901129.

[17] R. D. Ervin: Proving Radical Functionality to Serve Highway Transportation: A 20 Year Vision for IVHS, SAE Paper 901125.

S4-O-08

"COVER" Safety Synthesis Vehicle

Nelson Casadei
Renault

Abstract

The experimental safety vehicle presented by Renault embodies a global response to the problem of automotive safety by adopting a complementarity approach to the effects of active and passive safety at various speeds. The vehicle was developed from research work in every area of safety making use of a wide range of new investigative tools such as non-linear calculation. The field of application for the technological progress applied to this vehicle is particularly wide. It includes structure of the vehicle, occupant restraints, vehicle behavior, interior conditions and indication to other vehicles. The safety synthesis vehicle will be evaluated from the point of view of passive safety in more severe conditions than the regulations prescribe. For active safety, the intention is to provide the vehicle with the ability to avoid accidents by giving it an optimum dynamic behavior capability.

Introduction

Progress made in the area of safety over the last twenty years has resulted in a 58% reduction in the risk of being fatally injured in an accident in France.

The aim today is to take a further step in improving safety in vehicles by making use of the latest knowledge in the fields of accidentology, biomechanics and automobile technology with a concern for making a contribution in the area of legislation.

The work carried by the joint PEUGEOT.SA / Renault Accidentology and Biomechanics Laboratory on the causes and results of accidents has shown the potential safety gains.

The diagram (Figure 1) shows the limits of passive safety. As can be seen, in the hypothetical situation where all seat belts were worn; in spite of in-depth work on improving the efficiency of restraint systems, the number of victims saved is less than 50%. This is why improving vehicle performance from the point of view of active safety can make a significant contribution to reducing the number of victims.

The leading characteristic of Renault's research program, explained below, is the desire to provide a global response to the problems of vehicle safety by adopting an approach which makes optimum use of the complementary aspects of active and passive safety at different speeds.

Objectives

With regard to *passive safety,* the program concentrates on the development of new design concepts for restraint, design and design aids such as non-linear structural calculation.

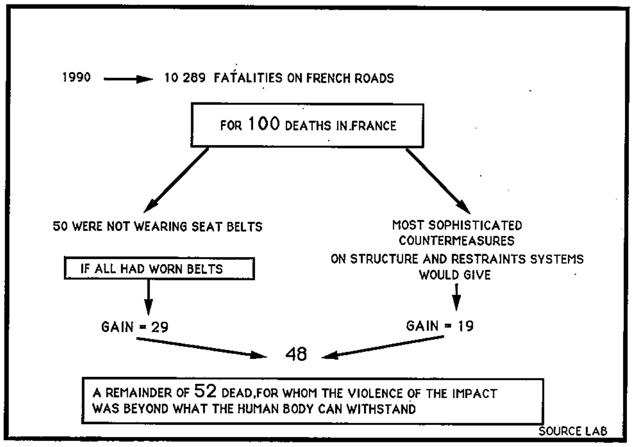


Figure 1. Potential Safety Gains

Where *active safety* is concerned, vehicle dynamics, lighting, indication systems and comfort are the major areas of concentration.

This approach has been applied in the past. It resulted in two vehicles, the B.R.V. and the E.P.U.R.E., presented respectively at the 5th and 7th International ESV Conferences. The first of these prototypes was representative of top of the range models, while the second was representative of down-range models. These two programs, run in the 1970's, had a lasting influence on the design of Renault vehicles, in particular with regard to structure. If all of the equipment developed with these two safety synthesis vehicles did not find their way into models in the Renault range, this was due to a lack of commercial opportunities and insufficient progress where safety legislation is concerned.

The new S.S.V., COVER, differs radically from the programs of the 70's in that it is conceived as a safety product and largely incorporates the results of research into active safety (see Figures 2/BRV, 3/EPURE and 4/COVER).

COVER, like its predecessors BRV and EPURE, is neither a concept car nor a motor show special, it is a vehicle which will be the proving ground, from the point of view of performance, for the safety, feasibility and cost of new technical solutions which may be progressively applied to the range, with a particular emphasis on the active safety aspect.

Methods

Defining Performance

The table (Figure 5) showing the expected gains from passive safety reveals the predominant influence of frontal impacts.

The distribution of collision speeds for cars colliding side-on (Figure 6) shows the limits of side protection.

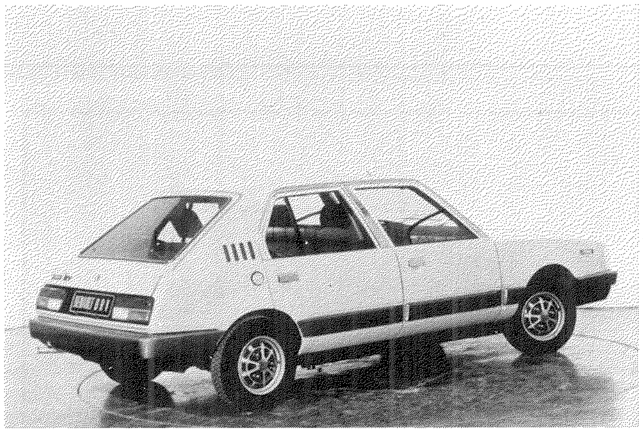


Figure 2. Renault B.R.V., 1974

Figure 3. Renault E.P.U.R.E., 1979

Furthermore, it must be remembered that side-on collisions between cars account for only one third of the victims of side impacts, the other two thirds are evenly divided between the victims of collisions with heavy goods vehicles and fixed obstacles.

Priority lines of research have been defined. Realistic objectives for the reduction of the numbers of victims per type of accident have been fixed taking into account the new possibilities of measurements made possible by the use of testing with dummies as well as technological, industrial and financial constraints (Figure 7).

The important gains for victims in the event of rollover can be accounted for by the wearing of seat belts at all seats and the resistance of the doors to opening in this type of accident.

COVER Specifications

The performance level to be reached is compliance with legislative requirements and internal Renault criteria for injuries under test conditions made more severe by increasing impact speeds; for a full frontal impact with an inclination of 30° at 65 Km/h a full side impact against a deformable CEVE barrier at 56 Km/h and a rearward impact against a rigid barrier offset by half a lane and rollover at 50 Km/h.

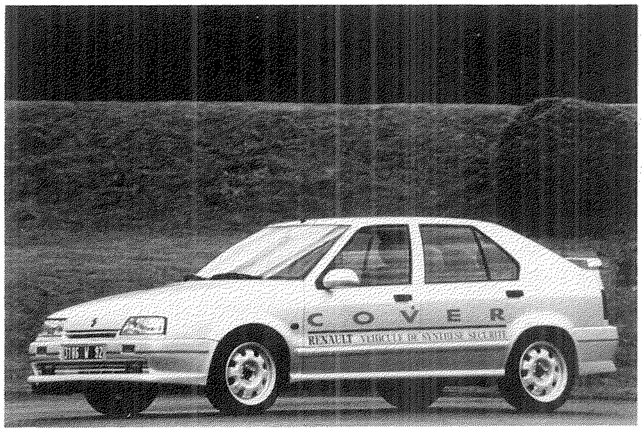
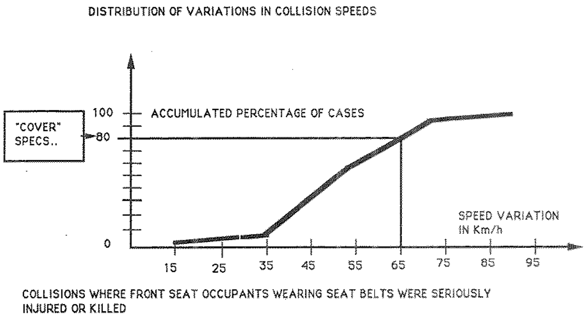
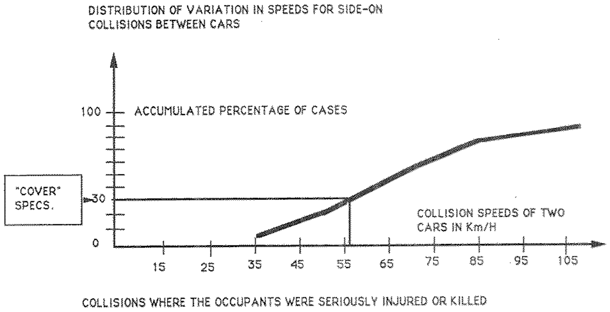


Figure 4. Renault COVER



SOURCE LAB

Figure 5. Frontal Impact Protection Objectives



SOURCE LAB

Figure 6. Side Impact Protection Objectives

Technology

The experience built up over the years has shown us that it is not necessary to design and build an entirely new vehicle to verify the validity of the technological solutions proposed. In fact, the vehicle chosen is one of our mid-range models, the Renault 19.

Passive Safety

Structure. The structure is of the monocoque integral chassis type. Certain characteristics of the architecture

	Number of fatalities in 1990 in private vehicles	Estimated reduction if100% seat belts worn	Estimated additional reduction with "COVER"
FRONTAL IMPACT	3 000	- 900	- 830
LATERAL IMPACT	1 900	-250	- 130
ROLLOVER	900	-770	- 80
REARWARD IMPACT	100	-20	- 20
OTHERS	400		
TOTAL	6 300	- 1 940	- 1 060

Figure 7. Gains in Safety Expected With Vehicles of COVER Type

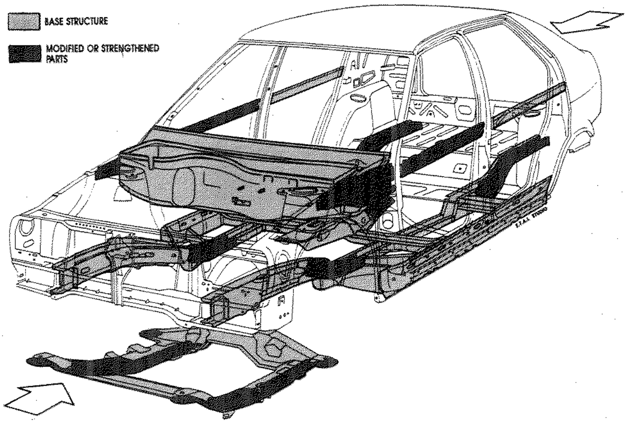


Figure 8. Frontal and Rearward Impact Structure

have been modified to improve performance with regard to dissipation of energy and stiffness of the cabin in the various impact configurations. These modifications have led to improved part design, the introduction of additional parts and reinforcements and the use of materials with high mechanical strength.

The most innovative architectural characteristic concerns the structure of the front seats, designed to meet two objectives:

- To resist stresses induced by the restraint system (the three seat belt anchor points can form part of the seat).
- To make a significant contribution to resistance to penetration of the body side in the event of side impact. (Detailed description on PAPER 91 S5 010).

The side impact tests gave us the opportunity of refining our calculation models. Indeed, mathematical modeling provides for realistic simulation of the various phenomena involved when impact occurs. A finite-element simulation comprising 20,000 elements was made at the start of the program and was extensively used in all the subsequent phases of the project. (Detailed description in PAPER 91 S5 0 11).

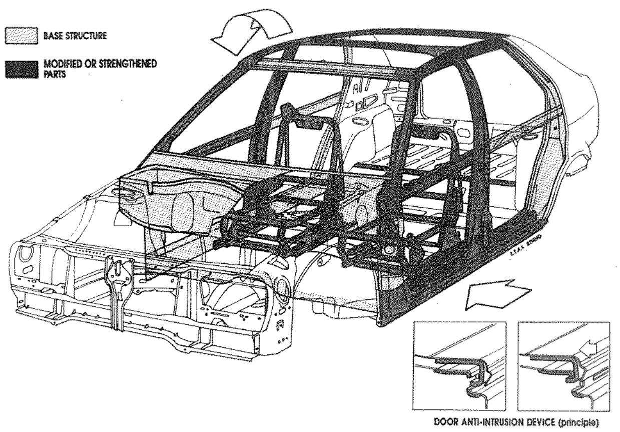


Figure 9. Side Impact and Rollover Structure

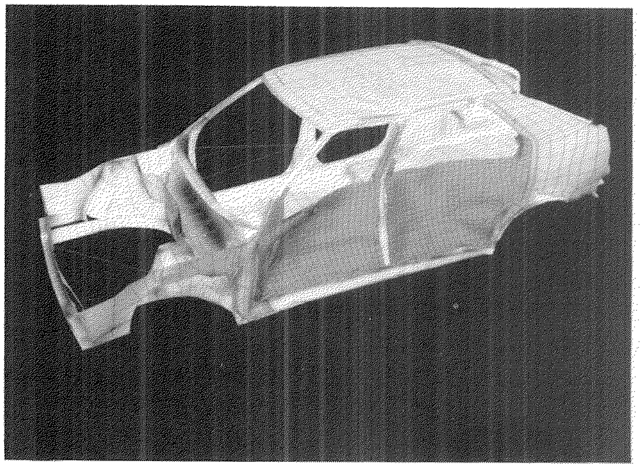


Figure 10. Meshing and Deformation of Body Side

Protection devices (Detailed presentation in PAPER No. 9199 W 32). For restraint of vehicle occupants, each seat is fitted with specific equipment.

The front passenger seat is equipped with three anchor points for the safety belt with a new functionality making it more agreeable to the user and allowing for better relaxation ("relax" position). The seat is of modular design, adaptable to different vehicles. This type of seat affords good protection in the event of rear impact, due to the adjustable and lockable head restraint;

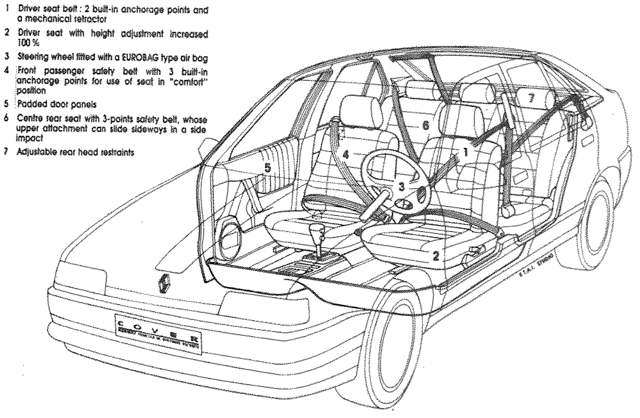


Figure 11. Restraint Systems

and good protection in the event of side impact, thanks to its robust structure.

The driver has the same type of seat, except that the relax function is not applicable for driving. The upper shoulder strap anchor point is located, in the conventional manner, on the center pillar. The central anchor of the restraint system retracts in the event of impact, going from the normal wearing position to the optimum restraint position (anti-submarining, thorax restraint). A belt locking device is incorporated into the belt reel. The restraint system is completed by a EUROBAG air bag.

For the rear seats, we have retained the principle of restraint by three-point seat belts as this type of belt is designed for greater wearer comfort. The central position is also equipped with a three-point belt providing effective restraint in the event of frontal impact without becoming dangerous in the event of side impact.

The three rear seats are fitted with head restraints with adjustable and lockable positioning.

The right side seat has a booster cushion for children from 4 to 10 built-into the seat.

Work is in progress on effective protection for children from 0 to 4.

The dummies used for development testing for frontal and rear impacts and rollover are of the HYBRID 3, 5, 50 and 95 percentile types and for children of 3 and 6 years of age.

COVER is equipped with a "belt-up" warning light for all seats.

Side-impact protection is provided by door padding. This required a great deal of work to optimize reduction of thicknesses, weight and cost. (Detailed presentation in PAPER 91 S5 010).

The dummy used for development of side protection was the EUROSID 1.

Test results. See Figures 12 and 13.

Active Safety

With regard to active safety, the search for improved comfort and safety was a guiding principle.

Accident research data indicates that 47.6% of fatal accidents took place in conditions of poor lighting.

COVER has innovative solutions for improving visibility and indications.

- Low-Beam Headlights. The low-beam headlights are equipped with discharge bulbs. This technology gives lights which are three times more intense than conventional halogen lamps.
- Rear Fog Lights (Figure 14). Fog lights, which are indispensable in low-visibility conditions, become a nuisance for other road users when visibility is normal. The Valeo company has developed for Renault a system which switches rear fog lights on and off under the automatic control of a fog detector built into the rear optical unit. The detector operates by emission and reception of a modulated infrared beam which is reflected by the microdroplets.

RESULTS FOR FRONTAL IMPACT against 30° angled barrier at 65 Km/h
Measurement criteria on HYBRID III 50 – percentile dummy

		INJURY CRITERIA	RESULTS		
	OBSERVATIONS	Standards + Renault COVER Specs.	DRIVER	FRONT PASSENGER	REAR SIDE PASSENGER
HEAD	In presence of head contact	HIC<1000 at 36ms	326	No head contact	No head contact
NECK	No presence of head contact	Force /x < 2500 N	Head contact (EUROBAG)	1680 N	
		Moment/ y < 250 Nm		124 Nm	
THORAX		Deflection < 50mm	27 mm	40 mm	29 mm
		Acceleration /3ms < 60 g	48 g	51 g	53 g
ABDOMEN	If detection of submarining	Force < 1500 N	No detection	No detection	No detection
FEMURS	Left Right	Force < 10 000 N	1970 4620	1660 2050	

Figure 12. Results for Frontal Impact Against 30o Angled Barrier at 65 Km/h

RESULTS OF SIDE IMPACTS by deformable CEVE barrier at 56 Km/h
Criteria for injuries of EUROSID I dummy

	INJURY CRITERIA			RESULTS
				DRIVER
HEAD	HIC<1000			340
	Angular acceleration (limit is being determined)			
THORAX	Deflection	Upper rib	→ 42 mm	43 mm
		Central rib		36 mm
		Lower rib		30 mm
	T.T.I < 85 g			73 g
ABDOMEN	Force < 2 500 N			1 030 N
PELVIS	Acceleration < 130g			52 g
	Force at pubis < 10 000N			1 630 N

Figure 13. Results for Side Impacts by Deformable CEVE Barrier at 56 Km/h

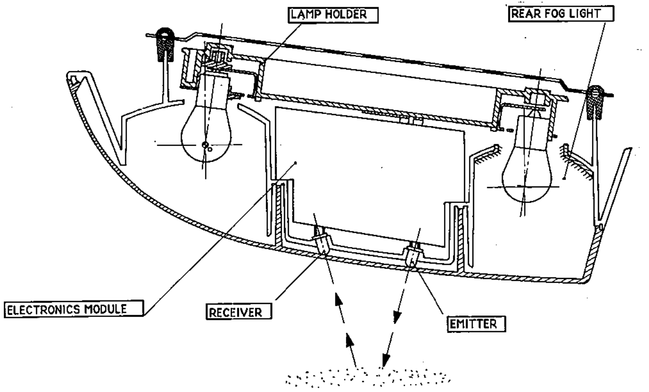


Figure 14. Principle of Operation of Rear Fog Light Automatic On/Off Switch

- Advanced Brake Light. The use of automatic transmission provides the possibility for an additional feature. By special data processing, the control computer commands lighting of the brake lights when the foot is removed quickly from the accelerator. This advanced warning gives the vehicle behind an extra 0.2 seconds of braking time.
- Emergency Brake Light. A raised third brake light has been incorporated into the body of the rear spoiler. This light comes on when the anti-lock

system is operating or for deceleration greater than $4 m/s^2$ which corresponds to heavy braking.

- Anti-dazzle Rearview Mirror. The rearview mirrors have an extended field of vision and are made from automatically darkening electrochromic glass.
- Monitoring of Tyre Pressure. Tyres remain a particularly sensitive point for active safety as they provide transmission of the forces of steering braking only if they are correctly inflated. This explains why Cover was equipped with a tyre-pressure monitoring system.

The work carried out by Renault on controlling skidding of wheels on the ground surface to optimize the ABS have resulted in a wider application of the wheel-speed data, which can also be used to detect variations in tyre pressure.

In practice, it is the rolling circumference of each tyre which is observed during a journey. An abnormal variation in one or two of these in relation to the others reveals an abnormal change in pressure which can be due either to a burst or slow puncture.

If the principle behind this is simple, creation of a measuring device is a lot more complex.

In fact, each tyre has its own identity, given manufacturing differences, differences between makes, wear, etc. In acceleration, braking or cornering, the behaviour pattern of each wheel is specific to it at any given moment. It is therefore necessary to give the system a memory which, by the ability to learn, will identify what is normal behaviour for each tyre assumed to be in good condition. Permanent reference to this memory in conjunction with strategies for detection of cornering, braking, load or high acceleration, by comparison of the different wheels, provides reliable detection of losses of pressure of around 500 mbar.

The system guarantees detection of a burst during a journey after a learning period of just a few minutes. This is not therefore a pressure indicator which frees the driver from the responsibility of regular checking and inflating of tyres. Processing of the wheel-speed signal also provides the driver with an indication, by means of an indicator light, as to the adherence of the road surface and possible skidding of drive wheels.

- Detection of Drowsiness. (Detailed presentation in PAPER No. 91 S4 W 17.) Analysis of accidents shows up the role of flagging attention and fatigue, in particular for motorway journeys (32% of fatal accidents in 1990 against 26% in 1989). The driving aid on which the Physiology and Biomechanics Laboratory is working is based on the correlation between the minor steering adjustments made by drivers (necessary even on a straight road due to irregular surfaces) and their degree of attentiveness. The system consists of a detector which continuously calculates the steering wheel angle and a microprocessor processing the data so as to warn the driver at the first sign of reduced vigilance.
- Cartographic Suspension. (Detailed presentation PAPER 91 S7 0 04.) The search for improved adherence by optimum contact between tyres and surface has been a prime active safety objective. Studies concentrated on the development of semi-active electronic variable damping systems with proportional adjustment of damping and known as "cartographic suspension."

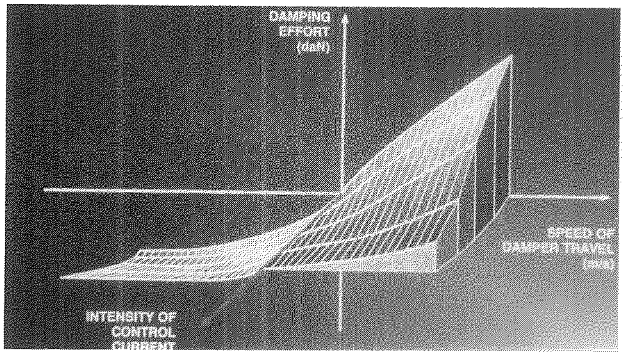


Figure 15. Cartography of the Semi Active Damper

COVER's "cartographic" suspension system is without doubt the latest stage in perfection of suspension systems before the so called "active" suspension systems. It has been designed to give the very best in safety with regard to road holding and braking while providing optimum comfort. Technically, the idea is to provide perfect control at each instant of the contact between the tyre and surface while isolating the body from variations in road surface form.

For the now "classic" variable damping systems with two or possibly three damping laws, the corresponding damping variations correspond to the need to give optimum surface adherence.

However, this adherence is not optimized wheel by wheel, as the control instruction is equal for all four dampers.

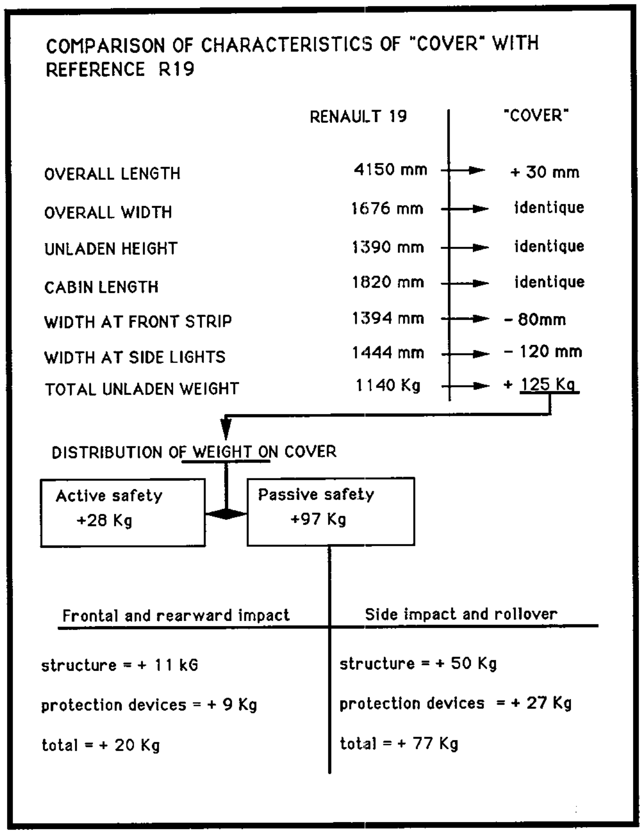
Cartographic suspension provides real-time control of the damping force for each wheel in accordance with the road surface conditions. Response time is extremely low, around 10 milliseconds, which is 5 to 10 times quicker than for classic electronic variable damping systems.

This highly innovative system means that the vehicle has permanent better road holding and is therefore easier to control.

Tyre adherence is optimized and braking distances on bad roads are reduced. Furthermore, cornering safety is improved in critical conditions.

This type of suspension provides the best compromise between comfort and safety.

All of the equipment described above is of course in addition to that already provided for series models; like the ABS, air conditioning, power-assisted steering, automatic transmission with shift-lock, rapid de-icing of windscreen and rear window.



COMPARISON OF CHARACTERISTICS OF "COVER" WITH REFERENCE R19

	RENAULT 19	"COVER"
OVERALL LENGTH	4150 mm	+ 30 mm
OVERALL WIDTH	1676 mm	identique
UNLADEN HEIGHT	1390 mm	identique
CABIN LENGTH	1820 mm	identique
WIDTH AT FRONT STRIP	1394 mm	- 80mm
WIDTH AT SIDE LIGHTS	1444 mm	- 120 mm
TOTAL UNLADEN WEIGHT	1140 Kg	+ 125 Kg

DISTRIBUTION OF WEIGHT ON COVER

Active safety +28 Kg

Passive safety +97 Kg

Frontal and rearward impact	Side impact and rollover
structure = + 11 kG	structure = + 50 Kg
protection devices = + 9 Kg	protection devices = + 27 Kg
total = + 20 Kg	total = + 77 Kg

Figure 16. Comparison of Characteristics of "COVER" with Reference Renault 19

The table in Figure 16 invites three comments:

- High performance with regard to frontal impacts has not affected available longitudinal internal space.
- Protection against side impacts requires padding of doors which reduces available internal width to an unacceptable degree. This means that the small vehicle of the future will have to have greater external width.
- The extra weight required for protection from side impacts is 3.5 times more than that required for frontal impacts.

Conclusion

The performance of the new synthesis safety vehicle COVER marks a new stage in improved active and passive safety. However, if technical feasibility has been demonstrated, the cost and weight of the new safety features remain a heavy handicap for transfer of solutions into series models.

To attain that objective manufacturers and legislators must work together to define the optimum performance level required for vehicles to reduce the risk of accidents and afford maximum protection. The level fixed must be compatible with the constraints on costs, weight, energy saving and pollution.

In addition to all of COVER's safety advantages we must add further measures which could come from public authorities in the form of improvements in road networks, indications and placing of safety barriers around trees or other obstacles in order to limit the violence of impacts. Education and consciousness raising amongst drivers should also serve to multiply the effects of future safety equipment.

References

Status Report of Renault Experimental Safety Vehicule, Philippe Ventre, ESV Paris 1979.

Characterization of a System for Detecting Lapses in Driver Alertness by Recognition Techniques, S. Planque, ESV Paris 1991.

Renault VSS Safety Vehicle: Occupant Safety in Lateral Impacts, J. Rio, ESV Paris 1991.

Parametric Study on the Side Impact Simulation of Renault VSS, C. Steyer, ESV Paris 1991.

Renault VSS Safety Vehicle: Controlled Suspension for Better Safety, J. Reille, ESV Paris 1991.

How About Average Driver in a Critical Situation? Can He Really be Helped by Primary Safety Improvements, A. Priez, ESV Paris 1991.

The HYBRID III Head Dynamics in Automotive Safety Tests, F. Bendjellal, ESV Paris 1991.

Influence of Seat and Head Rests Stiffness on the Risk of Cervical Injuries in Rear Impact, J.Y. Foret-Bruno, ESV Paris 1991.

Renault VSS Safety Vehicle: Occupant Safety in Frontal Impacts, G. Walfisch, ESV Paris 1991.

Could a Lap Belt in the Real Central Position Seat Save Human Lives?, J.Y. Foret-Bruno, ESV Paris 1991.

S4-O-09

Vehicle Safety in the 1990's

John M. Leinonen
Ford Motor Company

Abstract

The vehicle safety issues of the 1990's transcend national boundaries. In North America, Europe and Asia Pacific, there is a common desire for the adoption of certain safety technologies in automobiles. This commonality, along with other factors such as the EC 1992 Program, a reduction in trade barriers, the need for efficient resource utilization, and an increase in vehicle safety awareness on an international level, have created

opportunities for greater harmonization of vehicle safety standards.

The current status of safety technologies such as air bag supplemental restraint systems, dynamic side impact protection, lighting, light-signalling devices and the potential for unification of design approaches and/or research efforts will be discussed. Further, the extent to which light truck safety issues require different approaches to those for the passenger car will be evaluated.

To resolve these safety issues efficiently requires development of harmonization strategies. Specific harmonization issues and opportunities will be identified including apparent success on vehicle braking harmonization; work required to achieve greater lighting commonization; strategy needed for convergence between Europe and North America on side impact; common worldwide approaches to pedestrian protection; and opportunities for unification of offset barrier crash performance standards.

Introduction

This paper presents an overview of the safety issues that face the world in the 1990's. As a prelude to an examination of the issues, the factors—economic, governmental, and societal—which impact their resolution are discussed. The constant evolution of these factors over time may change the vehicle safety needs or wants of society. Consequently, a re-examination of these effects is a necessary first step to a comprehensive analysis of safety issues. The second step will be to look at the role of current and proposed vehicle safety standards in the United States (U.S.) and abroad. Finally, the progress of global harmonization of vehicle safety standards is investigated. This paper proposes that efforts to develop a unified set of safety standards and to coordinate safety-related research programs should be intensified.

Factors that Impact Worldwide Safety Issues

Societal Factors

Competition. The safety concerns and desires of the motoring public represent a significant source of input to manufacturers' decisions related to the incorporation of safety technology in automobiles. In the 1990's, public interest in motor vehicle performance, both in terms of safety and in relation to the environment, has increased worldwide. Increasingly greater levels of safety performance are expected.

As a result of customers' heightened interest in vehicle safety, it continues to evolve as an area of strong competition. Competing manufacturers strive to find ways to differentiate their products through promotion of safety features and environmentally-conscious designs and programs. This trend is most evident in Europe, where the media, primarily consumer magazines, present the public with purported vehicle safety and environmental performance comparisons. The publishing of offset barrier crash performance comparisons in Germany, for example, has surely prompted many manufacturers to investigate methods to improve this aspect of vehicle crash performance.

Similarly, there is growing international environmental concern, which focuses on global warming, ozone layer depletion, and recyclability. Heightened sensitivity to these environmental issues will likewise serve as a means to gain a competitive edge. In recognition of important considerations highlighted by the "green movement," for example, certain manufacturers in Europe are advertising programs where the company agrees to take back vehicles at the end of the vehicle's useful life for recycling purposes.

In North America, competition for the safety conscious customer also has prompted increased advertising of vehicle safety features, like air bags. The promotion of safety and environmental performance in the U.S. is likely to escalate to mirror the activity in Europe.

Increased safety-based advertising could produce an adverse result that would require a corrective remedy. Consumers could erroneously perceive that the air bags in their vehicle reduce the importance of wearing their safety belts. So far, safety belt usage has not declined in air bag-equipped cars, according to studies performed by the University of North Carolina Highway Research Safety Center and the Insurance Institute for Highway Safety (IIHS). However, the situation should continue to be monitored and safe driving behavior should continue to be promoted.

Demographics. Demographic changes will also shape consumer expectations. Gradual aging of the population will strengthen concern for enhanced ergonomics and desire for safety features which are designed to accommodate all age groups, especially the particular needs of older drivers.

Governmental Factors

Trade Policy. In the past, even within the European countries that form the European Economic Community (EEC), the adoption of unique regulatory requirements have perpetuated barriers to trade. Trade conditions are in the process of change, however, prompted by the pending formation of a single market in Europe ("EC 1992"). As the December 31, 1992 deadline for forming a single market in Europe approaches, sporadic trade disputes between the EC and the U.S., the EC and Japan, and the U.S. and Japan, may arise. The Community could even erect new trade barriers to ensure important European industries are not eroded by non-European imports. After the relationships between the new Community and other governments are better defined, the single market in Europe should create further opportunities for unification of international safety standards having substantially eliminated the differences in safety requirements among EC countries.

The EC '1992' Program. The EC '1992' Whole Vehicle Type Approval Program, in eliminating regional variations in safety requirements by mandating compliance to all European Economic Community (EEC) Directives for all EEC countries, will create opportunities for manufacturers to reduce build complexity. In addition to this direct benefit, the EC '1992' Program will also reduce the complexity of the safety standard unification problem. Manufacturers will be relieved of the task of determining the most cost effective and competitive way in which to comply with each of the various safety requirements in Europe. With a level playing field having been provided in Europe, manufacturers can focus on promoting the unification of safety standards between continents.

Although the likelihood of the successful unification of vehicle safety standards in Europe will be greatly enhanced by the Whole Vehicle Type Approval Process, much work remains to be done to apply the process in EC countries as well as the rest of Europe. Negotiations are in progress between EC member states to finalize the set of Directives that will be mandated, but the harmonization of standards with the EFTA (European Free Trade Area) countries and Eastern Europe is still lacking. European Economic Area (EEA) negotiations may lead to phased harmonization of EEC Directives and EFTA standards.

Asia/Pacific. Japan is currently interested in expanding existing motor vehicle standards to adopt U.S. or European safety standards that will prove most beneficial, given accident experience in Japan. Japanese society is becoming more aware of vehicle safety issues. The Subcommittee of the Automobile Committee of Council for Transport Technology and members of the Japan Ministry of Transport held a hearing on "Future Technical Measures to Ensure Vehicle Safety" on June 26, 1991, to discuss the potential adoption of air bag, side impact, and rear seat lap/shoulder belt standards. At the hearing it was suggested that Japanese regulations be developed to be compatible with current U.S. or European safety regulations.

As a result of the safety hearing, the Automobile Committee of Council will advise the Minister of Transportation (MOT) which standards should be adopted and appropriate phase-in plans for compliance by manufacturers. The MOT will then amend its existing MOT Ordinance 67, "Safety Regulations for Road Vehicles" and submit the revised ordinance to manufacturers.

Economic Factors

Limited resources require government agencies to set "safety priorities." Generally, regulatory priorities established by the NHTSA have been based on the potential for reduction of life threatening injuries. This basis for priority setting will likely have to be modified in the 1990's as more is learned about the societal consequences of other types of injury.

Harm/Injury Experience with 1990 Safety Technology. As occupant protection in vehicles is improved, the basis for setting safety priorities will shift to include the reduction of disabling non-fatal injuries. The frequency of disabling non-fatal injuries and their contribution to societal cost is becoming more evident. At the same time, improvements in anthropomorphic dummies, such as the Hybrid III, will enhance the ability of researchers to assess a wider range of crash-induced injuries and human impact responses.

Competing Interests. The relationship between safety objectives and priorities and existing regulatory requirements must be evaluated and conflicting interests resolved. This evaluation must also take into account the financial burden imposed on manufacturers and ultimately, the consumer. For manufacturers, measures taken in the U.S. to comply with current CAFE (Corporate Average Fuel Economy) requirements and the requirements imposed by the Clean Air Act may conflict with potential safety improvement measures. For example, in an effort to meet greater CAFE requirements, manufacturers may be required to produce smaller vehicles. This trend toward downsizing of vehicles adversely impacts safety, as larger vehicles generally offer a greater chance of survival in car-to-car accidents. In addition, the ability of manufacturers to address environmental as well as safety issues through vehicle design changes or technology development is limited by financial and resource constraints. Furthermore, factors such as driver behavior and traffic management must also be addressed to reduce the incidence of accidents attributed to poor driving habits such as drunk driving and speeding, and poor driving conditions such as eroded road surfaces and intersections which are not clearly marked.

Current Global Safety Issues

The factors noted above will shape safety issues and priorities in the 1990's. Although cultural differences exist, the U.S., Europe, and Asia Pacific are moving in a common direction with respect to the desire for the adoption of certain safety technologies in automobiles. The proven benefits of air bags as supplemental restraint systems and the perceived benefits of side impact protection, interior head impact protection and stability, have prompted manufacturers around the world to investigate performance improvement opportunities for their vehicles. In the U.S., vehicle dynamic stability and improved interior head impact protection are the NHTSA's first and second regulatory priorities, respectively. In Japan, the Ministry of Transportation (MOT) is expected to adopt air bag, side impact, and rear lap/shoulder belt standards similar to the U.S. standards.

Air Bags

Industry-wide in the U.S., the combination of air bags and a properly worn safety belt will save 2,400 lives and prevent 29,000 moderate to serious injuries during the six-year span from 1990 through 1995, according to NHTSA estimates. The lifesaving benefits of a properly worn safety belt supplemented by today's air bag system have been demonstrated. By the end of the 1990's, air bags probably will be standard on all U.S. passenger cars and most light trucks. U.S. regulations stipulate that all passenger cars must be equipped with passive restraint systems for both front outboard passengers by the 1994 model year. Similarly, 20% of light truck production must incorporate passive restraints for both front outboard passengers for the 1995 model year, followed by a phase-in for subsequent model years: 50% for 1996, 90% for 1997, and 100% for 1998.

Although there is no legislation in Europe which mandates air bags in passenger cars or light trucks, air bags are being incorporated by manufacturers due to competitive pressures. At least one manufacturer has announced plans to offer air bags on all its passenger car models sold in Europe by the mid 1990's.

Even if manufacturers choose not to offer air bags, it is unlikely that many European countries would regulate the incorporation of air bags. In Europe, safety belt use rate is much higher than in the U.S., and the incremental benefit achieved by an air bag and 3-point restraint system over a 3-point restraint systems without an air bag, would not appear to justify rulemaking.

In Australia, safety belt use is required by law for both front and rear seat passengers, consequently, safety belt use rate is higher than in North America. There is currently no air bag regulation, however; manufacturers may offer air bags due to market demands.

Air bags are a relatively new technology and, like any complex equipment, have experienced a few problems. In fact, several challenges, including design, testing, and manufacturing complexity; an emerging supply industry; and evolving designs; remain both in Europe and North America.

Design Complexity. Different air bag designs are required for each unique application. The crash energy management pulse shape of each vehicle is unique. This, along with the need to consider different locations within the vehicle and the range of seating positions that must be accounted for at each location, calls for analysis of each air bag design parameter: shape, size, construction, and amount of propellant for the proper amount of cushioning. Different physical characteristics of the occupants (adult/child), further complicate the design process.

Differences also exist between air bag design approaches in North America and in Europe. In the U.S., air bags are designed for unrestrained occupants pursuant to the Federal standard. In Europe, air bags are designed for restrained occupants based on the high safety belt usage rate, thus smaller, "face bag" designs are preferred in order to minimize head/face injuries caused by impact with the steering wheel or instrument panel. Likewise in Australia, if air bags are adopted for marketing reasons, "face bag" designs will be the most likely choice.

In vehicle applications on existing platforms, design changes are required for non-air bag components as well. Components which influence the performance of the air bag system include the steering wheel and column, the instrument panel and knee bolsters, and the body structure.

Test Complexity. Another challenge to the large-scale incorporation of air bag systems is the extensive testing that is required to verify the performance of these systems. HYGE Sled tests are required to study conditions and systems that can influence air bag system performance. In addition, barrier tests, both head-on and at 30 degree angles are required to certify vehicles in the U.S. to Federal standards. Typically, as many as 200 tests (sled and barrier combined) may be run for a single air bag design.

The requirement for rigorous, costly testing heightens the need for alternative developmental methods, like computer modeling techniques. The development of simulation models is now reaching the stage where significant efficiencies in both design optimization and developmental time and cost should be experienced.

Manufacturing Complexity. The rapid increase in air bag demand has also created manufacturing problems. Current sodium azide-based air bag propellant materials, due to their volatile nature, are not easy to manufacture. A risk of supply interruptions exists should an event such as a fire occur in a manufacturing plant. The additional demand generated by passenger air bags followed shortly by significant requirements for light trucks, represents an even greater potential for supply interruptions due to a steep ramp-up schedule, need for additional facilities, and limited production experience. The future development of second generation hybrid "stored gas/azide" systems, which would significantly reduce the dependence on sodium azide, holds potential for further reducing this sensitivity.

An additional potential concern is mismanufacture of air bag systems and the necessity of related recalls. Some risk of mismanufacture still exists due to the use of many new manufacturing processes. As suppliers gain more experience with these processes, such risk is expected to be negligible.

Evolving Designs. In the future, efforts to design simpler sensor systems with equivalent or better performance will continue. Further, integration of components and size and weight reductions will be pursued as well as improvements in air bags, air bag deployment doors, and alternate propellants.

Other issues that will require further attention are the disposability of vehicles containing air bag propellants and the serviceability of air bag components.

Dynamic Side Impact Protection

North America. In the U.S., a new Federal standard has been issued requiring a phase-in beginning in the 1994 model year. Manufacturers are now trying to define the product effects of this new standard. The standard is difficult to meet, particularly for smaller cars, and in some cases may necessitate extensive re-engineering of existing product lines. Consumer costs and vehicle weight will necessarily increase with concurrent effects on fuel economy and interior package dimensions.

The industry and government have been doing side impact research for a long time. Much of the effort has been directed at developing the engineering tools needed to design and evaluate motor vehicles for this type of crash mode. Side impact test dummies and injury criteria are fairly recent innovations, however. Many safety engineers are still unsure of the relationship between real-world injury and the NHTSA-mandated SID dummy and Thoracic Trauma Index (TTI). BIOSID, a side impact test dummy developed by a Society of Automotive Engineer (SAE) task group, and EUROSID-1, developed in Europe, are being considered for possible inclusion as alternative test devices for the SID in the NHTSA dynamic side impact test procedure.

In many respects side impact technology is still in its infancy. Innovations are still needed to provide more effective means of complying with the dynamic side impact requirements. There is advanced work underway on side impact air bags, for example, as a potential means to meet the standard. Technological requirements for sensing and early activation provide challenges for further innovation.

Another challenge is the need for the development of light weight energy absorbing side structures. Research has shown that stiffer side structures can help to moderate the effect of a side impact on the occupant and help to reduce the amount of padding under the interior trim. Even with today's technology, stiffer structures are still considerably heavier and occupy more space that could otherwise be used to help reduce energy imparted to the occupant. A break-through in this technology is required to provide improved means of absorbing the impact energy and/or helping to cushion the vehicle occupants during a side collision.

In addition, computer-aided engineering (CAE) structural and occupant simulation modeling tools need further refinement. These highly sophisticated CAE tools provide an additional way to help engineers evaluate more design alternatives and should help to reduce the number of crash tests required to confirm a particular design concept. Further refinement of simulation models, more powerful computers, and enhancement of user interface software, will greatly increase the usefulness and value of these tools.

Europe. There is currently no passenger car side impact regulation in Europe. There is, however, a proposed EEC Directive, and an ECE GRSP Passive Safety Working Group Draft Regulation (GRSP/R.48 Rev 1, dated 1/23/91). Test conditions, test devices, and performance criteria differences exist between the EEC, the ECE and the U.S. Federal standard. For example, Europeans favor different test barriers, a different test dummy (EUROSID-l), and different injury criteria (HIC, chest deflection, and pelvic force), to reflect the "average" side impact injury experience in Europe.

Australia. There is active pressure for Australia to upgrade its current side door strength legislation (similar to the U.S. standard), to include a dynamic test and injury criteria performance standards. Following other recent legislative changes, revision of the side door strength legislation will likely harmonize with European Regulations.

Harmonization Required. The automotive industry needs a test dummy that can measure chest deflection, as it may be a more meaningful measure of thorax injury than acceleration responses. The BIOSID test dummy, favored by some in North America, and EUROSID-l, favored by Europe, both measure chest deflection. However, the industry needs to be able to design its vehicles to one test device, not multiple ones.

While the size of an average vehicle in different markets may vary, unique side impact test procedures and dummies for various areas of the world unnecessarily increase consumer costs without providing any real safety benefits. These increased costs obviously result from additional design, development, and testing required to certify vehicles in multiple markets.

Harmonization is required on a global basis. Harmonization of test barriers, test dummies, and injury criteria will not happen immediately, but should be attainable in the longer term. The time to start working on one harmonized, next generation, side impact dummy and its accompanying injury criteria is now, through a joint effort by government, industry, and the International Standards Organization. A joint effort is required to insure "buy-in" by the world's experts in developing and designing anthropomorphic test devices that will help achieve real safety benefits.

In the interim, a single set of dummy performance standards needs to be developed. It is potentially feasible that equivalent performance standards could be developed such that BIOSID and EUROSID-l could be used as alternative test dummies.

Pedestrian Impact Protection

North America. The focus of pedestrian protection research in the U.S. is somewhat different than in Europe. Because the most severe injuries occur to the pedestrian head and thorax, research in the U.S. during the past several years has focused on these areas [1]. In contrast, the complex problem of pedestrian lower limb injuries has received relatively little attention in the U.S. in recent years.

There is currently no pedestrian protection regulation in the U.S., however, NHTSA says a decision regarding pedestrian head impact rulemaking will be made by the end of the year. Manufacturers continue to express concerns regarding proposed regulations which could require significant redesign of the front end of vehicles and competing performance factors (aerodynamics, crashworthiness) which the design of the front of vehicles must accommodate. There is also some question whether there is greater potential to reduce pedestrian deaths and injuries through vehicle design changes or through accident avoidance programs and requirements.

Europe. Pedestrian impact protection in Europe may require more priority attention since there are significantly more pedestrians injured in the countries of Europe than in the U.S. Consequently, organizations such as the British Department of Transport and the Transport and Road Research Laboratory have developed pedestrian protection guidelines in Europe which manufacturers are encouraged to follow.

European researchers have concentrated primarily on the pedestrian lower limb for the last several years and are just now beginning to closely reexamine head and thorax injuries. The focus on lower limb injuries was chosen because these types of injuries occur more often in Europe than head and thorax injuries.

Harmonization is Appropriate. Now that the focus of U.S. research is moving toward examination of lower limb injuries as well, it may be an opportune time to investigate joint research efforts. Even though injury experience is somewhat different, coordinated research programs would save resources and avoid duplication of effort.

Efforts to segregate pedestrians from vehicular traffic need to be increased as the reduction in pedestrian injuries and fatalities that can be achieved by improvements to the vehicle are limited.

Lighting and Light-Signalling Devices

Regulations currently present a major obstacle to common lighting designs worldwide. The requirements in the U.S. differ from those in Europe, generally because requirements are design-based rather than performance-based. Harmonization is further thwarted by differences in opinion and preference regarding lighting performance.

Lighting harmonization efforts are focused within The Meeting of Experts on Lighting and Light-Signalling (GRE), an organization of the United Nation's Economic Commission for Europe. While it would be ideal to have identical requirements for both Europe and the U.S., both standards contain many design-based requirements that are not currently compatible with each other. The GRE harmonization efforts, therefore, have sought to establish a range of overlapping requirements that would accommodate both Europe and the U.S. Using this objective, the GRE has achieved harmonized intensity requirements for rear stoplamps, amber rear turn signals, and side marker lamps. In addition, agreement has been reached on harmonized requirements for lamp mounting heights. Efforts are continuing within GRE to harmonize requirements for such lighting parameters as separation distances between lamps, geometric visibility, light-emitting areas, electrical connections, and low beam passing pattern.

Australia has just updated its lighting regulations to harmonize with European legislation.

Light Truck Safety Standards

In the U.S., nearly all essential differences in safety rulemaking for light trucks and passenger cars have been eliminated because many light trucks are used as a primary means of transportation by U.S. motorists.

In Europe, although light trucks do not comprise a large portion of the private transportation fleet, most light trucks are subject to passenger car safety requirements according to Europe's vehicle classification scheme.

Despite the different classification schemes and driver usage patterns, common light truck safety concerns exist. The unique collision experience of light trucks requires different approaches, in some cases, than those adopted for passenger cars.

Side Impact Protection. In particular, simply extending the passenger car side door strength requirements (essentially requiring car-like door beams) to light trucks could decrease the potential for the safety benefits of dynamic side impact protection. Accident experience indicates that drivers and passengers of light trucks are at a lower risk than passenger car occupants in side impacts [2]. Differences in the design and construction of passenger cars and light trucks account for differences in side impact performance.

Side impact research has shown the importance of vehicle designs which preserve space within the side doors during a side impact collision. The preserved space allows for energy absorption by the vehicle structure thereby softening the impact of the door against the occupant and, researchers believe, lessening the potential for injuries. An important related factor to occupant safety in side impacts is that door designs be as free as practicable of "hard objects inside the doors.

In addition, car-type door beams may be ineffective or counterproductive on light trucks because the fixed objects impacted by light trucks are not effectively simulated by the U.S. passenger car standard. Poles, trees, narrow bridge abutments and other tall, narrow, fixed objects in real-life crash situations strike both the roof and sill of light trucks, and not primarily the middle of the door. Guard rails, bumpers, and other objects not extending the total height of light trucks also do not primarily strike the middle of the door: they generally strike light trucks below the doors at their sills, because light truck sills are positioned higher than passenger car sills. Although the height of light trucks can vary greatly because of wheel size, tire size, suspension, and model, it is always greater than or equal to a typical passenger car. Door beams in trucks will not be as effective in side impact protection of the occupant because light truck occupants are seated above the deformed impact zone in many accidents. Research should be conducted to determine whether any practicable countermeasures exist for light trucks.

Stability. Likewise, the development of vehicle stability standards should take into account such vehicle differences as inherent vehicle class design parameters, user demographics, in-use environment and real world accident statistics. More research is needed to fully assess the importance of these differences. Real world accident data must be correlated to proposed test procedures to aid in the development of a meaningful test. Further, reliable computer models must be developed and validated in order to evaluate rollover tendency and potential countermeasures, without the need for lengthy, costly and potentially dangerous testing.

The Motor Vehicle Manufacturers Association (MVMA) has initiated two research projects that should help address these research needs. One project, MVMA Project #11303, "Sensitivity Analysis of Tilt Table Test Procedure," will assess the sensitivity of the tilt table static rollover threshold of vehicles to parameters of the test facility and methodology. The other project, MVMA Project #11302, "Evaluation of Select Vehicle Dynamics Models," will evaluate three vehicle dynamics models for rollover simulation capability.

Proposed U.S. Senate legislation would direct the NHTSA to undertake rulemaking addressing the rollover of light truck and utility vehicles. NHTSA has assigned vehicle stability as its first priority and appears to favor the tilt table test. The MVMA tilt table research project along with the NHTSA correlation study to be released with an Advanced Notice of Proposed Rulemaking (ANPRM), should assist manufacturers in providing comments regarding this test procedure.

There currently are no vehicle stability Regulations or Directives in Europe or in Asia Pacific. Although the United Kingdom has had, for many years, requirements for certain buses which require tilt table testing, the application of this test procedure to light trucks appears to yield different results than the NHTSA proposed tilt table test procedure. Consequently, it is understood that the ECE which was investigating the adoption of a vehicle stability test procedure, has decided to review the results of testing being conducted by the NHTSA prior to proposing a particular tilt table test procedure.

Resolution of Safety Issues

Unification of Global Safety Requirements = Efficiency

Resolving the safety issues described above in the most efficient manner requires a global outlook. Harmonization of vehicle safety requirements creates opportunities for technological advancement in the area of Automotive Safety. Market forces in the 1990's, an era of heightened safety awareness, have proven to be especially strong; rewarding manufacturers who incorporate the state-of-the-art in safety technology as soon as practicable. These market forces should therefore provide an effective means to drive the advancement of safety technology. Moreover, it is not cost-effective for manufacturers to develop unique safety feature designs solely to accommodate vehicle safety standards needlessly different between markets. Unification of safety standards would allow resources to be used more effectively.

Likewise, unified research programs save resources. Uncoordinated research programs tend to be inefficient and result in unnecessary redundancy. Also, they may not lead to the most innovative or optimized safety countermeasures.

Some variation in market preferences will still exist that may stem from cultural, political, and/or economic differences. It is important to distinguish, however, between unique design requirements that stem from market-based needs and barriers to harmonization of design that stem from artificial trade barriers, bureaucratic burden and "not invented here" thinking. The latter have thus far prevented much meaningful accomplishment toward the unification of vehicle safety standards.

The Status of Harmonization Efforts

Although effort at harmonization is often a struggle, some attempts at it are beginning to bear fruit. An example is the achievement made in developing an international brake standard. In the U.S., the NHTSA has proposed a standard which would replace Federal Motor Vehicle Safety Standard 105—Hydraulic Brake Systems. This proposal is the result of the agency's long and diligent participation in the proceedings of the United Nations Working Party 29 Committee on Brakes and Running Gear (GRRF).

Unfortunately, the requirements of the U.S.-proposed "harmonized" standard (Docket 85-06; Notice 4) are more stringent than the existing U.S. standard, the existing European standard and the "harmonized" standard proposed by the Europeans. Consequently, U.S. manufacturers and European governments were reluctant to adopt the "harmonized" standard proposed by the NHTSA.

Nevertheless, the process of harmonization is underway, and some refinement of the NHTSA proposal may be all that is needed to accomplish the stated purpose of the rulemaking: to reduce manufacturing and certification costs by removing trade barriers. In fact, the recently published Notice 5 is in the process of being evaluated by the U.S. and the European communities. Although much investigation remains to be completed, it appears that the NHTSA has attempted to close the gap with this most recent proposal.

Some progress toward harmonization has also been made in lighting requirements, as described earlier. Although progress toward harmonization has only been made incrementally in this area, the process (the GRE) has been established. Continuing efforts should bring about additional accomplishment in harmonizing lighting and light-signalling devices.

Next Steps

The success that has been achieved in the process of harmonization of brake standards and to a lesser extent in lighting should be used as a guide to seek the harmonization of other standards. Through the ECE, a wider committee of international "experts" could be established to initiate the convergence of side impact protection requirements, test dummies and injury criteria. In addition, coordination of the direction of U.S. and European pedestrian protection research programs could also be pursued.

The U.S. and Japan currently attend ECE working group meetings as observers and thus have a voice in the development of ECE proposed Regulations. In order to improve the current ECE process to facilitate harmonization, it may be appropriate to expand the role of working group members.

One area that could benefit from a coordinated U.S./European effort is in the development of offset barrier crash performance criteria and test procedures. Since there is no current legislation in Europe or in North America and the establishment of offset barrier crash performance criteria and test procedures are only in the initial stages of development, there is an opportunity for international coordination.

The goal is global harmonization. Given the reduction in trade barriers, the emergence of the EC '1992' Program, the need for efficient resource utilization and the increased level of vehicle safety awareness worldwide, it is an opportune time to pursue this goal.

Acknowledgment

The author wishes to acknowledge the contributions to this work of R. W. Fraser, M. L. Harokopus, D. B. Head, R. W. Hultman, R. W. Lewis, R. J. Pheiffer, C. S. Saunby, and M. J. Stando of Ford Australia, Ford Britain, and Ford North America.

References

[1] C. Brian Tanner, Thomas F. MacLaughlin, "Pedestrian Lower Limb Research in the 1980's," VRTC-87-0019 Event Report, March 1991.

[2] Ford Motor Company Comments on Proposed Amendment to 49 CFR Part 571, Federal Motor Vehicle Safety Standard - 214: "Side Impact Protection," Docket No. 88-06; Notice 8, 9, 10; "Anthropomorphic Test Dummy; Side Impact Protection," Docket No. 88-07; Notice 3.

[3] Ford Motor Company Comments on Supplemental Notice of Proposed Rulemaking: "Hydraulic Brake Systems; Passenger Car Brake Systems," Docket No. 85-06; Notice 4.

S4-O-10

Guiding Drivers through a Metropolis: Traffic Safety Aspects of the Guidance and Information System Berlin (LISB)

M.M. Popp, B. Farber, A. Schmitz
University of the Armed Forces

Introduction

Disorientated drivers are problematic traffic participants (Popp, 1987). Their interaction with other drivers (oriented or also disoriented ones) is a source of safety risks. Incar electronic guidance systems, either autonomous working or externally supported, which are available now, could lower these risks.

The guidance information of these systems is mostly displayed visually. But to reduce visual load, a better realization seems to be the usage of systems which transmit the route guiding information by means of a voice generation system.

Within PRO-GEN, part of the European PROMETHEUS activities, we investigated the route guidance and information system in Berlin (LISB) with respect to the psychological and traffic safety aspects.

Experiment

In our first investigation of the LISB-system four questions should be answered:

- To what extent the use of the new electronic route-guidance system influences the driving behavior with respect to traffic safety, in comparison to conventional maps?
- To what extent the system changes driving behavior with respect to mental load, eye-glance patterns, and driving behavior patterns?
- What objective benefits can be observed in terms of route choice behavior and travel time?
- How do people evaluate subjectively such a system before and after having used it?

Experimental Procedure/Design

The experimental paradigm included a competition. This induces temporal stress to the subjects. That stress is comparable to realistic situations, where drivers have to reach a special location right in time in an unfamiliar town.

Route-Guidance Aids

All subjects used either conventional city maps or the electronic guidance system (see below). The LISB-system provides route recommendations to drivers using information transmitted to the car by roadside beacons linked to a central computer. The interface in the car consists of a visual display (see FIG. 1), an additional auditory output system and a keyboard (see Hoffmann et al., 1987).

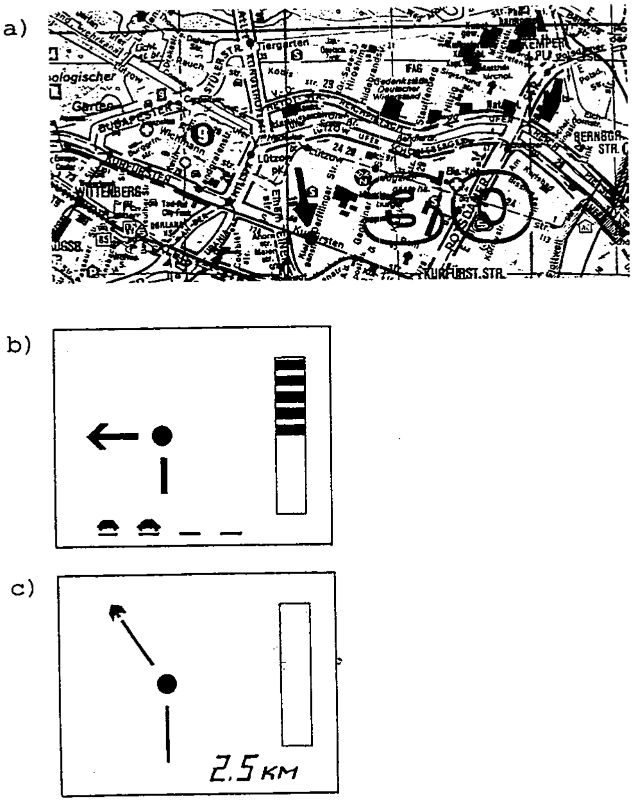


Figure 1. The Experimental Route-Guidance Aids

a) conventional city map (detail with destination highlighted), b) display of the route guidance system in guiding mode (advice to turn at the next crossing, which is in some distance to the right, using one of two available lanes); the driver hears in parallel the voice commands: "Please change lane to the left!" "Turn to the left!", c) same device in direction mode (destination is now in 2.5 km apart, the flight line direction to it is 45 degrees).

Design

Psychological investigations of man-machine-interfaces using field tests confronts the experimenter with the fact that the variance between subjects is usually high. This is due to small samples, different personal styles and changing environmental conditions. To eliminate the interpersonal variance we decided to measure the effects of the different route-guidance aids by a within subject design. To control learning and sequential effects which happen if one person performs an experimental situation twice, the following design was chosen:

Table 1. Experimental Design

	VP-group A n = 9	VP-group B n = 9
Destination 1	LISB	MAP
Destination 2	MAP	LISB
Destination 3	LISB	MAP
Destination 4	MAP	LISB

To control environmental effects the four different routes were equal with respect to difficulty and length. Subjects had to drive from 4 different starting points to 4 destinations. On each route they used the city map or the LISB-system according to the experimental design (see above). Also daytime was held constant to minimize disturbing effects from varying traffic density or traffic quality.

Subjects

18 subjects participated in the first experiment. They were balanced with respect of gender and divided in two age classes (12 subjects < 30 years and 6 subjects > 45 years). All of them were strangers in Berlin and had no experience with the location.

Dependent Variables

In accordance with the experimental goals a series of parameters was measured:

- Eye movements (duration and frequency) to the dashboard while driving and during stops.
- Total driving time, separated in moving time and stopping time.
- Turns and route choice decisions.
- Evaluation of the traffic safety behavior. It was performed with a modified version of the traffic-conflict-technique, introduced by Zimolong (1982) and Gstalter (1983). This measure includes 'number of violations of traffic rules' and 'number and severity of traffic conflicts.'
- Mental load, measured by the registration of heart-rate and by means of subjective ratings.
- Estimation of acceptance and of subjective control, analyzed by questionnaires and interviews.

Equipment

We used a special equipped experimental car (DB 230 SE) containing the LISB-System components and a series of sensors und data storing devices (see FIG. 2).[1]

---

[1] We thank Daimler-Benz AG, Berlin and Stuttgart and SIEMENS AG, Berlin for their support.

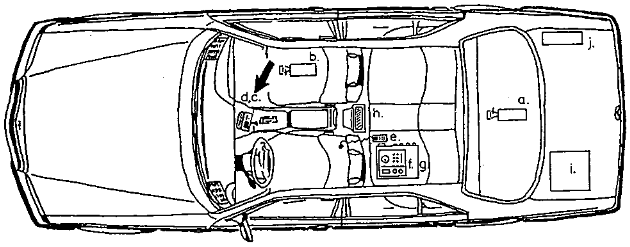


Figure 2. Experimental Car

a) video-camera 1 to record the eye-movements of the driver, b) video-camera 2 to record the traffic scene outside the car, c) display of the LISB-system, d) mirror to reflect the glances of the driver onto the display to the video-camera 1, e) sensor of the heart-rate measuring device, f) video-mixer, g) video-tape-recorder, h) video-monitor, i) power-supply (12 V dc to 220 V current), j) processor of the LISB-system (the sensors of the system are not shown).

Results

Traffic Safety

Eye-movements with LISB. While driving with the LISB-system drivers look 17% of the whole driving time onto the route guidance display instead of observing the street and the traffic. Calculated on a mean driving time of 22 min, drivers do not look at the traffic outside for about 4 min. The differences of glance times while driving or while stopping (i.e. on a red light) are not significant. Drivers do not use the secure stopping intervals pauses to regard the display in order to prepare for the next part of the route.

The long distraction from traffic is especially surprising. In the guiding mode each significant change of the display is announced by a tone, inviting the subject to look on the display. However, the data show no significant differences between the mode with acoustic announcements (guiding mode) and the mode with no acoustic aids (direction or compass mode).

The tremendous glance times to the display decrease significantly during the experiment (see TAB. 2). This indicates a learning and habituation effect. The extrapolation to a 'final' level of glance frequency and duration is not possible on the basis of the existing data. Further experiments must bring more clarification.

Table 2. Mean Display Glancing Time Splitted Into First and Second Part of the Experiment

	Group A	Group B
Experiment part 1	19,9%	19,0%
Experiment part 2	13,3%	15,0%

We observed no significant differences in the overall looking times onto the display with respect to age or gender of the subjects.

Looking times with the conventional city map. To guarantee security and traffic safety of driver and co-driver, the usage of the conventional city map was restricted to stopping times. As a consequence, no comparison of this dependent variable can be done.

Traffic Safety

Traffic safety was evaluated with a protocol using the traffic conflict technique. In nearly all categories driving behavior using the LISB-system was slightly better compared with the behavior using the paper map. One prominent result is a speed moderating and equalizing effect for drivers with the LISB device.

Only the category 'sudden initiated maneuvers' showed higher values when drivers used the LISB device (see FIG. 3). Those situations are characterized by changing direction or lane disregarding the other traffic whenever the guidance-system gives an advice.

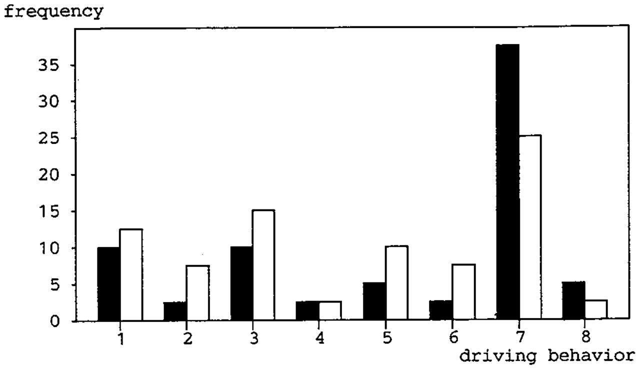


Figure 3. Frequency of Safety Relevant Driving Behavior

Solid bar) LISB drives, white bar) map drives, 1) speed too high, 2) speed too low, 3) nervous unexpectable driving behavior, 4) distance to preceding cars to small, 5) driving maneuvers started with hesitation, 6) maneuver initiated too late, 7) maneuver initiated without care of other traffic participants, 8) risky maneuver.

Workload of Drivers

An analysis of drivers workload shows differences between physiological measurements and the results of the questionnaires. 90% of the subjects report a higher load caused by the map compared to the electronic aid. But, the physiological measure 'heart rate' is identical under both circumstances. A division of the data in two parts—driving and stopping—offers an explanation for this discrepancy: reading the map at a standstill imposes the highest load while LISB leads under the same conditions to the lowest heart rate (see table 3). While driving, the use of the two route guiding aids results in mean physiological load.

Subjective Impression, Acceptance

Questions concerning the acceptance of both route guidance aids showed diverse judgments about the map, but a clear positive result for the electronic system. In accordance with this finding subjects experience no loose of control using LISB. They also feel more secure with LISB compared to routes driven with the aid of a map. However, it must be stated that these answers can be

Table 3. Mean Heart Rate for Trips with LISB or Conventional Maps, Differentiated in Stand-still and Driving

aktion	aid	mean	error prob.
standstill	map	94,8	n.s.
driving	LISB	93,6	sig. **
driving	map	92,3	p< 0.006
standstill	LISB	91,8	

Action) action of the driver, aid) route guidance system, mean) mean heart rate, error prob.) error probability.

influenced by the attitude of the drivers resulting in a tendency to be “a good subject.”

Driving Time

The driving time was calculated on the basis of 62 driving tasks of 18 subjects . The mean driving time was 22.4 min. The differences between the various are shown in TAB. 4.

Table 4. Results of t-Tests for Differences in Driving Time with Respect to Experimental Conditions

route	n	mean	s	error prob.
map	7	23.1	4.6	
route 1				n.s.
LISB	9	21.2	5.7	
map	9	22.1	7.9	
route 2				sig. *
LISB	8	14.0 .	5.2	p< 0.023
map	6	30.1	12.6	
route 3				n.s.
LISB	9	22.9	2.5	
map	9	27.5	11.3	
route 4				sig. *
LISB	5	17.9	4.5	p< 0.048

Mean) mean of driving time in minutes, n) number of drives, s) standard deviation, error prob.) error-probability.

The driving time with the city map was in all cases higher compared with drives with the LISB-system. But only the differences between route 2 and 4 are significant. In general, the use of the LISB-device reduces the driving time remarkably.

Conclusions

Foreign and disoriented drivers represent a higher danger for traffic safety than oriented drivers. This fact must be contrasted to the positive and negative findings of this experiment. Positively can be stated that drivers feel more secure and relaxed while driving with LISB and produce less traffic conflicts. Negative aspects concern the glancing times to the display during driving and the unconventional driving behavior under the LISB condition which is characterized by sudden lane changes.

Nevertheless the experiment shows that only a system like the LISB device which is able to guide drivers under all circumstances to their destination—regardless whether they follow a certain advice or not—provides foreigners with the appropriate information. But only a modified and well designed voice output interface is capable to reduce glance times and the frequency of ‘sudden initiated lane changes.’

The questions, whether the results of our experiment are stable over time, and how the performance of the system relates to an ‘ideal’ route guidance system (e.g. a well informed human co-driver), shall be answered by a subsequent experiment.

References

Gstalter H. (1983). Der Verkehrskonflikt als Kenngröße zur Beurteilung von Verkehrsablaufen und Verkehrsanlagen. Braunschweig, Technische Universität Carlo-Wilhelmina, Dissertation.

Hoffmann G., Rüenaufer P., Sparmann J., von Tomkewitsch R. & Zechnall W. (1987). Großversuch: Leit- und Informations system Berlin. In: Straßenverkehrstechnik (Heft 2/1 987), 3539 .

Popp M.M. (1987). Orientierungsprobleme von Kraftfahrern in fremden Städten: subjektive Einschätzungen und objektive Beobachtungen. In: Kastner M. (Hrsg.) Fortschritte der Verkehrspsychologie (Band 21): Mensch - Fahrzeug - Umwelt, 385394. TÜV Rheinland, Deutscher Psychologen Verlag.

Zimolong B. (1982). Verkehrskonflikttechnik - Grundlagen und Anwendungsbeispiele. Unfall- und Sicherheitsforschung Straßenverkehr (Nr. 35). Köln, Bundesanstalt für Straßenwesen.

S4-W-11

Collision Avoidance—Function Allocation to Humans and/or Machines

G. Reichart
BMW AG

Introduction

Various international road traffic related research programmes, like PROMETHEUS in Europe, IVHS in USA and similar Japanese projects aim at an improvement of the active safety which means the prevention of accidents.

Some proposals have been made to achieve this goal by an automation of driving. These concepts seem to be mainly stimulated by the increasing availability of very powerful computers and the rapid progress of image processing techniques.

However this technology driven development towards a more or less complete automation of driving has to be questioned from a human factors point of view. Function allocation to human and/or machine determines not only the system performance but also the quality of the "work situation" the human will experience. Thus these implications have to be carefully considered.

Often also another line of argumentation is used. That is, the human is supposed to be the weak link in road traffic safety and should consequently be replaced by a more reliable automation.

However, even this argument does not hold, if a closer look at current practices of accident recording is taken. Moreover data from the traffic conflict research indicate a surprising high human reliability in performing the complex driving tasks [Gstalter 1983].

In this paper some aspects of function allocation to human and/or machine are discussed in the context of collision avoidance, a function which is taken quite often as a paradigm for the advantages of automation of driver tasks.

Function Allocation Concepts and Criteria

Each goal oriented activity can be based on various technologies which imply frequently different tools and organization principles. Choosing a specific technology specifies thus intentionally or not basic decisions on the tasks a human operator has to perform as well as the requirements on his performance [Hacker 1986]. Mechanization and automation transfer functions performed so far by humans to machines. Thus function allocation is the decision in the system design process which functions should be performed by humans and/or machines. This is from the human engineering point of view one of the most important steps in the design process, even if this decision is quite often based solely on the technological possibilities. It is somewhat surprising that despite of its importance concepts and criteria for function allocation are not established to the same degree as other ergonomic concepts and criteria. Quite often Fitts List [Fitts 1951] or some of its successors (e.g. Fig. 1, according to [Shneiderman 1987]), are guiding this decision, even if some serious concern exists about the usefulness of this approach [Meister 1985, Wirstad 1979, Price 1985].

This seems to reflect a widespread tendency of the human engineering discipline to concentrate only on the system performance aspect. However function allocation does not only affect system performance, it determines also the quality of the work situation as experienced by the human operator. Job satisfaction and motivation are highly dependent on the roles assigned to the human in a given work situation. [Price 1985] has called this the affective values of a function.

Moreover the function allocation process can be considered as a tradeoff problem [Swain 1987] since many different design criteria forming a multidimensional decision space have to be considered [Fig. 2].

Humans Generally Better	**Machines Generally Better**
• Sense low level stimuli	• Sense stimuli outside human's range
• Detect stimuli in noisy background	• Count or measure physical quantities
• Recognize constant patterns in varying situations	• Store quantities of coded information accurately
• Sense unusual and unexpected events	• Monitor prespecified events, especially infrequent
• Remember principles and strategies	• Make rapid and consistent responses to input signals
• Retrieve pertinent details without a priori connection	• Recall quantities of detailed information accurately
• Draw upon experience & adapt decisions to situation	• Process quantitative data in prespecified ways
• Select alternatives if original approach fails	
• Reason inductively: generally from observations	
• Act in unanticipated emergencies & novel situations	• Perform repetitive preprogrammed actions reliably
	• Exert great, highly controlled physical force
• Apply principles to solve varied problems	
• Make subjective evaluations	
• Develop new solutions	
• Concentrate on important tasks when overload occurs	• Perform several activities simultaneously
	• Maintain operations under heavy information load
• Adapt physical response to changes in situation	• Maintain performance over extended periods of time

Figure 1. Relative Capabilities of Humans and Machines [Shneiderman 1987]

It is rather obvious that the reduction of this decision space to system performance criteria alone will miss important aspects.

Every rational decision on function allocation requires to specify the criteria for the various system design aspects in quantitative or at least qualitative terms as well as to weight their relative importance. Some ideas to cope with this difficult task will be outlined in a later section of this paper. Some aspects of the collision avoidance function have to be discussed in some detail before.

- User Acceptance
- Technological Constraints
- Performance Requirements (e g. speed, accuracy)
- Social Aspects
- Legal Aspects
- Safety Aspects
- Dependability Aspects
- Equipment weight and volume
- Environmental Aspects
- Maintenance Aspects
- Costs

Figure 2. Some System Design Criteria Important for the Function Allocation [modified after Swain 1987]

Collision Avoidance—What Does it Mean?

In its true sense collision avoidance means a function which realizes evasive or avoidance manoeuvers in case of otherwise impending collisions with stationary or moving obstacles under all relevant environmental conditions. This general function can be differentiated into various subfunctions which are:

- perception of the relevant objects and their characteristics in the scene,
- perception and knowledge of the own vehicle status and performance capabilities as well as of other relevant situation parameters,
- assessment of the situation with respect to the potential of conflicts,
- interpretation of the situation assessment in terms of necessity and possibility of countermeasures,
- decision making on the suitable actions,
- performing of the selected actions,
- continuous updating of the effectiveness of the chosen action(s) and decision on additional or correcting measures.

These subfunctions have to be performed independently from the assignment of the collision avoidance function to man and/or machine.

In a vehicle only a rather limited set of possible control actions is available for avoidance respectively evasive manoeuvers. The longitudinal control can be used for decelerating or accelerating of the vehicle and/or the lateral control (steering) can be effected. Due to the coupling between longitudinal and lateral control the latter is only possible if the vehicle moves longitudinally. Since there are a number of technical and physical constraints involved, e.g. limitation due to the vehicle systems, due to the interaction with the road surface and due to barriers, the availability of escape or avoidance manoeuvers is limited. Thus it is highly questionable whether an avoidance of all collisions will ever be possible. Moreover these constraints are not fix, they vary quite considerably over time and from situation to situation. Thus the potential for evasive or avoidance manoeuvers is more or less unique in each situation. This confirms the well-known fact that each accident contains a unique pattern of factors leading to this accident. From a human factors point of view this aspect prevents the transparency of the system behaviour of an autonomous collision avoidance system.

Discussion of the Subfunctions

One of the key functions of the driver is to monitor the traffic scene around her/him and to extract all information relevant for the tasks in navigation, guidance and stabilization [Bernotat 1970]. To maintain her/his own safety and that of other traffic participants a more or less continuous visual search for critical objects which are or could become obstacles, and the monitoring of their trajectories as well as a perception of road surface characteristics and potential constraints for manoeuvers has to be performed. This task has to be accomplished under a huge variety of environmental conditions ranging from very bright daylight to foggy nights.

There is no unique sensor currently available which could fulfill this wide range of tasks. Much hope is placed on a combination of sensors and concepts of multi-sensor data fusion, but only rather limited progress has been made in that field throughout the past years and there is still little light at the end of the tunnel if any.

Beyond this scarcity of appropriate sensors there is another and from a human engineering view more important problem which is that the perceptual processes of man and machine are differently organized.

The interpretation of sencoric data by humans is mainly based on the knowledge which the humans have about the signal [Hacker 1986], [Lindsay, Norman 1981]. Of much less importance is the information contained in the signal. This is often called the context driven interpretation of signals [Dreyfuss 1989], [Winograd, Flores 1989] have shown how many difficulties Artificial Intelligence (A.I.) based systems have in dealing with such a concept.

Moreover human perception is only partly a reactive stimulus-driven process but to a large degree also an active process. The a priori-knowledge about the context and the expectations derived from this knowledge and previous experiences guide the perceptual processes.

The different visual behavior of novice drivers and experienced drivers [Mourant, Rockwell 1974] are a clear indicator of this fact. Another example is that we do not expect to encounter major problems from an oncoming car in the other lane, an expectation which is in contrast to our increased attention to a child standing close to the roadside. From a purely stimulus oriented concept both objects would require the same level of attention. To formulate such a simple situation e. g. in production rules creates huge problems. Just to give an example one could specify a rule like:

"If there is an object which is classified as a child close to the roadside then slow down, observe its behaviour and be prepared to stop, if the child starts to enter the road."

Thus we immediately run into the problem of needing additional rules for what determines the concept of child, the concept of "close to the road" and so forth. A seemingly endless sequence of rules will be necessary to handle such a simple situation, if at all possible.

Again the human ability to assess the situation with respect to the potential of conflicts is based on context information, a priori-knowledge and previous experience. Sometimes this human assessment is wrong and leads to conflicts or even accidents. But is it really justified, to believe, a system designer can anticipate all such situations and formulate appropriate rules? Who could and would take responsibility in case of design errors?

Even the further task of deciding on the necessity and feasibility of countermeasures requires a lot of situation specific information, like current vehicle status, performance capabilities, road surface characteristics, road geometry and the likely actions of the other objects. The decision on the suitable action includes not only the analysis and evaluation of such a complex situation but also a lot of value judgements. To avoid collision with a child could probably have higher priority than to collide with another vehicle during an evasive manoeuver. Such ethical problems have to be resolved in personal responsibility. Otherwise the ethics of the system developers will determine the resulting consequence raising difficult questions of moral and legal responsibility.

Once a decision of the appropriate actions has been made timing, dynamics and intensity of the actions are important. Systems under investigation like safety distance indications and warnings, intelligent brake systems, active steering systems help the driver in timing the action, in choosing the appropriate intensity of action and in the control of the system dynamics. If the performance is completely left to an automated system, the passengers in the car will have no idea about the what, when and how of the actions. Due to the usually short time period during which actions have to be initiated and performed pre-information and thus transparency of system-behavior cannot be achieved. People inside of the car would have to blindlessly rely on the correct and reliable functioning of the system.

Since it is very likely that in automated driving the passenger will no longer monitor the traffic scene, a mental decoupling between the passenger view of the world and the system view is to occur. It is not only the increased sensitivity to motion sickness [Rolnick, Lubow 1991] which will negatively influence the acceptance of such concepts, even more the lack of transparency, predictability and anticipation of system behavior will create stress for the car passengers [Lindsay, Norman 1981], [McGrath 1970]. Once an action has been initiated a continuous feedback on its effectiveness controls the human performance. Corrective or additional manoeuvers are taken if the intended goal seems to be missed. Unfortunately, due to the very limited time span available in critical situations and due to the limits of the human decision making as well as due to the human tendency to stick to learned patterns of behavior (stereotyped reaction) in stressful situations these corrections and additional actions are often insufficiently performed or even omitted. Since it is an inherent human characteristic, as a consequence the system design has to be able to tolerate these limitations.

A number of systems have been developed or are under research as well as special safety training courses have been established to help drivers to cope better with these situations. The antilock-brake system (ABS), the anti-skid control (ASC) and advanced steering concepts (active steering systems) are examples of such technical aids.

A Proposed Concept for Function Allocation to Human and Machine in Collision Avoidance

Once a clear structure of the subfunctions contained in collision avoidance exists, a careful analysis is needed on what specific problems limit humans to successfully perform these tasks. This has to be compared with the technical possibilities to overcome these difficulties. Some aspects have been illustrated in the previous chapter. If these alternative configurations have been established and their advantages and drawbacks are identified, they have to be evaluated in the light of all relevant system design criteria. This will be illustrated on the example of distance keeping to other vehicles in front of the own vehicle, which is only a partial aspect of collision avoidance. It is well known from accident analysis as well as from ergonomic research that drivers have considerable difficulties to keep sufficiently safe distances. The reasons for this are manifold, ranging from the problem of dealing with nonlinear relations as between velocity and safe distance, the problem of distance estimation in the absence of supportive visible cues (e. g. in fog), to the problem to estimate correctly the impact of the road surface condition.

Based on this analysis of driver problems in distance keeping various technical solutions can be defined:

- Information and Assistance Systems
  - safety distance display, e. g. by means of Head Up Display-technique as proposed by [Bubb 1985]
  - active gaspedal (pedal force characteristic varies with the deviation from the appropriate distance)
  - visual range information for poor visibility conditions
- Road Surface Condition Information
  - Intelligent brake systems
  - Obstacle warning systems
- Automated Distance Keeping
  - limited functionality, e.g. limitation of automatic deceleration to a maximum of 0.3 g
  - full scope systems, i.e. complete range of control up to 0.9 g
  - intervention systems; i.e. systems which intervene only in case of an otherwise impending collision

To decide on the function allocation the best compromise between the sometimes conflicting system design criteria—as described in section 2 of this paper—has to be found.

The rather globally formulated system design criteria have to be specified in more detail to make them operational. An example for the criteria on user acceptance is shown in Fig. 3.

Some criteria may be exclusive, which means that the alternative is not viable, if a specific criterion, e. g. a legal requirement, cannot be met. To the other criteria weights can be assigned and formal methods, like decision matrices can be applied Fig. 4.

Even the application of formal decision procedures cannot exclude a considerable degree of subjectivity and uncertainty, but will nevertheless support decision making as rationally as possible. This concept of the function allocation process as described here corresponds

- Usefulness
- Transparency and consistency of system behaviour
- Tolerance against faulty operation
- Compatibility with other systems
- Flexibility/Adaptability
- Controllability
- Reliability
- Safety
- Learnability/Self-explanation
- Comfort

Figure 3. Acceptance of New Systems by the Automobile User—Important Factors

System Design Criteria	Weights	Evaluation of Alternatives (A_i)		
		A_1	A_2 ...	A_n
1. User Acceptance	0,2	+1	0	–1
2. Safety	0,15	0	–1	+1
3. Reliability	0,15	+1	0	0
4. Weight/Volume	0,05	–1	+1	0
•	•	•	•	•
•	•	•	•	•
•	•	•	•	•
n: Costs	0,2	+1	0	–1

Figure 4. Simplified Example of a Decision Matrix for the Evaluation of Alternative Function Allocations

well to what has been found appropriate in other complex technical fields, see [Pulliam et al. 1983] for an extensive description of such a concept for nuclear power plants.

As a first result of the still not fully accomplished function allocation process for BMW's collision avoidance concept the following basic principles have been selected:

- Responsibility of the driver must be maintained.
- The driver has to be kept in the loop.
- System failures must not lead to uncontrollable situations.
- Overreliance and risk compensation effects have to be avoided as far as possible.
- The actions of the system must be transparent for the driver and consistent over the various situations.
- The system should support the driver even in normal driving not only in extreme situations.

These principles exclude the concept of automatic collision avoidance. Instead a subset of the information and assistance functions as described above will be realized. Laboratory and field test are planned to verify some of the premises of this concept. The resulting configuration follows some of the ideas of the electronic cocoon [Wiener 1985] and the concepts for a human centered automation [Norman 1989], [Sheridan 1991].

Conclusions

Achieving both improvements of active safety and the user acceptance requires a thorough function allocation process. Attempt has been made to explain the complexity of the considerations and decisions involved in function allocation. Function allocation must be understood as the prime system engineering task. Sometimes conflicting system design criteria will only allow to find the best compromise. But it is the job of the human engineer to assure that the costs of this compromise do not have to be paid by the user.

References

Bernotat R., Anthropotechnik in der Fahrzeugführung Ergonomics 13, 3, 1970.

Bubb H., Arbeitsplatz Fahrer, Eine ergonomische Studie, Automobil-Industrie 3, 1985.

Dreyfuss H. C.,Was Computer nicht können, Athenaum, Frankfurt, 1989.

Fitts P. M. et. al., Human Engineering for an Effective Air Navigation and Traffic Control System, National Research Council, Washington DC, 1951.

Gstalter H., Der Verkehrskonflikt als Kenngrölße zur Beurteilung von Verkehrsabläufen und Verkehrsanlagen. Dissertation, Univ. Braunschweig, 1983.

Hacker W., Arbeitspsychologie VEB Deutscher Verlag der Wissenschaften, Berlin, 1986.

Lindsay P. H., Norman D. A., Einfuhrung in die Psychologie Springer, Berlin - Heidelberg - New York, 1981.

McGrath (ed.), Social and Psychological Factors in Stress, Holt, Rinehart and Winston, New York, 1970.

Meister D., Behavioural Foundations of System Development, Robert E. Krieger Publ. Company, Malabar, 1985.

Mourant, R. R., Rockwell T. H., Strategies of Visual Search by Novice and Experienced Drivers, Human Factors, Vol 14, No 4, 1974.

Norman D. A., The Problem of Automation: Inappropriate Feedback and Interaction, Not "overautomation," ICS-Report No. 8904 Inst. for Cognitive Science, Univ. of California, San Diego, La Jolla, California, 1989.

Price H. E., The Allocation of Functions in Systems, Human Factors, 27 (1), 1985.

Pulliam R., Price H. E., Bongarra J., Sawyer C.R., Kisner R., A Methodology for Allocating Nuclear Power Plant Control Functions to Human or Automatic Control, Nuclear Regulatory Commission, NUREG/CR-3331, Washington, DC, 1983.

Rolnick A., Lubow R. E., Why is the driver rarely motion sick? The role of controllability in motion sickness, Ergonomics, Vol 34, No 7, Taylor and Francis, 1991.

Sheridan T. B., Automation, Authority and Angst-Revisited. Proceedings of the Human Factors Society, 35th Annual Meeting, San Francisco, CA, 1991.
Shneiderman B., Designing the User Interface Addison Wesley, Reading Massachusetts, 1987.
Swain A. D., "Relative Advantages of People and Machines in Process Industries" in Woodward J. L. (ed), International Symposium on Preventing Major Chemical Accidents, Inst. of Chemical Engineers, Washington D.C. 1987.
Wiener E. L., Cockpit Automation: in need of a philosophy. Proceedings of the 4th Aerospace Behavioural Engineering Technology Conference, Long Beach, CA, 1985.
Winograd T., Flores F., Erkenntnis Maschinen Verstehen Rotbuch Verlag, Berlin, 1989.
Wirstad J., On the Allocation of Functions Between Human and Machine Ergonomrad AB, Report No. 13, Karlstad, 1979.

S4-W-15

From Accidentology Analysis to the Intelligent Vehicle

J.P. Colinot
PSA Peugeot - Citroen
D. Lechner
INRETS

The Study Objectives—The Methods Used

Amongst road traffic accidents there is a large percentage of which physiological consequences for the passengers cannot be avoided by using secondary safety, particularly due to the energy levels involved above a certain relative speed between the vehicle and a fixed or moving object. (1)

With the view of maximum effectiveness of the road user safety activities, it is therefore necessary, in addition to passive safety measures, to implement active safety initiatives with the aim of accident prevention.

Here we are going to present the results of this research started in 1989 by PSA Etudes et Recherches in association with the joint PSA/RENAULT Accidentology and Biomechanics Laboratory and INRETS.

The joint work of INRETS (Accident Mechanism Dept.) and PSA has been undertaken within the framework of the European PROMETHEUS research programme, aimed at improving the effectiveness and safety of road traffic. The first results appear in document (2).

The overall objective of the study is to understand, in a quantitative manner, the process of accident generation and the resulting sequence of events in order to create counter- measures and be able to validate their performance by using simulation techniques.

The method of implementation comprises three stages:

- Prioritise the work objectives by producing categories of serious accidents, clearly representative in percentage, and homogeneous in terms of their mechanisms. This is done through a statistical survey.
- Reconstruct and analyse in detail a small number of real accidents which are representative of the categories above, and which have been chosen for the quantity and the quality of the data collected after the accident, as a guarantee of reliable reconstruction.
- In the light of the recalculated movements, determine the malfunctions in terms of the vehicle and the driver's behaviour or the infrastructure and imagine actions, and their timing, which could have been taken to prevent this accident.

Each one of these stages will now be described and illustrated.

Statistical Study—Accident Category Validation

At this stage, the emphasis is put on representativity. Therefore it is necessary to analyse a large number of accidents from all over France, avoiding any seasonal bias.

The Accidentology and Biomechanics Laboratory has therefore studied the computerised records of the Gendarmerie Nationale. Towns with more than 5,000 inhabitants do not come under the responsibility of the Gendarmerie with regard to accident reports, and therefore accidents occurring in urban surroundings do not appear in our statistical study. This type of accident could require further study at a later date.

Selection criteria:

- Serious accident: at least one serious injury or death.
- At least one vehicle likely to be fitted with a primary safety interactive aid, "adaptable," i.e. in our selection a passenger car, bus or truck involved in the accident.
- Analysis made vehicle by vehicle: an accident involving two "adaptable" vehicles will appear twice in our classification, and this represents two opportunities for suitable active safety measures.

Field of application:

- Metropolitan France, excluding towns of more than 5,000 inhabitants, over the years 1983-88; i.e. a total sample of more than 190,000 vehicles involved in serious accidents.

- The number of kilometres travelled x vehicles in 1988 was:
  - passenger cars 258 x 109 km x vehicles, 15% of which on motorways
  - heavy goods vehicles 139 x 109 x vehicles, 65% of which on motorways.

Of this total, about 30% of the cumulative figure (travel in built-up areas) is excluded from our study.

Classification:

- After having tested several sorting grids, the first of which, giving a finer analysis, revealed 432 possible circumstance combinations; in the interests of efficiency we decided upon five types of possible circumstance (place + obstacle) and three explanatory identifiable variables linked to visibility and friction, by separate categories of passenger cars and heavy goods vehicles.
- The alcohol/blood level was finally rejected as an explanatory variable, as relative data appeared somewhat unreliable (notoriously underestimated compared with published data).

The 1988 results have been used to illustrate this chapter (refer to Table 1).

Table 1. 1988—Severe Accident Results

PASSENGERS CARS	TOTAL (1)	LOW FRICTION (2)	NIGHT (3)	POOR VISIBILITY DAY + NIGHT (4)
Highway, pileup collision (1)	1,70%	1,80%	2,30%	3%
Highway, collision against a steady obstacle (2)	1,40%	1,10%	1,30%	1,70%
Crossroads (3)	16,80%	13,30%	10,50%	14%
Road, collision in curve against steady obstacle (4)	12,80%	13,30%	18,80%	14%
Road, collision in curve against other vehicle (5)	15,20%	19%	12,50%	14%
Total number of accidents passengers cars (6)	29671	10492	9536	4974
TRUCKS				
Highway, pileup collision (7)	4,10%	3,50%	10,30%	4,10%
Highway, collision against a steady obstacle (8)	2,70%	2,40%	4,50%	4,30%
Crossroads (9)	17,50%	13,60%	9,50%	13,60%
Road, collision in curve against steady obstacle (10)	5,70%	4,40%	5,50%	5,30%
Road, collision in curve against other vehicle (11)	22,90%	32%	16,10%	20%
Total number of accidents trucker (12)	2617	1057	670	484

Results Analysis:

1) Nearly 45% of accidents fall into three circumstance categories (off motorway network):
   - Road junction
   - Bend, loss of control of one vehicle
   - Bend, collision between two vehicles

   which determines clear priorities for continuing the study.
2) Detailed examination of the percentages points to a certain number of explanations and therefore possible measures:
   - Fewer accidents at night at junctions and in bends, involving mobile obstacles (true for passenger cars and HGVs). Please refer to comparison lines 3 and 5, columns 3 and 1 and lines 9 and 11, columns 3 and 1.
     Suggested explanations:
     - Less traffic, therefore reduced probability of meeting other vehicles.
     - Earlier awareness of the presence of another vehicle by its headlights.
   - Considerably fewer HGV accidents than passenger car accidents, in bends, against a fixed obstacle, under any circumstances. Please refer to comparison lines 10 and 4.
     Suggested explanations:
     - Professional drivers have a better knowledge of vehicle reactions, and frequently travelled routes.
   - More accidents involving passenger cars in bends, against fixed obstacles, at night. Please refer to comparison line 4, columns 3 and 1.
     Suggested explanations:
     - Poor appreciation of obstacle (the effect of surprise, lack of concentration).
     - Bad vehicle control.
   - A greater percentage of HGVs involved in accidents in bends, against mobile obstacles. Please refer to comparison lines 11 and 5, column 1.
     Suggested explanations:
     - Greater widths, making it more difficult to correct possible inadequate path of one OR the other vehicle.
   - More accidents in bends, against mobile obstacles, in the event of low friction (true for passenger cars, increased for HGVs). Please refer to comparison line 5, columns 2 and 1 and line 11, columns 2 and 1.
     Suggested explanations:
     - Avoiding manoeuvres more difficult on low friction road, especially when confronted with a very wide vehicle.

Therefore the conclusions of the first part of this study are:

- The types of accident to be reconstructed and analysed as a priority are:
  - Bend (loss of control of one vehicle—two examples presented), (collision between two vehicles—one example presented).
  - Junction (still being studied).
- The malfunctions which have occurred are probably of the following types:

- Imprecise or tardy perception of a driving hazard or a mobile obstacle
- Driver input unsuited to circumstances (speed, bend radius, friction)

This is what we will seek to confirm and quantify in the following section.

Detailed Analysis of Actual Accidents

Fiat Regata leaving the road, illustrating the type of accident "loss of control in bend under severe initial conditions"

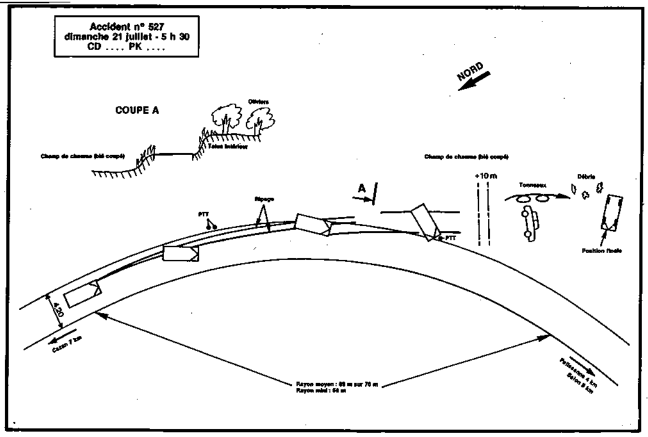


Figure 1. Plan of the Accident "Fiat Regata Loss of Control"

Circumstances of the accident. The accident happened at night on a very narrow secondary road one Sunday in July at 4.30 in the morning, in a right-hand bend.

The driver had spent the evening with his friends and admitted having drunk a lot of alcohol, which he justified by the fact that he did not think he would have to drive. However, due to one of his friend's cars breaking down, he borrowed his sister's Fiat Regata to go for a night drive. This vehicle is 18 months old, has covered 40,000 km and has no mechanical defects.

The itinerary used is a small, winding, narrow secondary road (4.2 m wide) chosen for the expected low traffic at this time of night. The accident spot is preceded by 200 m of straight road on a slight downward slope, encouraging a pick up in speed. There is a tight right-hand bend, with an average curve radius of 90 m for 70 m and with a minimum radius of 56 m. Visibility on entering the bend is reduced (Fig. 2). The road evenness is particularly bad, its camber is particularly bad, it is adverse at the bend entry and then corrected in the bend itself.

The driver states he had "seen the bend coming," despite the absence of specific vertical signs, but admits that his speed (70 - 80 kph) was too high. It is possible that his high alcohol intake delayed his reaction time on the steering wheel. He states that he felt the vehicle slide away, without him being able to do anything about it; he believes that he braked.

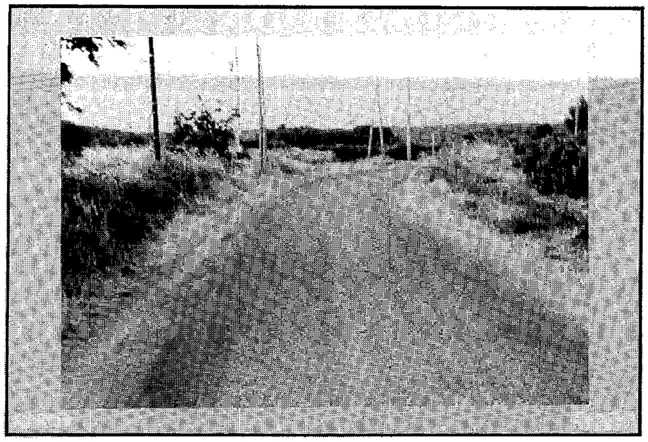


Figure 2. General View of the Site: Total Lack of Visibility at the End of the Curve

Marks on the road are characteristic of under-steering: the vehicle veers towards the outside on entering the bend, and skids (spin skid marks for 30 m before leaving the road) probably under the effect of a too brutal attempt at correcting the situation with the steering wheel. The car then rolls over several times and finishes up in a field at a lower level. Two of the occupants are only very slightly injured, even though they were not wearing seat belts. The consequences would have been much more serious in the event of an impact with a major obstacle.

Starting from an initial speed of 70 kph (or respectively 80 kph) and with regular deceleration along the 42 metres of skid marks, we obtain a residual speed of 40 kph (or respectively 56 kph) at the point of starting to roll over, a speed which is entirely credible.

Explanatory note: The figures 1, 4 and 7 in this paper show the measurements taken on the spot, immediately after the accident.

Research into the Dynamic Performance. In an attempt to quantify the vehicle's dynamic reactions, which led to the accident, we carried out test runs at increasing speeds, using an instrumented vehicle.

Explanatory note: The figures 3, 6 and 9 in this paper show runs with an instrumented vehicle, or with a dynamic model, on the bends where the accidents occurred. They are all constructed in the same manner:

- *The upper part contains the steering wheel control angle (continuous line) and its derivative (dotted line), as well as the vehicle speed (dots and dashes), which is kept constant for the model.*
- *The lower part represents the spread of lateral acceleration along the length of the digitised bend. Some points linked to the accident sequence of events (start of skid marks, final position etc.) have also been noted. Under the title the main parameter maximum values and their locations have been indicated.*

Figure 3 shows the fastest run which we carried out at the scene of the accident involving the Fiat Regata. The speed is around 65 kph in the bend itself, which corresponds to a maximum transversal acceleration of 6.3 m/s².

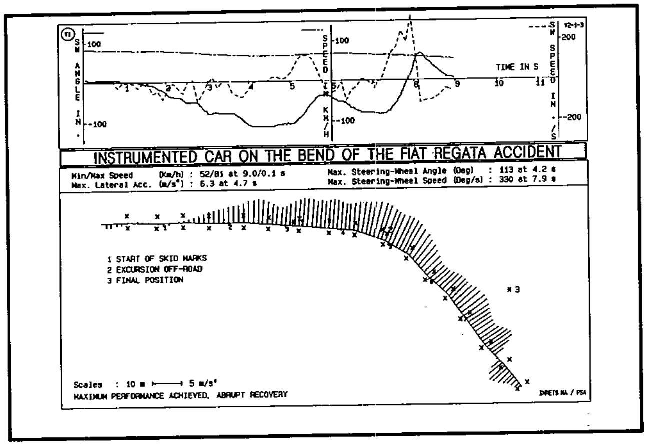


Figure 3. Measured Dynamic State

When runs are carried out at increasing speeds, the steering wheel controls become sharper and more complex: from being very progressive at slow speed, they turn to a two step action with a final sharp oscillation for the run in question.

It should be noted that lateral acceleration sets in very early and that its level reached at point 1 (start of skid marks left by the Regata, indicating the starting point of loss of control) is already significant and often increases further up to point 2, where the Regata left the road.

Analysis conclusions: Our maximum run speed in this bend is around 65 kph, which did not prevent us from having approach speeds greater than 80 kph, a few dozen metres before the bend.

It is definitely not possible to negotiate it at 80 kph and the Regata driver entered it too fast.

It is probable that the driver's high alcohol intake delayed his awareness of the bend, preventing him from slowing down to approach it at a reasonable speed.

The starting point of the skid marks probably indicates a too violent steering wheel movement, starting too late and with a too high angular rate: the vehicle is then pulling straight ahead and under-steering, the available friction being lower than that required for the vehicle to negotiate the bend.

It should be noted that on this small, narrow and bumpy road this bend, at the end of a downhill straight which encourages significant increases in speed, has no specific warning signs.

Loss of Control Prevention Strategy in Tight Bends. This category of accident usually highlights the true difficulties linked to road layout. These tight bends represent breaks in an easy itinerary, there are no specific speed limitations, and they lack sufficient warning signs. Drivers fall into a trap because they take the bends too fast.

Actions to be considered as driving aids particularly cover:

- identifying bends which present real difficulties on the itinerary,
- communicating messages warning the driver of the special difficulty in these bends,
- communicating advice or recommendation of a suitable bend entry speed,
- at a more sophisticated level, informing the driver of the moment when he should start reacting with an indication of the necessary steering wheel angle.

The main aim is to encourage progressive steering in order to reduce the maximum necessary value of steering input. The priority is to avoid manoeuvres which start too late and involve violent steering, resulting in uncertain vehicle reactions.

Renault 5 GT Turbo leaving the road, illustrating the accident type "loss of control in bend with easy initial conditions"

Circumstances of the accident. The accident occurred just after midnight one Sunday evening during June; the Renault 5 GT Turbo driver, alone in the car, loses control of his vehicle entering a sweeping left-hand bend on a major road.

The 35-year old driver acquired this new car four months previously, essentially "for the fun of it" after his divorce. On the day in question, after working from noon until 8.00 p.m., he spent the evening alone in front of the television. Tests showed a blood alcohol level of 1.6 g/L. Towards midnight, he decided to go out to withdraw money from a cash dispenser. On the way back, after 7 kms, the accident occurred.

It is night-time, the itinerary is easy, on a major wide road with little traffic. Shortly after the road became a three-lane one, in the first fast bend, with an average radius of 480 m over 70 m, the R5 carried straight on. Just after mounting the verge (not asphalted and impossible to drive on at high speed), the driver, who states he does not remember the accident happening, probably turns the steering wheel too violently towards the left. The vehicle starts a spin out (65 m of skidding on the right-hand verge), then completely crosses the road sideways (45 m skid marks) then the left-hand verge before hitting a mound on its right rear side. The vehicle continues to spin and finishes its path 22 m further on, in the left-hand ditch, pointing in the initial direction of travel. 145 m separate the beginning of the skid marks and the final resting place.

An estimate of the impact speed and an attribution of rates of deceleration over the various skid marks (3) enables the initial speed to be re-calculated. It is around 120-130 kph, which corresponds to the driver's statement. The driver, who was not wearing a seat belt, suffers injuries to his sternum and multiple bruising. The vehicle deformation is hardly spectacular, but the body is not repairable.

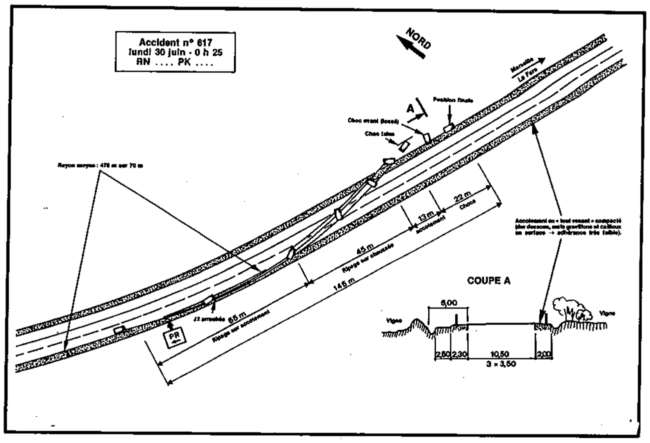


Figure 4. Plan of the Accident "Renault 5 GT Loss of Control"

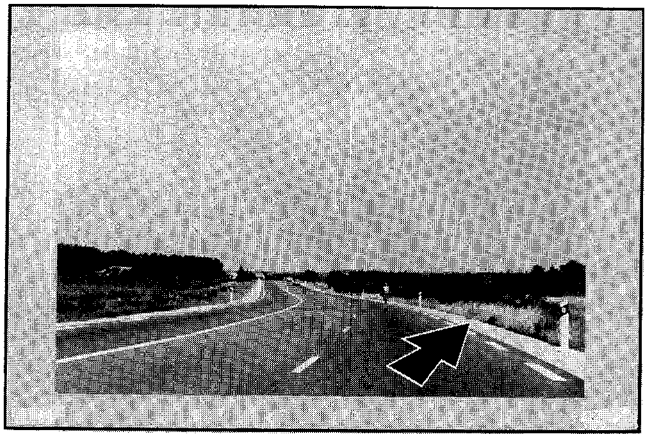


Figure 5. General View of the Curve (Arrow Shows Initial Point Where the Car Left the Road)

Research into the Dynamic Performances. Here we are using a model with three degrees of freedom (yaw, slip roll) to evaluate the vehicles reactions during high speed runs in this sweeping bend (Figure 6 and explanations above). The results of this model were validated by tests carried out using our instrumented vehicle. The nominal path at 130 kph creates lateral acceleration of 3.7 m/s^2. It is evident that this type of sweeping bend can be taken at high speed without any problem.

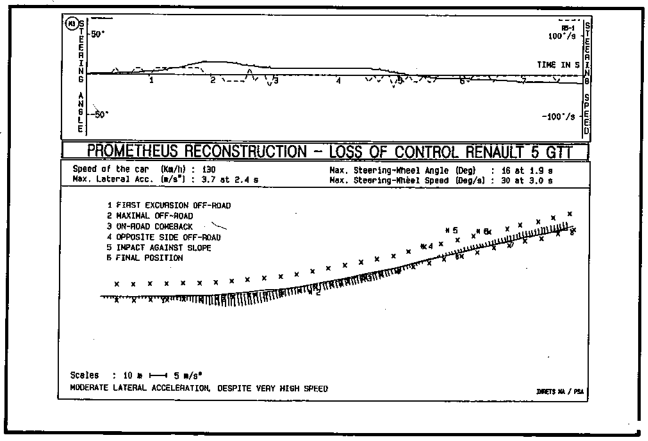


Figure 6. Dynamic Modeling Results

Analysis conclusions. Negotiating this sweeping bend, even at very high speed, does not really cause the driver any difficulty. The speed involved is however far above the current legal limits.

The accident is mainly due to initial driving on the verge, from which it is very tricky to regain the road at high speeds. The driver's alcohol intake is probably the cause of his delayed awareness of the bend, despite his familiarity with the itinerary.

The measures that can be considered for this type of accident would consist of warning the driver that he is straying from the nominal path and that he is about to mount the verge, but it is clear that the length of time available for a device to register these events, communicate the danger signal to the driver, and for the latter to react (especially when his concentration and reflexes are often diminished) is extremely short.

The other problem is the unsuitability of the verges, composed of compacted rubble but not asphalted in the present case, and not negotiable at high speed. They even present major changes of level in relation to the road, which means that it is difficult to return to the road surface.

It is also clear that driver reactions when confronted with this type of situation are often inappropriate, probably due to the dual effect of surprise and fear. The corrective action taken is too brutal or too great. Nevertheless, any chassis improvement, leading to increased yaw stability would have a positive effect in that case.

This type of situation, which is a question of regaining control of a vehicle, is clearly marginal in relation to the operating conditions for which the vehicle is designed. Furthermore, what proportion of drivers would be capable of taking benefit from possible improvements in the conditions of stress associated with an emergency situation?

Prevention strategies for loss of control in sweeping bends. The role of driving aids to be adopted to avoid this type of accident can be summarised as follows:

Aim: The priority is to avoid the driver mounting the verge. Compensate the driver's lack of concentration, which can cause delayed or no action.

Mean: Follow the vehicle's progress in relation to the road verge by checking:

- the vehicle/verge angle
- the verge approaching speed

This would require either a continuous (magnetic rail) or discontinuous (beacon) type relay on the infrastructure, or an autonomous on-board device (image analysis).

Action: Draw the driver's attention to the fact that he is not reacting to the approaching bend. Tell him the moment at which he should start his steering action, indicating the direction and initial steering angle.

Peugeot 104/Semi-trailer Accident

Circumstances of the accident. One Friday in September, mid-morning, on a secondary road, at the exit of a small built-up area, a Peugeot 104 ZS skids in a tight right-hand bend and hits the front of an articulated lorry coming the other way. The road surface was slippery as it was raining. The driver and the passenger in the 104 are slightly injured.

The infrastructure is particularly unfavourable. For the 104, the right-hand bend is tight, its average radius is 94 m over a distance of 50 m, with a minimum radius of 60 m. Visibility is reduced by vegetation on the inside of the bend, the road surface is bumpy and friction is low (worn with tar scabbing). The rainfall is the first after a dry period, which makes the road surface greasy and very slippery. The area of transition between the built-up area and open country, just before the scene of the accident, encourages high approach speeds and advance warning signs of the bend are insufficient.

The driver of the 104 is "joyriding" without a licence in a car stolen 10 days previously. When he entered the bend and started to turn, he felt his car slide away and pull straight, and believes that he braked. Considering the meteorological conditions, his approach speed is without doubt too high and his inexperience in driving did not enable him to regain control in an awkward situation. His lack of local knowledge, the effect of surprise and the dissuasive effect of the semi-trailer coming the other way probably caused him to be too violent with the steering and braking. The stated speed of 60 kph seems reasonable, as a higher speed appears to us to be completely impossible on wet surfaces. The 104 is a ZS model, of a sporting type, in good condition.

With regard to the infrastructure, we should also mention that for the semi-trailer driver, the poor friction and absence of suitable verges makes it impossible to take any avoiding action, even though he clearly sees the situation from his cab. He states that his speed was between 30 and 40 kph. The driver is especially alert in the rain and when he sees the 104 lose control he brakes in a straight line. The trailer rear wheels lock and leave a 13.7 m skid mark, of which 11.2 m are before the point of impact. The 104 crashes into the front of the semi-trailer, which has not yet completely stopped, and is pushed backwards by it for two or three metres.

Research into Dynamic Performances. Figure 9 shows the fastest run carried out on this bend in the direction taken by the 104 by our vehicle fitted with instrumented vehicle. It was carried out on a dry road, whilst the accident happened in the rain making the road particularly slippery. Furthermore, the road has been resurfaced since the date of the accident and now has much better evenness and friction.

The maximum lateral acceleration is 8.3 m/s^2; this is on entering the bend, because of violent steering wheel movement, which no doubt resembles that which caused the 104 to lose control. The speed here is in the region of 75 kph, but the accident happened in the rain. The presence of oscillations both at the start and the finish should be noted.

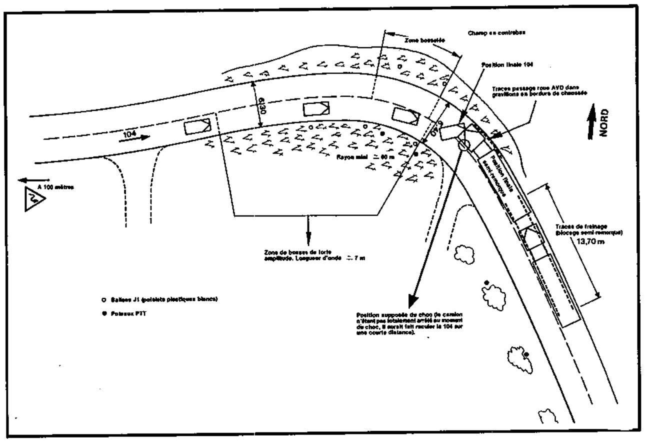


Figure 7. Plan of the Accident "Peugeot 104 - Semi-trailer"

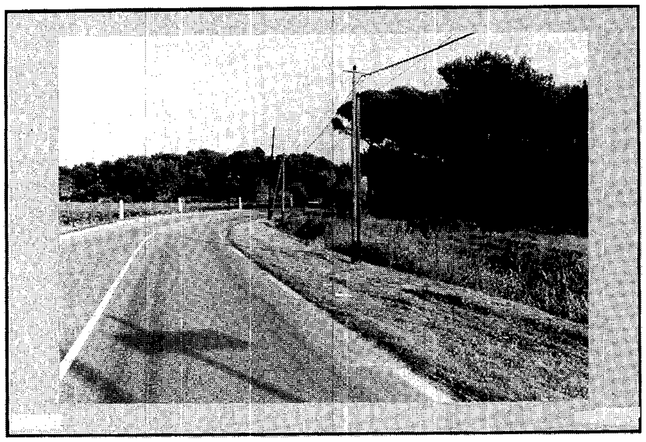


Figure 8. General View of Curve with a Vehicle Arriving in the Sense of the Semi-trailer (75 Meters Distance, 3.2 Sec. Before the Collision)

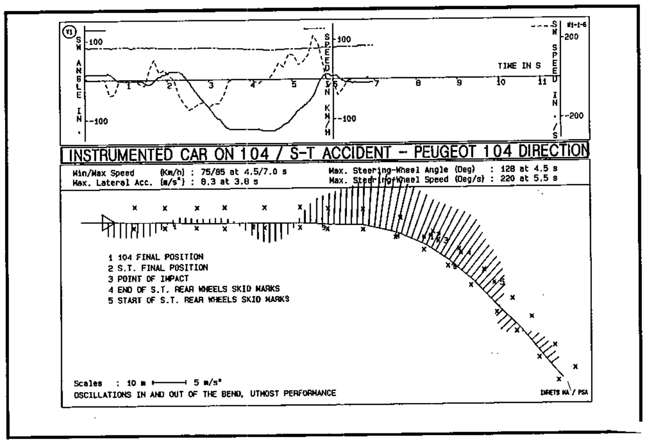


Figure 9. Measured Dynamic State

Kinematic reconstruction. The methodology used is shown in detail in the reference works (3) and (4). It is based on the cutting into sequences of the movement of each vehicle and to these sequences are applied simple kinematic models (constant speed or constant acceleration movements).

The analysis of the impact and the post-impact paths which enable the speed before impact of each vehicle to be calculated, is carried out by balancing out the momentum and kinetic energy conservation equations.

Speeds after impact are re-calculated by applying decelerations to the post-impact vehicle paths. Energy dissipated in deformation is quantified in the form of ETS (Equivalent Test Speed) by comparing photographs of the damaged vehicles with reference tests carried out under controlled conditions.

Then the pre-collision phase is reconstructed by applying a deceleration factor to the semitrailer's skid marks, and by evaluating the approach movement characteristics of the 104, when it slows and then brakes. The following summary tables show the different conditions of the two vehicles in the 2.5 seconds which preceded impact.

Time in seconds	semi-trailer events	Distance in m	Speed in kph
0	Impact	0.0	15.0
1		5.7	25.8
1.7	Start of skid marks	11.2	33.1
2	Start of braking	14.3	36.6
2.5	Sees 104 loss of control	19.4	36.6

Time in seconds	104 events	Distance in m	Speed in kph
0	Impact	0.0	40.0
1	Start of braking	13.1	54.4
1.7	Slowing down	24.2	59.4
2	Slowing down	29.2	61.6
2.5	Slowing down	38.0	65.0

We have checked at the scene of the accident that these data correlate with the reciprocal visibility distances. Figure 8 shows the maximum visibility for the 104 driver, around 75 m, which corresponds to 3.2 seconds before impact, taking into account the reconstructed speeds. The reconstruction diagram is shown in Figure 10.

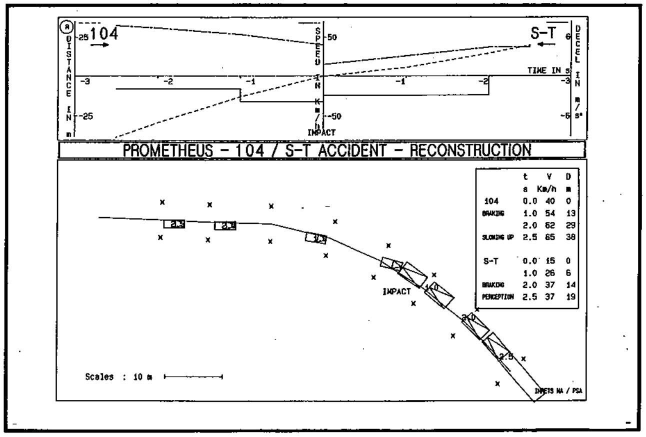


Figure 10. Results of Kinematic Reconstruction

Prevention strategies—conclusions. The main cause of the collision is the loss of control of the 104 on entering the bend. From the moment when the 104 strays into the semi-trailer's lane, no action by the semi-trailer driver can avoid the accident happening.

- He very quickly brakes as soon as he sees the danger of the situation, but this action is shown to be insufficient. Even without the wheels locking, therefore with somewhat more efficient braking, the consequences would have been the same.
- In the absence of any proper verges (the field alongside the road being a good metre below), no lateral avoiding action is possible for the semi-trailer driver.

It should also be noted that the reduced visibility distance does not really play any part in the accident sequence, as the vehicles could see each other before the accident situation trigger factor, i.e. the fact that the 104 was not able to negotiate the bend, occurs.

Consequently, we should look to the 104 when considering possible action. For this vehicle we have reconstructed a speed of 65 kph, 2.5 seconds, and about 40 m before the point of impact, being the moment of actually entering the bend. Even if this speed is suitable on a dry surface, as has been shown by our test runs with instrumented vehicles, it is too fast to allow the 104 driver to negotiate the bend on a wet surface and leads to the loss of control.

Any safety measures must therefore have as a primary objective preventing the loss of control by the 104. Three levels of intervention can be considered:

- *Level 1:* preventing the accident situation from occurring:
  - by warning of the bend difficulty, by increasing pre-bend warning signs, even by introducing an on-board device producing a warning sound for the driver.
  - by recommending a suitable bend speed, compatible with the reduced ground friction caused by the falling rain.
- *Level 2:* attempting to recover a hazardous situation:
  - by preventing the driver from carrying out a combination of unfortunate actions (wild steering movements—braking with locked wheels), which led the 104 to throw itself towards the semi-trailer in a straight line path, whilst it could perhaps have been possible to retain control of the situation at this point. However, as in all cases where the situation calls for a high degree of urgency, the performance required from co-piloting actuating systems would be very high as well as the number of parameters to be controlled simultaneously (operating the controls in relation to available friction, path to be followed in relation to the evolution of the semi-trailer's position to regain the 1 04's original side of the road).
- *Level 3:* minimising the consequences of a hopeless situation:

- from a very quick examination of the emergency situation conditions, by researching whether any ultimate evasive action is feasible. In the present case, it could possibly be launching oneself into the field below to avoid colliding with the semi-trailer, as it can be seen that owing to its braking, it would have stopped 3 m after the point of impact. The consequences of such an action are however difficult to establish, even if one considers that they would be less drastic than those of an impact with a semi-trailer with a closing speed of 55 kph.

The interesting point arising from this detailed reconstruction work is that it shows that the complete accident sequence represents a very short period of time: here 2.5 s. separates the beginning of loss of control of the 104 and impact, and furthermore, it appears that criteria which enable positive confirmation of the loss of control can only be validated at a later stage. The performance objectives of driving assistance' systems in emergency situations consequently appear particularly ambitious.

Statement of Required Safety Measures

For the three accidents studied here:

- We have not met a case which justifies the implementation of vehicle to vehicle communication.
- Useful safety measures would be in terms of a single vehicle.
- The suggestion (a) (information arriving sufficiently early) or the automatic application (b) of a vehicle speed appropriate to the bend characteristics (curve radius, wet road).

For the two cases concerning the Peugeot 104 and the Fiat Regata:

- The suggestion of the timing (c) (and possibly the amplitude) of steering in all three cases, even better automatic steering application (d). (In fact, in the event of losing control in a bend with low dynamic stresses, we can see (refer to the paper by E. Girardot and P. Tardivon - "Simulation as a design aid" - ESV 1991) that the simple discontinuity of friction on road verges can create loss of control. By avoiding the right-hand wheels running on the verge the accident here can be avoided.)
- The indication of the presence of a vehicle (e) (even stronger in the case of a very wide vehicle) in the case of the Peugeot 104, leading the driver to foresee a safety margin in relation to his nominal path.

To satisfy the four functions (a) (b) (c) and (e), applying the vehicle infrastructure communication system ISIS, presented by PSA could represent a solution (refer to the paper "Interactive road signalling system ISIS" by L. de Vaulx - ESV 1991).

The function (d) could be satisfied by a device providing help to follow road markings, such as those which are presently being studied by some automobile manufacturers, including PSA.

Conclusion—Further Research

Although still incomplete, this study enabled us to list counter-measures adapted to several accident categories, and it also makes possible to state necessary performance levels.

The continuation of the work will cover the analysis and reconstruction of road junction accidents (INRETS-PROMETHEUS 1991 program) and complementary investigations on curve configurations different from those being presented here.

Bibliography

(1) C. Thomas, S. Koltchakian, C. Tariere, B. Tariere, C. Got and A. Patel, "Primary safety priorities in view to technical feasibility limits to secondary automotive safety." Proceedings of 23rd Fisita Congress, TURIN, 7-11 May 1990.

(2) D. Lechner, J.L. Jourdan, "Control strategies and road accidents." PROMETHEUS 1990 report published in January 1991 distribution restricted to the PROMETHEUS community.

(3) D. Lechner, F. Ferrandez. "Analysis and reconstruction of accident sequences," Technical paper no. 905121, Volume 1. Proceedings of XXIII FISITA Congress, Turin 1990 (p.931 to 939), May 1990.

(4) D. Lechner, with the participation of G. Malaterre and D. Fleury. "The cinematic reconstruction of accidents." INRETS report no. 21, December 1986 (in French).

S4-W-16

Control Station for Moving Car

A. Clerc
INRETS

A New Approach to Motor Vehicle Check-Up

In most European countries today, all vehicles are obliged to pass a partial check-up since many accidents are due to a poor condition of the vehicle. This type of control was first established in Germany and Switzerland. France has now aligned itself along these rules, and cars older than 5 years must periodically undergo a partial test. This kind of periodic control is effective for the defects on the chassis, for example a rusty side sill, but cannot prevent components from wearing out quickly; tyres for example can be changed every six months. For this reason, the periodic control must be completed with a systematic control on vehicles about to be driven at high speed on a motorway.

It is evident that this local control must be carried out without loss of time for the drivers and apparently free of charge. The ideal location for this control is at a toll station at the entry of a motorway. The vehicles are in one file and the speed can be limited at 60 km/h. The drivers can be informed of the results by means of a panel with a changeable message system. In the near future it is possible to envisage a direct dialogue between the fixed station and the car. In the more comfortable design, the measured values are displayed and compared with preset values. If the difference between the two values is too important, a red light switches on in front of the defective function.

These sensors are fixed on the road side and the good working is verified automatically by the statistic results. For the more luxurious and expensive car the same functions (pressure of tyre for example) can be controlled by an in-car sensor, which can also be checked for adjustment by the road side sensor.

New Juridistic Framework for the Security Service

The technical development of the control station should be linked to a new thought on the duty of motorway companies. The following questions should be considered:

- Who takes charge of the control station—the Ministry of Transport, the traffic police, the motorway companies?
- In countries where the motorways are free of charge, is it possible and efficient to install the control station on a gas-station or rest area?
- Who is responsible for maintaining the proper working condition of the sensors?
- Must the instrumentation be standardized?

Morally the control station for moving cars should be installed quickly, but to avoid administrative problems a juridistic framework of the control station should be undertaken on a political level.

General Features of the Control Station

The car must enter into a single file under a speed of 60 km/h. The control must be efficient during the most usual type of meteorological conditions such as rain, ice, and wind, both day and night. The maintenance period is once every 3 years for the sensors.

The incomplete list of parameters defines the security of the vehicle which is as follows. The INRETS can propose new solutions which have been subject to patent procedures and which are well adapted to the problem of the control station for moving cars:

- sagging rate of tyre
- dumping
- wear of tyres
- direction of projector
- weight
- brake equilibrium.

This station can also usefully verify parameters in other fields:

- geometrical parameters
  - speed (device patented by INRETS)
  - length (device patented by INRETS)
  - width
  - height
- green parameters
  - noise
  - opacity of exhaust fumes.

The set of primary parameters are communicated in the central processor of the station. A particular algorithm corrects every parameter; for example, the sagging rate of tyres is corrected by the forces of acceleration. At the end of this calculation secondary parameters are calculated and a general level of security is presented to the driver. The result must be understood clearly and rapidly.

The more innovating sensor (i.e., the sagging rate and the wear of tyres) is now ready for an on-site test run test on a real location. The other devices can be progressively added to in the first station.

Device to Measure the Wear of Tyres

Since 18 July 1989 a European directive recommends all states to comply with a maximum degree of tyre wear wherein the depth of a tyre must not be less than 1.6 mm. From the 1st of January 1992 that rule will become compulsory in France and will be applicable as soon as the decree has been published. From now on the rule will be uniform throughout Europe.

At 90 km/hour on dry ground, a distance of 69 meters is needed in order to stop with tyres worn at 1 mm (sculpture depth), against 64 meters with tyres worn at 1.6 mm. Morality: the new rule gains 5 meters and this is, sometimes, sufficient to avoid a catastrophe.

INRETS offers an apparatus that can read the wear of tyres of a car (up to a moving speed of 60 km/hour!) with a good accuracy. The apparatus is built into a water-proof box under the road surface indicated by a slit in the road. When a car passes over these slits, a luminous beam, originating from a laser, is reflected on the tyre. The operation only lasts 1/100 second, but is sufficient to analyse the reflected beam image and deduce the state of the tyre wear. The apparatus functions in all climatic conditions.

The device has 2 little doors that open when the tyre passes over the slits and then close by pneumatic means such as a mechanical lid. The time in which the optical components become soiled is therefore minimum. The box is under slight pressure of air such that when the lid opens a jet of air prevents soil from entering into the system.

A prototype has been built and has given satisfaction. Apart from measuring the depth of tyres, the device also states the width of the tyre and distance between the front tyres and back tyres. These values can be used with those the device provides for sagging rate. It is possible to identify every vehicle by this tyre print on the carriageway.

Device to Measure the Tyre's Pressure

Pressure and sagging rate. When a tyre is in use on the road, its material wears. The rubber compresses on the ground, and the tread sags. This cyclical work has a sensitive manifestation—overheating—and an internal consequence—the continuous and irremediable reduction of coherence in the tyre material. The magnitude of this internal destruction is a function of the instantaneous state and former use of the tyre and represents the probability of a burst tyre, which we may define as a danger of the tyre.

In a first analysis, the radial compression of the rubber is linked to the tyre pressure, and the bending level is linked with the sagging rate. These two variables are a function of the vertical load applied to the tyre.

In road use, where the tyre pressure is on the order of 2 kg per cm^2, sagging is the principal cause of a temperature rise and forms the main parameter to be supervised.

Principle and composition of sensor. The sensor is composed of 3 light transmitters-receivers and 3 retro-reflecting targets facing each other. These three optical links cross the traffic lane at the level of the bearing zone of the tyres on the ground. The three light beams aim at the circumference of an average tyre. The first and the last beam, cut by the tyre, are placed at a height of 8 cm over the ground (H1 = 8 cm). The second beam is placed as close to the ground as possible. Taking into account the defects of evenness, a height of 1 cm forms an average compromise (H2 = 1 cm).

The timing of the cutting instants of these beams permits the values of the tyre cords to be calculated at the heights of 8 cm and 1 cm. The value of the sagging rate is deduced from the measures of these cords. The sensitivity of these cords during deflation is even greater when they are near the ground.

A laser of a useful power of 1 milliwatt forms a light source whose intensity and range are sufficient. Helium neon lasers today have a long life and are inexpensive.

A microprocessor associated with the sensor makes the following calculations:

- calculation of the sagging rate and the radius
- calculation of the sagging rate deviation on the same axle
- calculation of wheelbase of the vehicle
- axle count.

A device of visualization of the results will be placed close to the driver's field of vision.

Using the calculation of the wheelbase; it is possible to classify the vehicles into three categories:

- passenger cars
- delivery vans
- heavy goods vehicles.

For each of these categories, the "ideal" sagging rate is close to 20%, 18% and 15% respectively. The alarm threshold will be fixed at 20% above these values, or 24%, 21% and 19% respectively. A danger message will be displayed when these thresholds are exceeded.

Device to Measure the Dumping

The principle is the successive measurement of sagging rate with two sensors identical to the previous one, placed side by side, when the vehicle clears an obstacle.

Device to Measure the Weight

Today, there are many kinds of device which can measure the weight, but they are not well adapted to this control station for moving cars. The problem is specific: the measure of weight must take advantage of the rigid structure which is installed in the ground for measuring the wear of tyre. The width, the lateral position and the speed of car are known. The best solution is to combine a mechanical flexion and an optical sensor to measure the elongation. A prototype will be shortly build by INRETS.

Direction of projector. This device requires a slight modification of the projector, wherein a small reflecting surface is fixed in relation with the optical axle of the projector. A laser fixed on the bracket above the passage way scans this mirror and can control the direction of the projector. While the measures are linked with a microprocessor, it is possible to obtain the dynamic curve and the position of vehicle in this path, which can correct the parameter security. For example the dynamic charge must correct the sagging of tyre and the value of angle of projector. For every projector it is possible to calculate the angle of the projector projected on the horizontal and vertical surface.

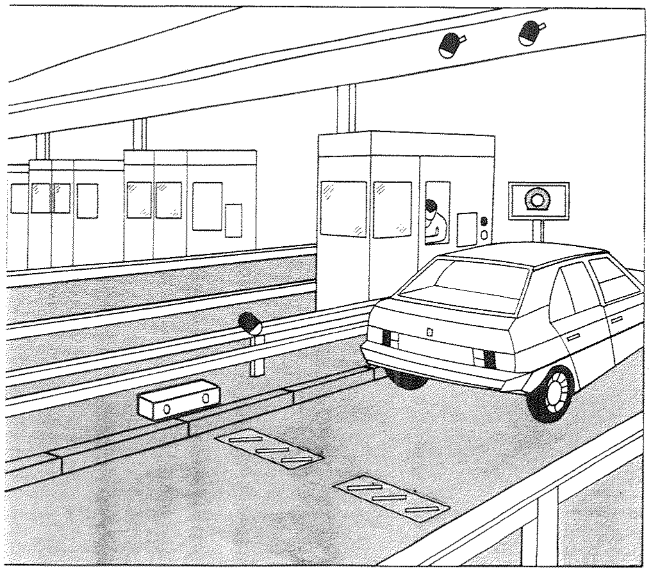


Figure 1. Control Station for Moving Car

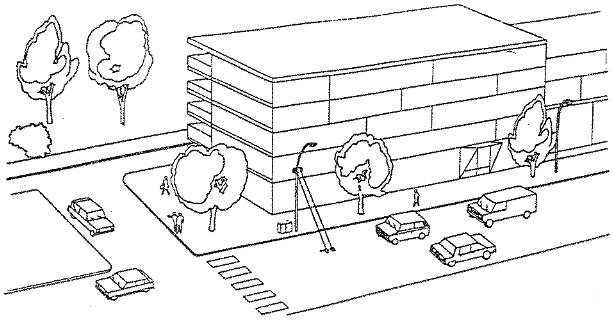
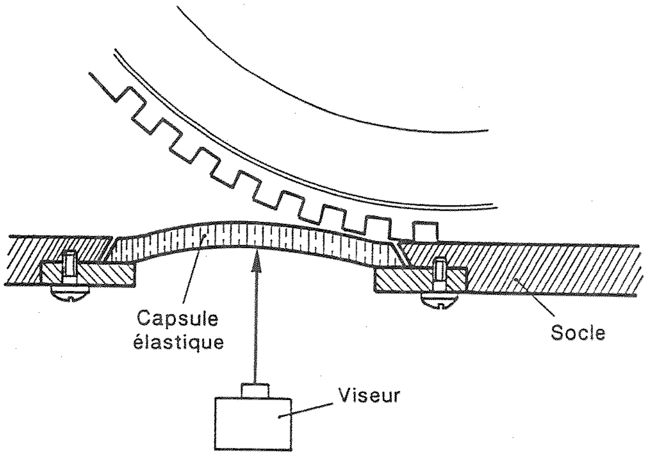


Figure 2. Sensor Laser to Measure Length and Speed of Vehicle



Point de lecture de pression

Figure 3. Sensor to Measure Weight of Vehicle

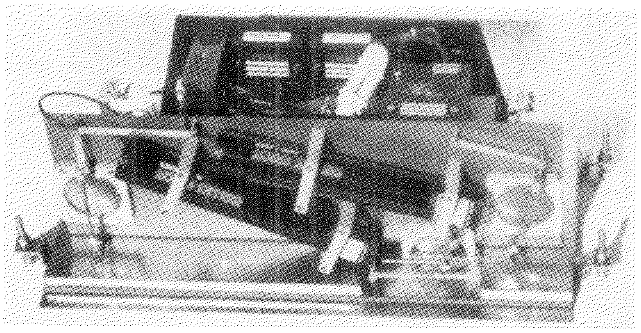


Figure 4. Device to Measure Pressure on Moving Car: Sensor for Sagging Rate

Figure 5. Test of Sensor with Motorway Companies (COFIROUTE)

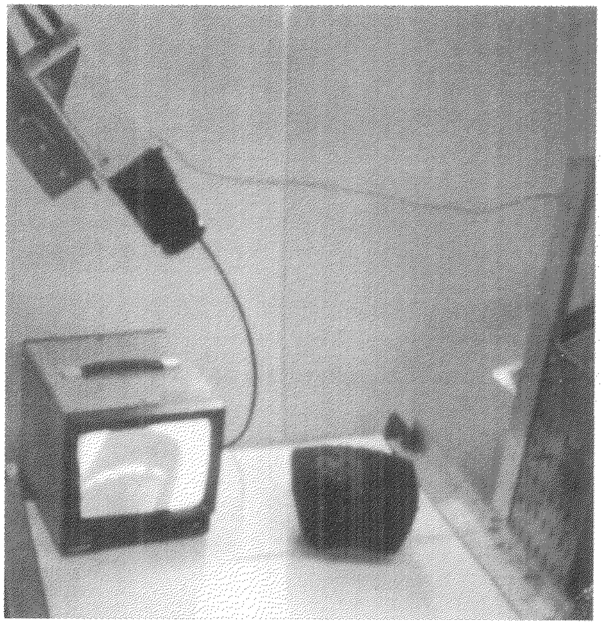


Figure 6. Measure of Wear for Tyres: Principle—3D Analysis

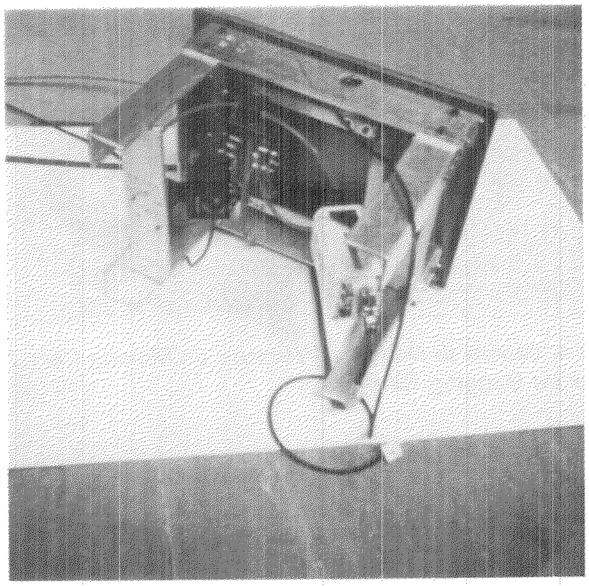


Figure 7. Sensor of Wear

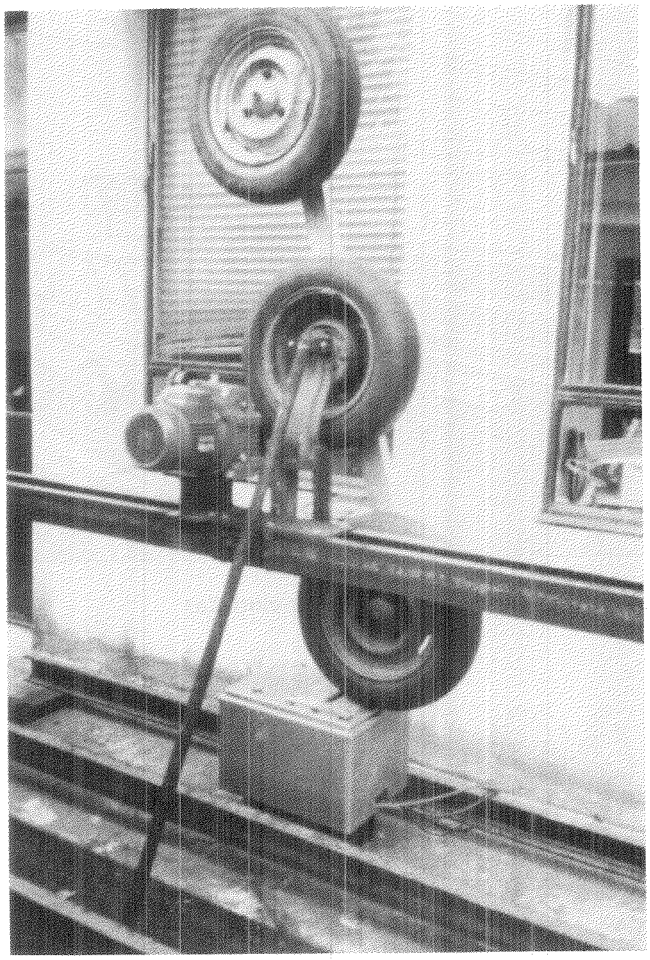
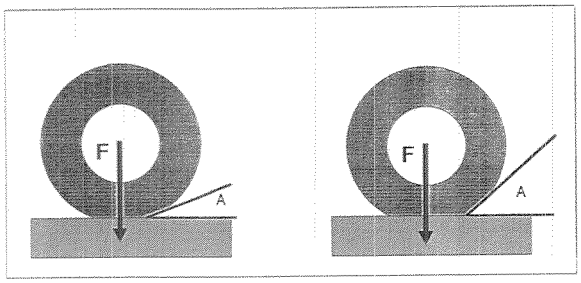


Figure 8. Test Bench for Sensor of Wear



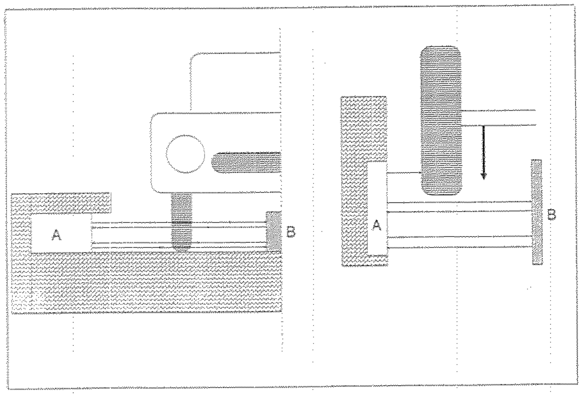


Figure 9. Measure of Sagging Rate of Tyre

S4-W-17

Analysis of EOG and EEG Signals to Detect Lapses of Alertness in Car Driving Simulation

S. Planque, D. Chaput, C. Petit,
C. Tarrière, C. Chabanon
Renault

Abstract

The Department of Environmental Sciences at Renault is designing a system for detecting lapses of driver alertness. This system, mounted on board the vehicle, will be designed to warn the driver of any deterioration in his state of alertness. The principle is based on the analysis, in real time, of movements lent by the driver to his steering wheel. The design of such a system requires a study phase in order to know at any time the alertness level of the subject on the basis of physiological signals, so as to be able to determine the parameters derived from the steering-wheel angle signal which, by themselves, will be most suitable for distinguishing between two states of alertness. We describe here a method for defining a physiological reference for the driver's alertness level.

Fatigue is responsible for 26% of the fatal crashes occurring on the motorway in France. The loss of control of the vehicle can be the consequence of drowsiness not perceived by the driver sufficiently early, in spite of the existence of numerous signs which are the precursors of such a state. The Department of Environmental Sciences at Renault is at present designing an on-board system for detecting lapses of driver alertness, the purpose of which is to notify the driver as early as possible of any deterioration in his state of alertness. This driving aid system should not require of the driver any additional task specific to alertness monitoring, but must be inherent in the task of driving. The principle is based on the real-time analysis of movements lent by the driver to his steering wheel. A microprocessor constantly compares the values adopted by certain parameters derived from the steering-wheel angle signal, with the values of a so-called "high alertness" reference, recorded for example at the start of the circuit. The selected parameters must be characteristic of the differences existing between a high alertness signal and a low alertness signal. They must, in particular, highlight any changes in the precision of directional corrections. This system is described in more detail in some of our earlier publications [1].

Here, we shall deal rather with the study phase aimed at obtaining a reliable physiological reference for the driver's alertness level. This level must be known objectively to be able to determine the parameters derived from the steering-wheel angle signal, following fluctuations of alertness as closely as possible. We shall therefore describe a method for analysis of physiological signals indicating the alertness level, from recordings performed on driving simulator.

Choice of Physiological Indexes

Many authors have described the changes occurring, in particular, on the electroencephalographic signals (EEG) and electro-oculographic signals (EOG) as alertness decreases.

The EEG signal is conventionally used as an indicator of the subject's alertness level [2], [3], [4]. Sharp changes in the frequency content of this signal are observed during the passage from alertness to a stage of hypoalertness, then to drowsiness and finally sleep. For the hypoalertness and drowsiness stages which interest us, analysis of the beta (12 to 25 Hz), alpha (8 to 12 Hz) and theta (4 to 8 Hz) frequency bands seems the most appropriate method. A slowdown of the cerebral waves, expressed by an increase in the percentage of alpha waves to the detriment of beta waves which characterize active waking, is observed concomitantly with a decline in performance. The correlations between performance and the EEG indexes are significant: they are positive for beta activity and negative for alpha and theta activities.

The characteristics of the EOG signal also change greatly with the alertness level [3], [5], [6], [7]. Slow eye movements (SEM) prove to be one of the most characteristic signs of the phase of transition between waking and sleep. Such movements, which are different from the voluntary eye movements in waking subjects, are described as pendular movements from left to right [6] and are associated with a convergence of the eyes. On the EOG signal, they are translated by slow deflections lasting more than a second and of amplitude at least 100 microvolts [5]. Their detection is optimized by the use of horizontal or oblique EOG measuring channels, which are very sensitive to fine variations in alertness [7]. Numerous SEMs are detected during stage 1 of sleep, but they also appear during the long period separating waking from sleep [6]. Their amplitude is moderate initially, but increases with the degree of drowsiness [3]. On train drivers making long trips, it was noted that the proportion of SEMs increased sharply with the advent of drowsiness, while the number of blinks decreased [5]. Studies in laboratory have shown that the percentage of SEMs increases continuously during the entire period of waking prior to stage 1 of sleep, that it remains constantly high throughout stage 1, and then decreases during stage 2 [6]. Other authors describe waking ocular activities as pronounced, quick and very frequent movements (blinks, small saccadic movements). At the start of the transition period, there are slow eye movements of medium amplitude, and the frequency of blinking decreases. The real stage of drowsiness is characterized by SEMs of large amplitude [7]. The transition between the state of waking and stage 1 of sleep is therefore punctuated by a sequence of ocular events, the first symptom of which is the disappearance of movements characteristic of the state of active waking.

It seems, therefore, that a correct definition of this transition period cannot be based on the EEG signal only, and that simultaneous analysis of the EOG signal is essential to obtain a reliable electrophysiological definition [3].

Experiments

The tests were carried out on the driving simulator of the VTI (Vehicle Traffic Institute) in Sweden, to obtain, with no danger and in a short time, marked lapses of alertness. This simulator, with 4 degrees of freedom, allowed the subjects to feel impressions similar to those of real driving conditions.

27 subjects aged between 22 and 56 (mean = 30.5, standard deviation = 8.18), including 16 males and 11 females, were selected for their propensity to emit alpha waves with their eyes closed. The maximum driving time was stipulated as 2h30, but this time could be shorter if the subject left the road for a long time, thereby stopping the simulator. A film of a monotonous dual-carriageway road, with no intersections or other vehicles, consisting of long straight sections and corners of small radius of curvature, produced by means of composite images, was projected to the test subjects. The instructions were to keep the vehicle in the right-hand lane at a speed ranging between 100 and 120 km/h.

Two series of signals were recorded on magnetic tape:

- mechanical signals, which are not dealt with in this article: steering-wheel angle, steering-wheel torque, road curves, lateral position of the vehicle;
- physiological signals: 2 parietooccipital EEG channels, 2 EOG channels (vertical and oblique).

In addition, the driver's face was filmed by a camera to study signs of fatigue through facial expressions.

We thus have a large data bank which allows us, first, to establish a physiological reference for the driver's alertness level. Many subjects fell asleep at the end of the experiment, thus making it possible to study all stages of alertness between waking and sleep.

Results

We describe here a method making it possible to characterize the alertness level of the subject. This is based on the analysis of, on the one hand, the EEG and EOG signals which, as we saw previously, contain a large part of the desired information, and on the other hand the video film of the driver's facial expressions. The association of these three sources of information should make it possible to obtain reliable access to the desired level of alertness. This method is completely manual, with no effort being made to perform automatic analysis. Automatic processing of the EEG signal, and especially the EOG signal, has proved very hard to implement. Nowadays, the various phases of sleep are identified automatically through several physiological signals, but here we are looking for phenomena that are much less marked than sleep, and which are the very first signs of diminished alertness. Now, to our knowledge, there is at present no reliable automatic system for early detection of lapses of alertness. Moreover, our physiological reference is established off-line, in the laboratory, and concerns only the study phase of our project, since the final system will be based exclusively on the recording of mechanical parameters. Since there is no time constraint for definition of the reference, we therefore prefer to use a manual method for analysis of physiological signals. Although it is slower, this method provides more reliable results than automatic processing.

The method involves first studying in detail the video film of facial expressions; this film contains a wealth of information and includes a large number of behavioural indexes allowing a description of the alertness level. All the information collected during this analysis is then recorded, corresponding to the exact times, on the paper plot of the EEG and EOG signals (analogue signals). At any time, therefore, we can have the correspondence between these signals and behavioural aspects. An analysis of the EOG and EEG signals is then performed using the criteria described previously. This set of results allows definition of a classification by four levels of alertness. An additional criterion, based on analysis of the secondary task of maintaining speed, is used to confirm the previous information.

Behavioural Aspects and Facial Expressions

The video film is centred on the face of the subject. The arms are also visible. The behaviour of the subject changes sharply during the experiment. At the start of the test, the subject is concentrated on his tasks: maintaining the trajectory and maintaining the set speed value.

He looks either at the road, or the speedometer. He sits upright, with both hands on the steering wheel. These are periods of high activity, during which the subject is tonic, especially during the phase of task learning.

Fairly quickly, his behaviour changes (after about 20 minutes' driving), and one observes various phenomena which appear increasingly frequently:

- Movements on the seat: bearing against the seat back or the head restraint, straightening actions, changes of posture;
- Arm movements: change in the position of the hands on the steering wheel;

- Self-centred movements: the subject tends to bring his hands back towards himself (scratching his nose, cheek, etc.);
- Head movements: the head sometimes drops from fatigue;
- Yawning and sighs;
- Other phenomena, such as movements of the lips, or periods remaining completely motionless.

All these behavioural indexes provide a huge amount of information concerning the subject's alertness level. The changes of posture seem to be signs of self-stimulation: the subject tries to pull himself together after a spell of hypoalertness. At the end of the test, these stimulations represent a struggle to ward off sleep. They occur increasingly frequently as time goes by. The self-centred movements are the precursory signs of a state of hypoalertness. They are first merely signs of weariness, and then, later, of drowsiness.

Analysis of the EEG Signal

The analysis is performed in conventional manner. The appearance of drowsiness is indicated chronologically by a decrease in the rate of beta waves, followed by the appearance of alpha waves, and then their gradual disappearance and replacement by theta waves.

Analysis of the EOG Signal

The deflections observed on the EOG signal can be explained, in the event of interpretation problems, thanks to the video film.

All the following events can be identified on the EOG signal during a test:

- blinks;
- closing of the eyelids;
- glancing to the right or left;
- glancing at the speedometer;
- rotation of the eyes during spells of hypoalertness (associated or not with SEMs).

The steepness of the signal's rising and falling edges provides information on the speed of the movements. This index is generally a good indicator of the alertness level. Figure 1 shows typical examples of some eye movements.

The nature of the ocular events changes greatly with alertness. A chart of high alertness includes only blinks and glances at the speedometer. The movements are quick, and the rising and falling edges are almost vertical. In low alertness, the chart is more complex, because various eye movements are combined with one another. Blinks give way to closing of the eyelids. All the ocular patterns are deformed. The movements become slow and the eyes move perpetually in a struggle to ward off sleep. SEMs appear.

Between these two stages, the changes are gradual. By analyzing the EOG, it is therefore possible to follow clearly the deterioration of alertness. Figure 2 clearly illustrates the appearance of hypoalertness.

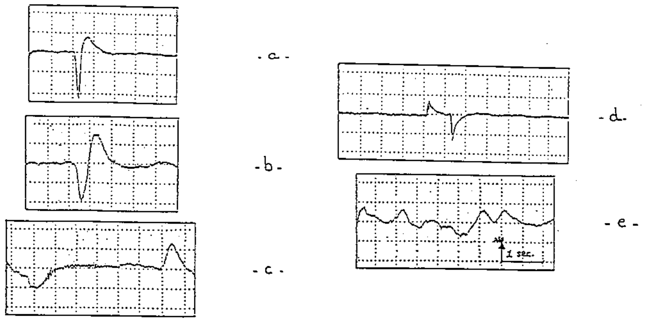


Figure 1. The Various Eye Movements Translated on the EOG Signal

a - blink; b - closing of eyelids with eyes remaining closed for a very short time; c - closing of eyelid for more than 2.5 sec.; d - check on speedometer; e - rotation of the eyes during a spell of hypoalertness, associated with partial closing of the eyes.

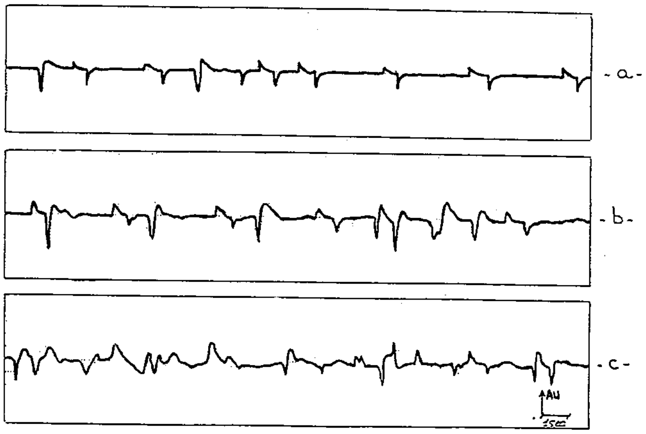


Figure 2. EOG Signal

a - after 5 min 46 sec; b - after 30 min 13 sec; c - after 1 h 8 min 22 sec of driving (the subject falling asleep after 1 h 10 min of testing).

Figure 3 shows, for a subject who fell asleep after 1h 10 min of testing, the change in the number of blinks (3a) and in the eye closing time (3b). The number of blinks decreases at the end of the test, but this index is hard to exploit because it shows temporary recoveries which may be interpreted as self-stimulation reactions. Moreover, this index is liable to undergo excessive inter-subject variations. The eye closing time (definite closing other than blinks), on the other hand, is very characteristic of the alertness level: the first eye closings are especially revealing of a state of hypoalertness. This index then rises continuously until the end of the test.

Additional Decision-Making Criterion

The main task required of the subject was to maintain his trajectory in the right-hand lane. Since the purpose of the study is to process the steering-wheel angle signal, the physiological reference must not be established based on the analysis of this task. On the other hand, we define

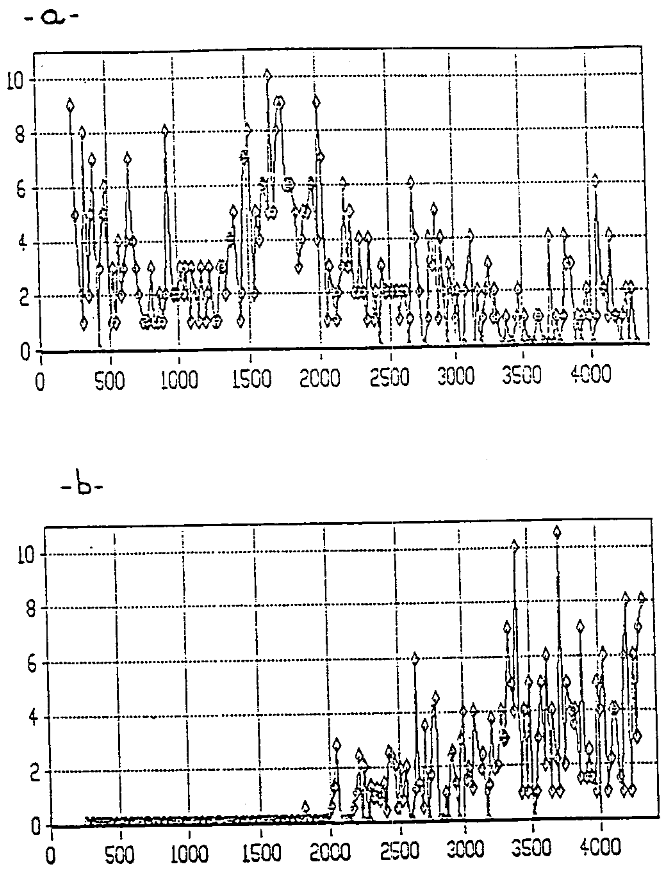


Figure 3. Changes in Number of Blinks and Eye Closing Time

a - number of blinks; b - eye closing time. Each point: 21.5 sec. Subject fell asleep after 1 h 10 min of testing.

as a secondary task the maintaining of speed between 100 and 120 km/h, and we can observe whether this set point is complied with in order to confirm the subject's alertness level. Figure 4 shows the change in the number of glances at the speedometer. This number decreases sharply during the test, indicating that the driver is less and less attentive to maintaining his speed. This is always confirmed on the speed signal, whose variability increases with time.

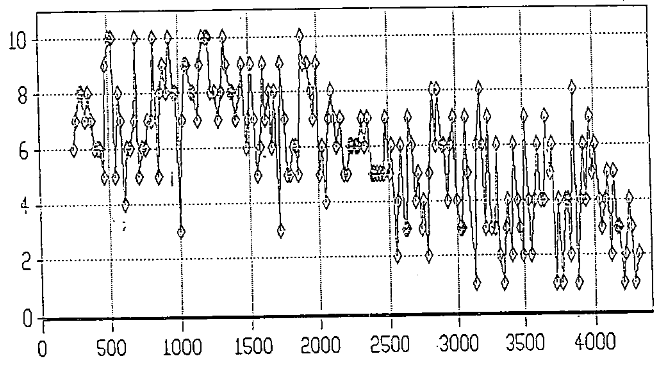


Figure 4. Change in the Number of Speedometer Checks

Each point: 21.5 sec. Subject fell asleep after 1 h 10 min of testing.

Establishment of the Physiological Reference by Classification into Various Levels of Alertness

This classification must be established continuously throughout the test, so as to know the alertness level of the driver at any time. We define 4 levels:

- Level 1: High alertness. The driver is in full possession of his faculties
- Level 2: Level of early hypoalertness
- Level 3: Level of marked hypoalertness
- Level 4: Final stage. The driver seems to be sleeping.

The establishment of these classifications provides the expected results: the start of the test consists uniquely of level 1, then level 2 appears gradually, becomes general and is in turn replaced by level 3. The ends of tests are characterized by a more or less large proportion of level 4 states, depending on whether the driver has left the road or not.

Processing of the Steering-wheel Angle Signal

The mathematical functions developed by us [1] on the basis of the steering-wheel angle signal also change in the expected direction. Their gradual increase during the test proves that the selected parameters (amplitude and counts) follow variations of alertness [Figure 5], in the same way as the physiological classification. It now remains to establish the correlation existing between the physiological reference and these functions. This is being carried out for the 27 subjects.

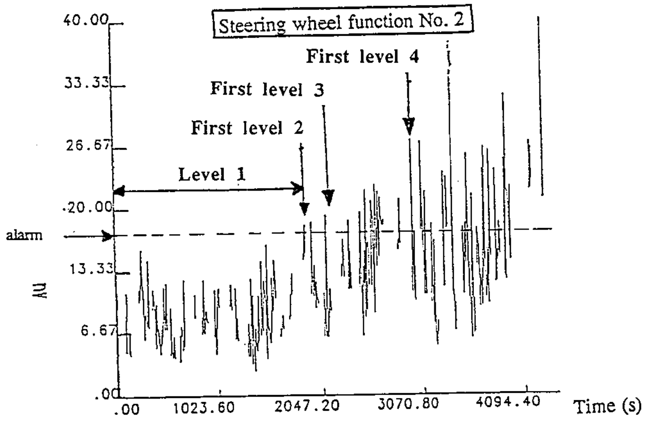


Figure 5. Steering Wheel Function for the Same Subject as Before

The zero values correspond to corners.

However, before carrying out a comprehensive statistical study, we can report certain intermediate results in terms of the functionality of the end system. The three steering-wheel functions are computed continuously throughout the test and set opposite the physiological classification. For the subject in Figure 5, who fell asleep after 1h 10 min of driving, it would have been possible, with steering-wheel function No. 2 and using a suitably selected alarm triggering threshold, to obtain satisfactory results for early detection of hypoalertness. By setting a threshold of 18, the alarm can be triggered at the first appearance of hypoalertness level 2, without any false alarm beforehand on high alertness level 1 [Figure 5]. Since the subject's hypoalertness state then increases continuously, it can be observed that the system would have alerted him regularly, especially at the initial appearance of level 3, and of course level 4.

The physiological classification performed thus makes it possible to obtain good hypoalertness detection through the steering-wheel angle signal. This physiological reference, compiled from the video film and the EEG, EOG and speed signals, is very worthwhile here, because the results obtained with a reference based exclusively on analysis of the EEG signal were far more mediocre. With the latter reference, which is insufficiently precise, we were unable to select a suitable threshold so as to trigger an alarm at the first level 2, without any false alarm beforehand.

Prospects and Conclusion

Obtaining a reliable physiological reference for all tests performed on simulator is an essential step before undertaking processing of the steering-wheel angle signal. This classification inevitably involves subjective criteria, but the parameters selected are sufficiently reliable to allow a coherent decision to be made. Analysis takes a long time, but allows the remainder of the study to be approached with confidence. The aim is to detect, from the steering-wheel angle signal, hypoalertness level 2 (early detection). The techniques of pattern recognition (discriminant analysis with prior knowledge of the classes, for example) can allow us to extract from the steering-wheel angle signal the optimum parameters needed to detect level 2. The mathematical functions developed by us [1] from the steering-wheel angle signal will be tested in this way. As an initial step, level 1 and level 3 can be compared, and detection can then be refined by comparing level 1 and level 2, to ensure alarm triggering as early as possible.

References

1. S. Planque, C. Petit, D. Chaput, C. Tarriere, 1991. Un système de repérage des baisses de vigilance en conduite automobile, $3^{ème}$ conférence "Vigilance et Performances Psycho-Motrices" - ANNECY.
2. C. Tarriere, F. Harteman, M. Niarfeix, 1966. Recherche de correlation entre données de vigilance opérationnelles et physiologiques Bulletin 16, ONSER.
3. J. Santamaria, K.H. Chiappa, 1987. The EEG of drowsiness in normal adult. Raven Press, NY, vol. 4, no. 4, p. 887-894.
4. R.S. Daniel, 1967. Alpha and thêta EEG in vigilance. Perceptual and motor skills, 25, p. 697-703.
5. L. Torsvall, T. Akerstedt, 1988. Extreme sleepiness: quantification of EOG and EEG parameters Inter. J. Neuros., 38, p. 435-441.
6. Y. Hiroshige, Y. Niyata, 1990. Slow eye movements and transion period EEG sleep stages during daytime sleep. Shingigatu Kinky, vol. 6, no. 60, p. 378-385.
7. H. Berrichi, M. Tiberge, L. Arbus, 1990. Détection de la vigilance: enregistrement simultané des signaux EEG et EOG: etude préliminaire "Le maintien de la vigilance dans les transports" - Journées d'étude de l'INRETS LYON.

Technical Session 5
Side Impact Occupant Protection

Chairperson: Richard Lowne, United Kingdom   Co-Chairperson: Ian Neilson, United Kingdom

S5-O-01

Analysis of Dummy Readings Affected by Secondary Impact Point Intensity in Side Impact Tests

Tatsumasa Okamoto, Nobuhiko Takahashi
Nissan Motor Co., Ltd.

Abstract

In October 1990, the National Highway Traffic Safety Administration (NHTSA) in the United States issued Federal Motor Vehicle Safety Standard 214,(1)-(3) which specifies the occupant protection required in side impact crashes. This standard prescribes two dummy injury criteria for use in side impact tests—the thoracic trauma index (TTI) and maximum pelvis acceleration. Two major factors that are known to influence dummy injury criteria are the door intrusion velocity and secondary impact point intensity, i.e., the force-displacement characteristic of the door at the point of secondary impact with the dummy. The door intrusion velocity and the secondary impact point intensity are affected by such factors as the construction of the body side, door construction and firmness of the door padding.

This research focused on the maximum pelvis acceleration and an investigation was made of its relationship to the secondary impact point intensity. A force-displacement characteristic factor, η, at the secondary impact point was derived as an index for representing the secondary impact point intensity. The validity of η was confirmed by analyzing experimental data obtained in full scale tests. In addition, a new bench test procedure has been developed for assessing η in tests of door assemblies alone.

Introduction

Figure 1 shows typical velocity time histories measured for a moving deformable barrier (MDB), impacted door and dummy's pelvis in full scale tests conducted according to FMVSS 214 issued by the NHTSA in the U.S. The notations t_1, t_2, v_1 and v_2 in the figure represent the time of contact between the door and pelvis, the time of separation between the door and pelvis, the door intrusion velocity at t_1 and the velocity of the door and pelvis at t_2, respectively. In this study, the velocity of the MDB was used to represent the door velocity because of the difficulty of measuring the latter.(4)

The door impacts the pelvis at t_1 and at t_2 the velocity of the pelvis exceeds the door intrusion velocity and so the pelvis separates from the door. During this interval the dummy is accelerated from $v = 0$ to $v = v2$. The mean acceleration of the pelvis, Gmean, is equal to the slope of the increase in velocity that takes place from t1 to t2 and is given by

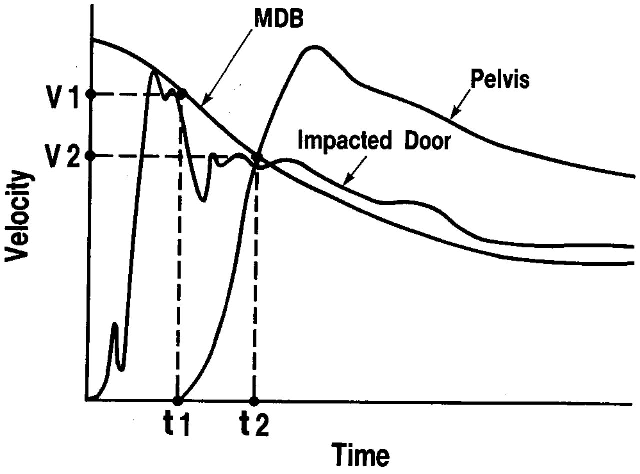


Figure 1. Velocity-Time History for MDB and Pelvis in Side Impact Test

$$\text{Gmean} = v_2/(t_2 - t_1) \qquad (1)$$

The ratio between the maximum acceleration of the pelvis, Gmax, and its mean acceleration, Gmean, is denoted here by α, which is given by

$$\alpha = \text{Gmean}/\text{Gmax} \qquad (2)$$

and thus we obtain

$$\text{Gmax} = 1/\alpha \cdot \text{Gmean} \qquad (3)$$

Multiplying the numerator and denominator of Eq. (2) by the effective mass of the pelvis, m, results in

$$\alpha = \text{Fmean}/\text{Fmax} \qquad (4)$$

This equation shows the relationship between the mean force and the maximum force received by the pelvis.

Most of the force applied to the pelvis comes from the force input of the intruding door. Consequently, the force-displacement characteristic of the door has a governing effect on α. Therefore, as an index for evaluating this characteristic, we will use the ratio of the maximum force received by the pelvis at the time of secondary impact to the mean force. These force values are found from the force-displacement curve between the door and the pelvis at that moment. This ratio, which is based on the same concept as α, is denoted here as η, and is referred to as the force-displacement characteristic factor of the door at the point of secondary impact.

The following sections will describe the method used to evaluate η and the results of full scale tests conducted to validate this index.

Analysis of η

Definition of η

Figure 2 shows how the factor η was defined in relation to the force-displacement curve for the door and the pelvis. As the value of η approaches 1, the force-displacement curve displays a rectangular waveform and, when η = 1, pelvis acceleration shows its minimum value.

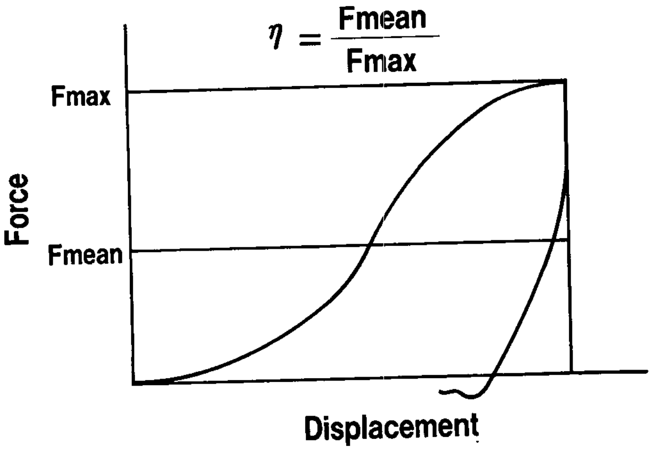


Figure 2. Definition of η

Examination of the Validity of η

A simple mass-spring model was used to investigate the validity of examining pelvis acceleration on the basis of η. As seen in Fig. 3, the model consisted of two masses and two springs. This simple construction was selected in order to examine as closely as possible the effect of η on pelvis acceleration. The pelvis mass was given a value equivalent to the dummy pelvis, and the door mass was estimated as the total of the door, the structure around the door and the MDB. One spring was provided for the door and the other spring represented the skin of the dummy's pelvis. The initial velocity input into the model was the door intrusion velocity measured in full scale tests at the moment of secondary impact.

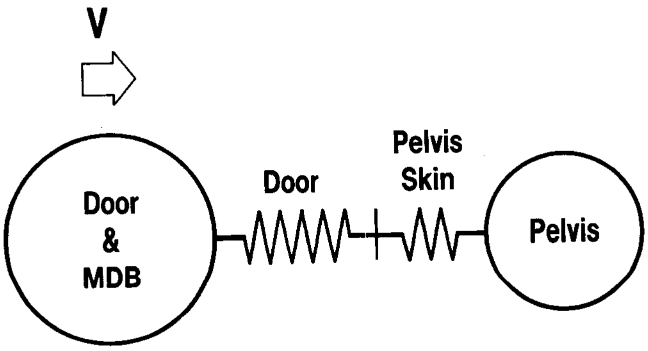


Figure 3. Mass-Spring Model

A force-displacement characteristic was input into the door spring of the model and calculations were carried out for different values of η. The level of absorbed energy was assumed to be constant as indicated in Fig. 4, and the waveform of the characteristic was varied between a triangular and a rectangular wave. An example of the results obtained is given in Fig. 5. It was confirmed that maximum pelvis acceleration decreased as the value of η increased.

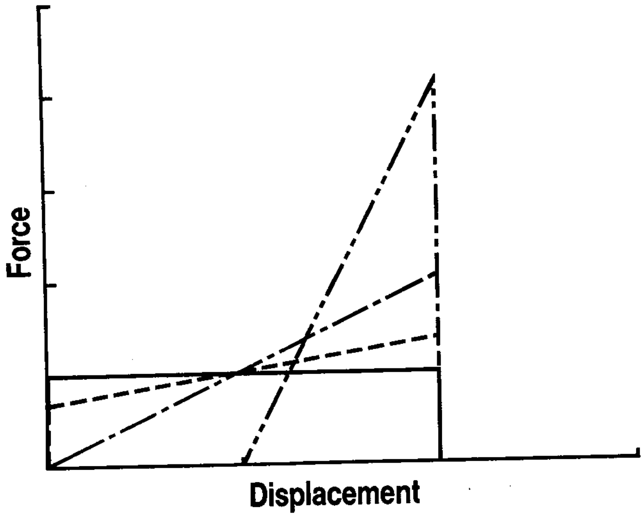


Figure 4. Force-Displacement Characteristics to the Door Input into Simulation Model

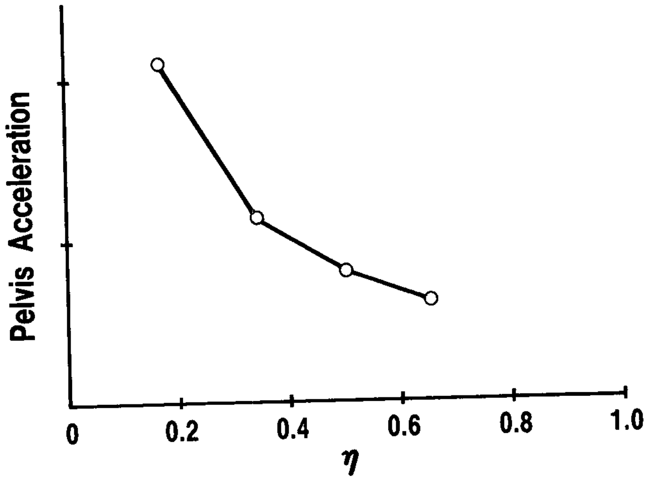


Figure 5. Calculation Results Obtained with Mass-Spring Model Showing the Relationship Between η **and Pelvis Acceleration**

Analysis of Full Scale Test Results

The results of full scale tests were then analyzed to investigate the relationship between η and pelvis acceleration. The experimental data that were analyzed were obtained in tests in which the dummy was sitting in the front seat. These tests were conducted according to the procedure specified in FMVSS 214. (1),(2),(3),(5)-(7)

In this analysis, the value of η was found from an acceleration-displacement curve determined by the relative displacement of the MDB and the pelvis and the pelvis acceleration. The moment of contact between the door and the dummy was detected using a switch attached to the dummy. The reference point for measuring door displacement was the point of contact between the front face of the barrier bumper and the door outer panel; the corresponding point for measuring pelvis displacement was the point where pelvis acceleration was measured (Fig. 6).

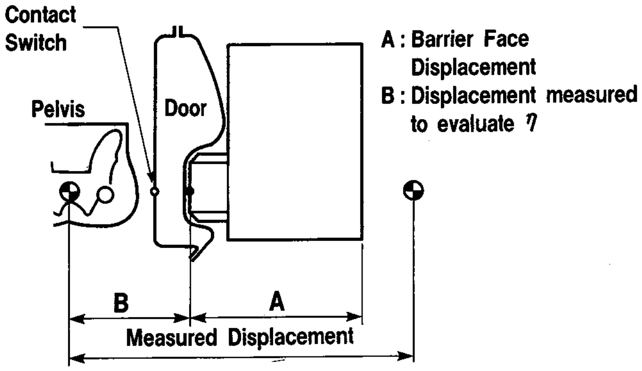


Figure 6. Measurement of Displacement in Full Scale Test

The crushing of the barrier face (A in Fig. 6) can become an error factor affecting dummy readings. An analysis of the full scale test results revealed that the barrier face was crushed about 10 mm during the interval of contact between the door and the pelvis. In view of this small value, it was not taken into account in this study. The measured signals were processed using a 300 Hz class 180 filter as specified in SAEJ 211.

The results of the analysis concerning the relationship between η and pelvis acceleration are given in Fig. 7. It is seen that pelvis acceleration tended to decrease with a larger η value. The correlation coefficient between η and pelvis acceleration was R = 0.72. This indicates that the contribution of η to pelvis acceleration was quite high.

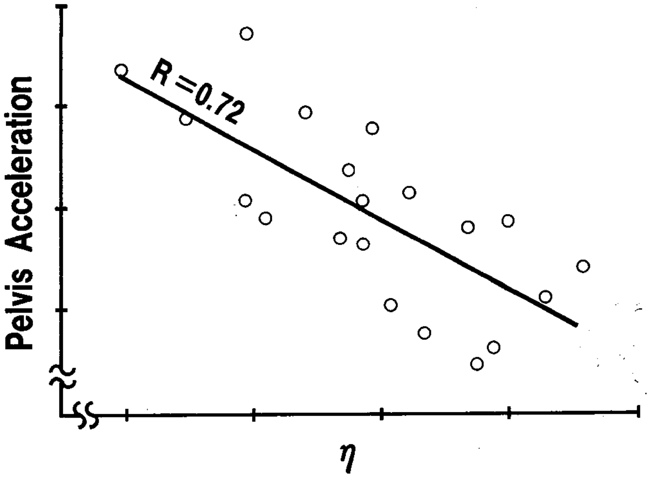


Figure 7. η vs. Pelvis Acceleration

The vehicles used in the full scale tests conducted in this work had different specifications with regard to the door construction, door length, wheelbase size and hip-point position. As a result, the relative positions of the door and pelvis, door construction at the point of secondary impact and other factors differed from one vehicle to another. Nonetheless, when the results were arranged in terms of η, good correlation was obtain regardless of such factors as the door construction, door length, and wheelbase size which tend to influence dummy readings. This confirmed that η is a valid index for examining the relationship between pelvis acceleration and secondary impact point intensity.

The present study was limited to an examination of the relationship with pelvis acceleration. Real-world side impacts, however, involve coupled phenomena that include both the pelvis and the chest area. Therefore, further study must be undertaken to confirm the validity of η as an evaluation index under such conditions.

Evaluation of η in Door Bench Tests

If the force deflection characteristic of the dummy pelvis is excluded, the value of η is determined solely by the secondary impact point intensity of the door. Bench tests of door assemblies alone were carried out to investigate η and the results were compared with the full scale test data.

The test procedure is illustrated in Fig. 8.(8),(9) A test setup for producing a secondary impact typical of a side crash was used to project the pelvis impactor.

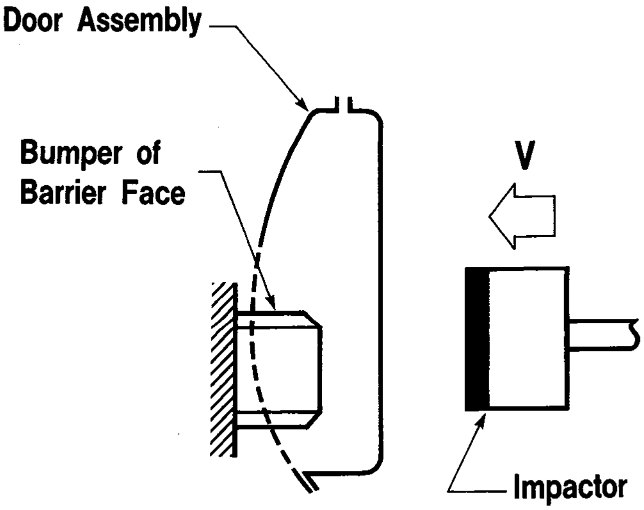


Figure 8. Bench Test Procedure

The front door was rigidly supported by jigs attached to the hinge and lock portions of the door. The degree to which the outer door panel would be crushed at the place of impact by the barrier bumper at t = t_1 was estimated from analyses of high-speed films of the full scale tests. The barrier bumper was then set at the estimated position of the door outer panel at t = t_1.

The impactor was designed to simulate the shape of the dummy's hipbone and the force-deflection characteristic of the pelvis skin. This type of impactor was used in order to achieve good correspondence with the method employed to analyze η in the full scale tests. The weight of the impactor, including the projection device, was equivalent to the pelvis mass. The velocity of the impactor was set to coincide with the door intrusion velocity, v_1, at the moment of contact between the door and the pelvis in the full scale tests. In setting the impactor velocity, consideration was given to the velocity dependence of the crush behavior of the plastic components in the door assembly including the door trim.

Figure 9 compares the acceleration-displacement curves obtained in the bench test and in a full scale test. In making this comparison, a correction was made for the difference between the energy ($1/2\ mv_2^2$) applied to the pelvis in the full scale test and the energy ($1/2\ mv_1^2$) applied to the door in the bench test. The shapes of the acceleration-displacement curves are nearly identical, indicating good correlation between the results of the two tests. The acceleration level in the vicinity where the load rose sharply was slightly higher in the bench test than in the full scale test, which is attributed to the effect of the difference in input energy.

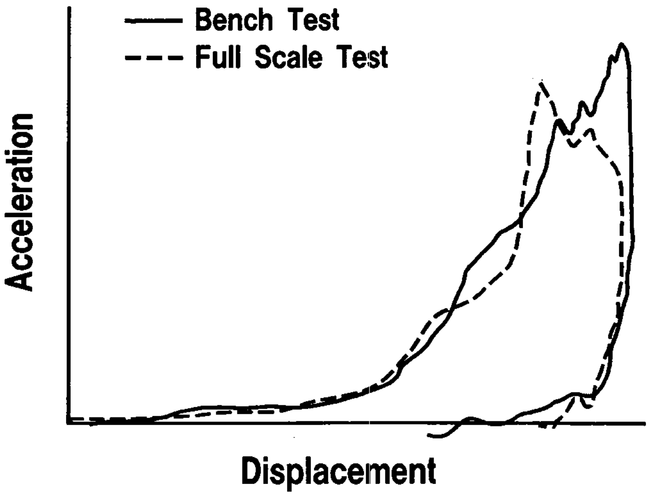


Figure 9. Force-Displacement Curves Obtained in Bench Test and Full Scale Test

The difference in input energy between the two tests was then corrected and the relationship between η in the bench test and η in the full scale test was determined. The results are shown in Fig. 10. Although the value of η in the bench test was somewhat smaller, good correlation is seen between the two sets of data. It can be concluded, therefore, that the bench test procedure reproduces with good accuracy the value of η obtained in full scale tests.

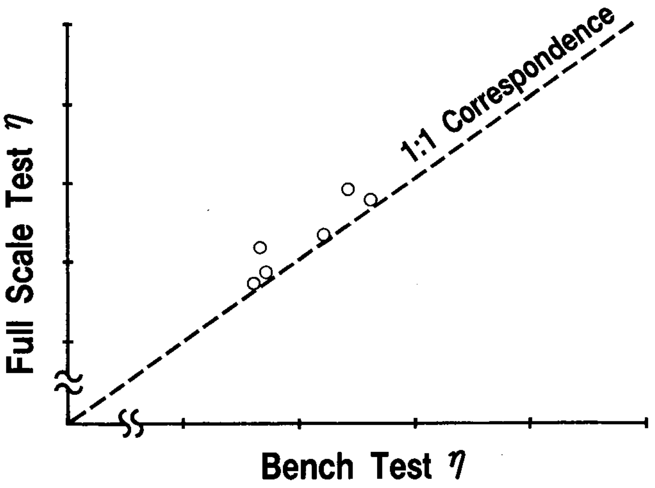


Figure 10. Comparison of η Values Obtained in Bench Test and Full Scale Test

Conclusion

(1) The force-displacement characteristic factor, η, at the point of secondary impact was derived as an index for examining the relationship between the secondary impact point intensity and pelvis acceleration. An analysis of full scale test results obtained with different vehicles showed good correlation between the tendencies displayed by η and pelvis acceleration. It was observed that pelvis acceleration decreased with an increasing η value. The same result was confirmed in mathematical simulations carried out with a simple mass-spring model. These results verified that η is a valid index for establishing a correlation between pelvis acceleration and the secondary impact point intensity.

(2) A simple bench test procedure has been developed for evaluating η at the secondary impact point in tests of door assemblies alone. The bench test results for η showed good correlation with the data obtained in full scale tests.

References

(1) "Federal Motor Vehicle Safety Standards; Side Impact Protection," NHTSA 49 CFR Part 571, Docket No. 88-06; Notice 8, 1990.

(2) "Side Impact Protection Anthropomorphic Test Dummy," NHTSA 49 CFR Part 572, Docket No. 88-07; Notice 3, 1990.

(3) "Side Impact Protection Moving Deformable Barrier," NHTSA 49 CFR Part 587, Docket No. 88-06; Notice 9, 1990.

(4) K. Watanabe and T. Yamaguchi, "Analysis of Factors Affecting Dummy Readings in Side Impact Tests," 12th ESV (1989).

(5) "Federal Motor Vehicle Safety Standards; Side Impact Protection," NHTSA 49 CFR Part 571, Docket No. 88-06; Notice 1, 1988.

(6) "Side Impact Anthropomorphic Test Dummy," NHTSA 49 CFR Part 572, Docket No. 88-07; Notice 1, 1988.

(7) "Set of Drawings for the NHTSA Side Impactor Prepared by Dynamic Science, Inc.," NHTSA, Docket No. 79-04 GR.

(8) "Preliminary Report of Door Impact Test," JAMA/JARI, ISO/TC22/SC10/WG1, N189A (1990).

(9) B. Richter, "The Composite Test Procedure (CTP)—State of the Art," 12th ESV (1989).

S5-O-03

The Effect of Door Structure on Occupant Injury in Side Impact

Hiroyuki Matsumoto, Hideaki Tanaka
Mazda Motor Corporation

Abstract

Employing the proposed NHTSA side impact test conditions, and utilizing MADYMO 3D computer simulation, this paper analyzes the performance of the DOT Side Impact Dummy (DOT-SID) subjected to various contact surfaces to the dummy. Based on the results, it was found that deformation characteristics, location of the door panel and the stiffness of the door have great influence on improving occupant injury indices. Simulation results are validated through the utilization of full scale crash tests as well as hyge sled tests.

Introduction

In order for side impact performance to be developed efficiently, it is important to procure and evaluate the effects of the door structure on occupant protection, as well as the vehicle deformation characteristics. In general, in a small vehicle, whose side structure may not be as stiff compared to a larger vehicle, the effect of that side structure on occupant protection is high.

Typically, computer simulation and sled tests are performed to examine the influence of the door structure on occupant behavior (1,2,3,4). Few of these simulations and tests, however, demonstrate the degree of effect of the collision on the occupant. In addition, concrete door structure improvements are not made clear.

Utilizing MADYMO 3D computer simulation, this paper analyzes the behavior of the DOT-SID and the regulated occupant injury indices (TTI, pelvic G etc.) employing the side impact test conditions proposed by NHTSA. Objectives of this study are; first, to clarify the effect of several door factors, such as pad stiffness and location, on occupant protection; and second, to establish the method to obtain specifications by which the desirable levels on occupant protection are achieved.

Mathematical Model Formulation and Simulation Fidelities

Occupant Model. Fig. 1 shows the DOT-SID model developed by T.C. Low and P. Prasad, using MADYMO 3D version 4.2 software, that is utilized in this study (5,6). The model is modified on the thoracic damper and the jacket, and is used for parametric studies on the door structure.

First, the thoracic damper has four orifices. The number of orifices available for oil flow, the effective orifices, changes according to the piston displacement. In addition, the damping characteristics changes (7).

Five MADYMO Kelvin models (non-linear, damper-spring model) are used to replace only one Kelvin model, one whose damping characteristics corresponds to the number of active effective orifices, as shown in Fig. 2.

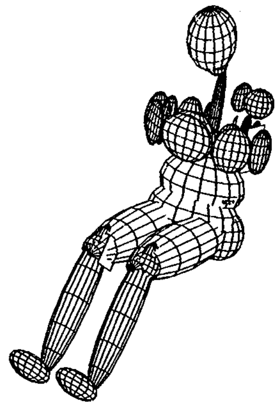


Figure 1. MADYMO DOT-SID Model

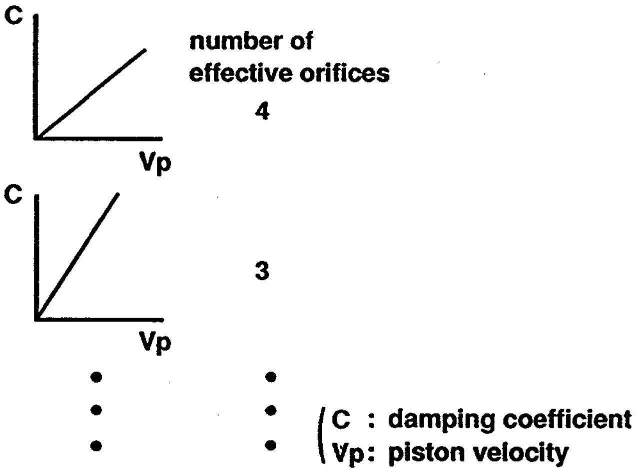


Figure 2. Damping Characteristics of Five MADYMO Kelvin Models

Second, in order to simulate the difference of the dummy response as a result of changing longitudinal jacket impact location, the jacket ellipsoid is divided into two parts. Each ellipsoid location is changed according to the jacket impact location. This is done to better simulate the transmission of the force between the jacket and the impactor (see Fig. 3).

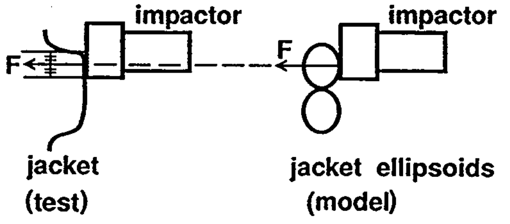
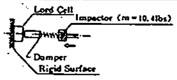
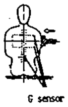
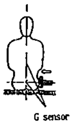
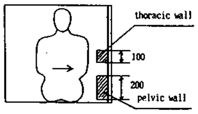


Figure 3. Method to Simulate the Center of Force Between Jacket and Impactor

Validation of the Mathematical Model. In order to verify that the occupant model can simulate the influence of the impactor stiffness and location, several types of tests were performed (see Table 1). Here, the input data required for pad model are obtained from dynamic pad impact tests using ribcage imitated impactor, as shown in Fig. 4.

Table 1. Validation Test of Mathematical Model

<table>
<tr><th></th><th>thoracic part</th><th>pelvic part</th></tr>
<tr><td>SID damper calibration test</td><td> <table><tr><th>velocity (m/s)</th></tr><tr><td>3.4
5.1</td></tr></table></td><td>——</td></tr>
<tr><td>dummy impact test
using calibration test impactor</td><td> <table><tr><th>velocity (m/s)</th><th>impactor stiffness</th><th>impactor location</th></tr><tr><td>7.0
9.0</td><td>rigid
padded</td><td>center
75mm upper
75mm lower</td></tr></table></td><td> <table><tr><th>velocity (m/s)</th><th>impactor stiffness</th><th>impactor location</th></tr><tr><td>7.0
9.0</td><td>rigid
padded</td><td>hip point
iliac crest</td></tr></table></td></tr>
<tr><td>hyge sled test</td><td colspan="2"> <table><tr><th>velocity (m/s)</th><th>wall stiffness</th><th>thoracic wall location</th></tr><tr><td>7.0
9.0</td><td>rigid
padded</td><td>center
50mm lower</td></tr></table></td></tr>
</table>

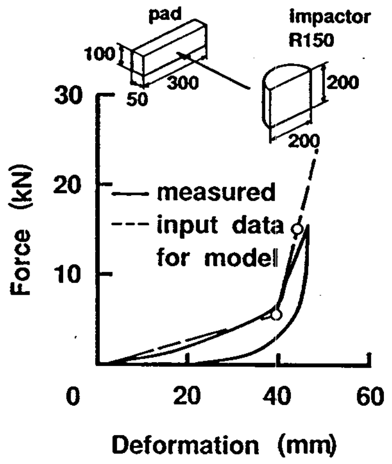


Figure 4. Pad Deformation Characteristics

Table 2 shows results comparisons of damping force and damper displacement between the mathematical model and the actual damper impact test. Table 3 and 4 show comparisons of occupant injury indices results from the mathematical model and by the dummy impact and hyge sled tests. The results demonstrate good correlations.

Table 2. Comparison Between Model and Test at Damper Calibration Test

velocity (m/s)	model		test	
	damping force (N)	damper displace-ment (mm)	damping force (N)	damper displace-ment (mm)
3.4	1052.6	34.1	965.3	33.2
5.1	2624.2	36.3	2293.6	36.1

Table 3. Comparison Between Model and Test at Dummy Impact Test

(a) Thoracic Part

impactor stiffness	impactor location	velocity (m/s)	model or test	lower spine G FIR	upper rib G FIR	lower rib G FIR
rigid	center	7.0	model	47.6	118.4	117.2
			test	49.6	115.5	119.9
		9.0	model	68.8	179.4	178.5
			test	69.6	177.1	183.8
	75mm upper	7.0	model	41.5	131.8	103.6
			test	43.1	127.0	115.3
		9.0	model	61.1	208.8	165.2
			test	63.7	212.7	183.6
	75mm lower	7.0	model	52.3	103.4	131.1
			test	52.4	101.6	138.8
		9.0	model	78.3	168.4	211.7
			test	77.5	166.4	221.4
padded	center	7.0	model	26.1	31.4	30.9
			test	25.3	32.6	32.2
		9.0	model	54.7	81.2	81.0
			test	50.1	83.6	83.8

(b) Pelvic Part

impactor stiffness	impactor location	velocity (m/s)	model or test	lower spine G FIR	pelvic G FIR
rigid	hip point	7.0	model	13.8	68.7
			test	14.8	63.0
		9.0	model	36.2	137.7
			test	35.9	127.0
	iliac crest	7.0	model	41.9	61.3
			test	38.6	57.9
	hip point	7.0	model	11.9	46.3
			test	12.4	48.1
		9.0	model	21.0	100.2
			test	21.6	106.5

Parametric Studies on Impactor Stiffness

Effect of Impactor Stiffness on Dummy G Occurrence Mechanism

First, utilizing the thoracic impact model, the effect of impactor stiffness on dummy G occurrence mechanism is examined. Fig. 5 (a) and (b) show the time histories of the lower rib G, lower spine G, impactor-to-jacket force, damper force and rib-to-spine force, on rigid impactor and padded impactor. After the jacket deforms completely, the jacket-to-rib force and rib G increases abruptly. Followed by increases in damper, rib-to-spine forces and

Table 4. Comparison Between Model and Test at Hyge Sled Test

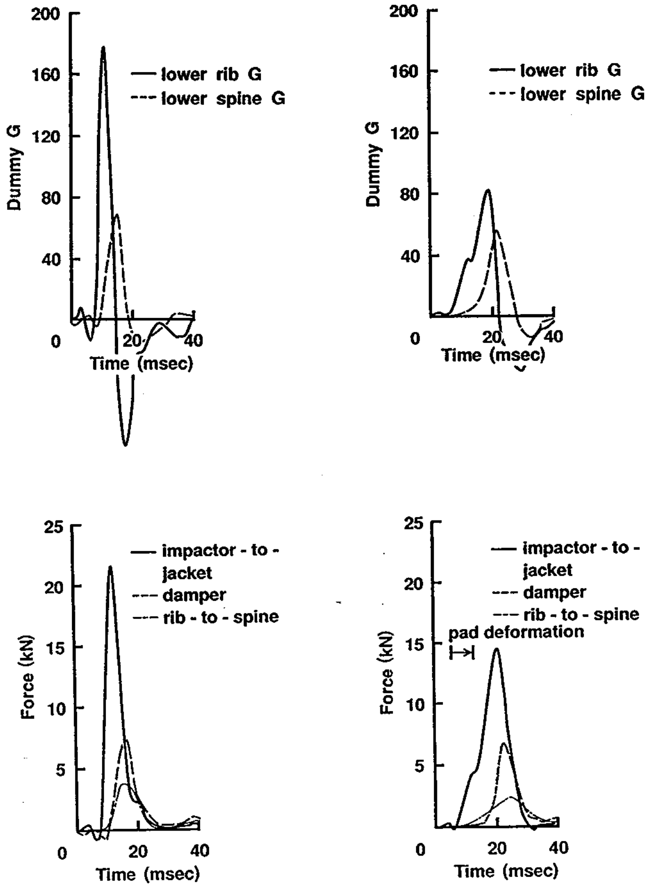
wall stiffness	thoracic wall location	velocity (m/s)	model or test	lower spine G FIR	upper rib G FIR	lower rib G FIR	pelvic G FIR
rigid	center	7.0	model	76.3	163.8	162.0	121.9
			test	79.2	172.3	176.8	110.5
				75.9	158.3	160.3	121.5
		9.0	model	128.0	223.2	219.2	163.9
			test	124.3	229.1	234.1	150.8
				141.6	207.6	209.8	166.8
	50mm lower	9.0	model	130.5	173.3	231.4	164.9
			test	132.2	205.3	236.3	160.4
				139.3	186.3	215.5	151.6
padded	center	7.0	model	67.9	79.0	77.1	63.5
			test	61.8	92.6	84.4	62.3
				62.8	82.4	83.0	61.6
		9.0	model	107.1	146.1	144.4	129.3
			test	96.7	146.4	140.3	133.9
				88.7	147.1	142.4	145.0

lower spine G. On the other hand, as illustrated in Fig. 5(b), on padded impactor, after the jacket deforms completely, the pad begins to deform and the jacket-to-rib force increases gradually. After the pad deforms completely, the jacket-to-rib force and rib G increase rapidly. In this case, since the impactor energy is absorbed by the pad deformation, jacket-to-rib, damper, rib-to-spine forces, rib and lower spine G, are lower than those on the rigid impactor.

Further, the effect of the impactor stiffness on the dummy G pattern is examined by changing the pad stiffness as shown in Fig. 6 (a). From Fig. 6 (a) and (b), the decrease of pad stiffness leads to the increase of the rib second peak G. Therefore, it is found that changing the impactor stiffness induces to the change of dummy G pattern and to the decrease of peak G.

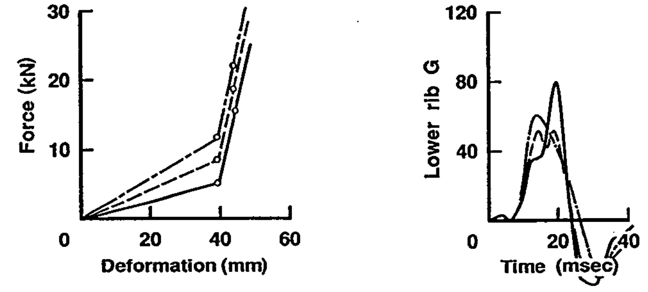
Second, using the pelvic impact model, the effect of impactor stiffness on dummy G occurrence mechanism is similarly evaluated. Fig. 7 (a) and (b) show the time histories of pelvic G, lower spine G, impactor-to-pelvis force, pelvis-to-lumbar spine torque and lumbar spine-to-spine torque. As can be seen from Fig. 7(a), on rigid impactor, after the pelvis deforms completely, impactor-to-pelvis force and pelvic G increases abruptly. Then, the pelvis-to-lumbar spine torque, lumbar spine-to-spine torque and lower spine G increase. In contract, as demonstrated in Fig. 7(b), on padded impactor, for the same reasons as in the thoracic impact, impactor-to-pelvis force, pelvis-to-lumbar spine torque, lumbar spine-to-spine torque, pelvic G and lower spine G are lower than those of the rigid impactor.

Effect of Pad Deformation Characteristics on Occupant Injury Indices. As a second parametric study, the effect of the pad deformation characteristics on occupant injury indices are examined utilizing the hyge sled model.



(a) Rigid impactor (b) Padded impactor

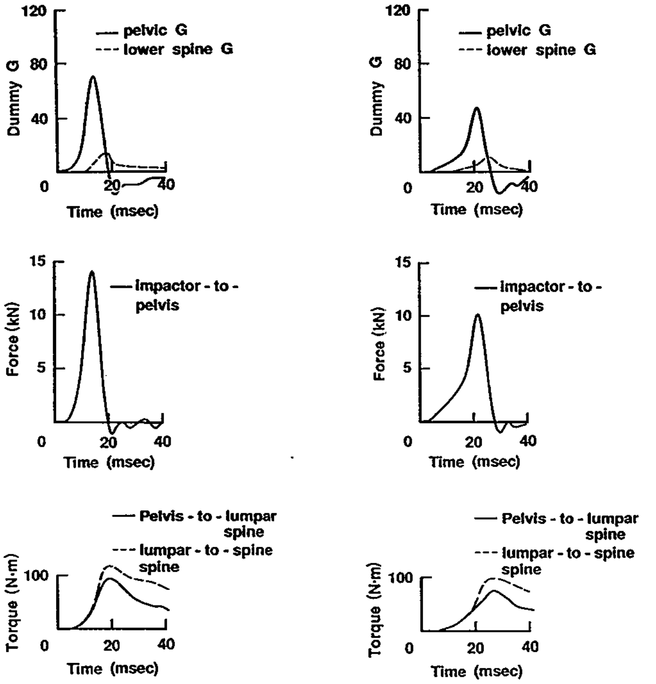
Figure 5. Effect of Impactor Stiffness (Thoracic Impact Model, Velocity 9 m/s)



(a) Pad deformation characteristics (b) Lower rib G

Figure 6. Effect of Impactor Stiffness on Dummy G Pattern (Thoracic Impact Model, Velocity 9 m/s)

First, under constant pelvic pad stiffness conditions, the effect of thoracic pad deformation characteristics is appraised by changing the deformation and force of the point P, where is pad force increases sharply (Fig. 8). Fig. 9(a) and (b) show that the increase of pad deformation improves TTI and there appears to be an optimal pad stiffness, which results in the minimum value for TTI. Additionally, the increase of impact velocity influences the optimal pad stiffness. Due to the difference of door intrusional velocities, in order to



(a) Rigid impactor (b) Padded impactor

Figure 7. Effect of Impactor Stiffness (Pelvic Impact Model, Velocity 7 m/s)

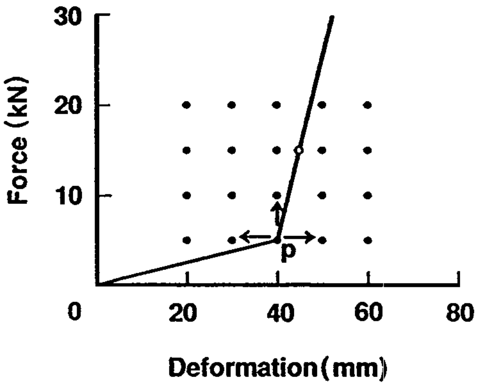
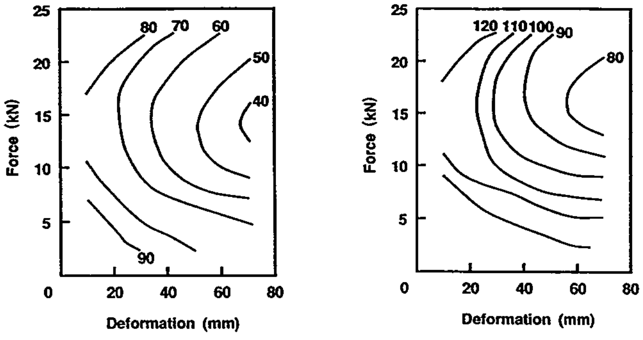


Figure 8. Parametric Study on Pad Deformation Characteristics

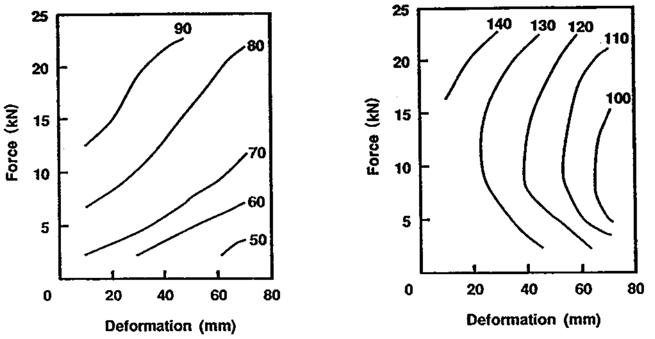


(a) 7m/s , TTI (b) 9m/s , TTI

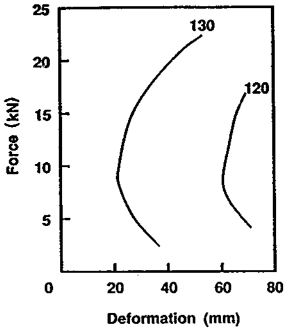
Figure 9. Effect of Pad Deformation Characteristics on TTI (Hyge Sled Model)

improve occupant protection it is necessary to specify the optimal pad stiffness for each ear line.

Second, under constant thoracic pad stiffness conditions, the effect of pelvic pad deformation characteristics is evaluated in the same manner. According to Fig. 10(c), TTI follows the same trend as pelvic G. This is due to the decrease of pelvic G leading to the decrease of lower spine G.



(a) 7m/s , Pelvic G (b) 9m/s , Pelvic G



(c) 9m/s , TTI

Figure 10. Effect of Pad Deformation Characteristics on Pelvic G and TTI (Hyge Sled Model)

Parametric Studies on Impactor Location

Effect of Impactor Location on Dummy G Occurrence Mechanism

Using the thoracic impact model, the effect of impactor longitudinal location on dummy G occurrence mechanism is examined. Fig. 11 shows that the lower impactor location is, the higher the lower spine G outcome. The impactor location at the center of the jacket yields the minimum values for rib G and TTI. This is due to the lower jacket-to-rib force and lower rib-to-spine force at the lower location of the impactor are higher than those at its center location (see Fig. 12(a),(b) and (c)).

Utilizing the dummy pelvic impact model the effect of impactor longitudinal location is also evaluated. Table 5 shows that the impact on the iliac crest tends to increase the lower spine G and to decrease the pelvic G. This is due to the counterclockwise pelvic rotation in the vertical plane and the increased pelvis-to-lumbar spine torque, lumbar spine-to spine torque, as shown in Fig. 13(b), (c) and (d).

Effect of Pad Location on Occupant Injury Indices. Using 9m/s hyge sled model, under conditions of constant pelvic pad location, the effect of thoracic pad

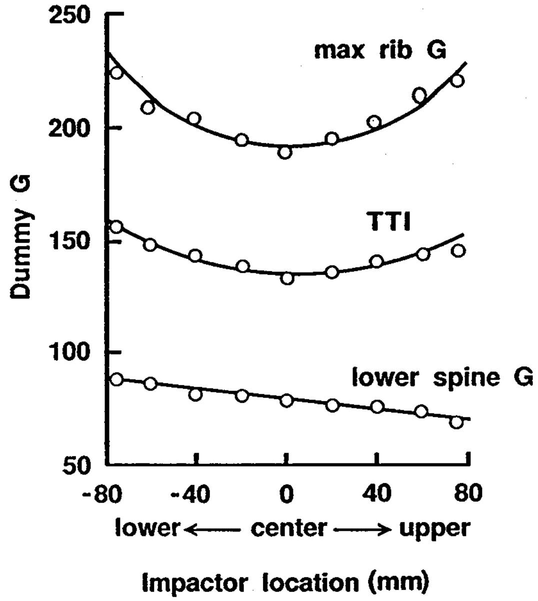
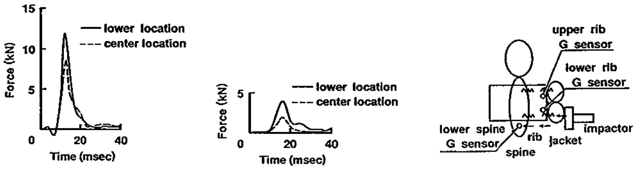


Figure 11. Effect of Impactor Location on Dummy G (Thoracic Impact Model, Velocity 9 m/s)



(a) Lower jacket - to - rib
(b) Lower rib - to - spine
(c) Impactor lower location

Figure 12. Effect of Impactor Location on Dummy Force (Thoracic Impact Model, Velocity 9 m/s)

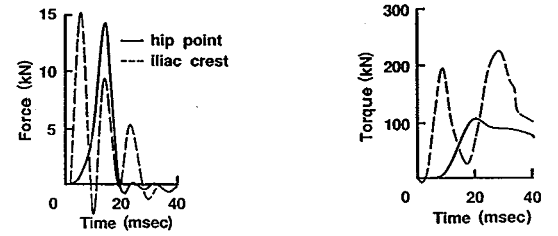
Table 5. Effect of Impactor Location on Dummy G (Pelvic Impact Model, Velocity 7 m/s)

impactor location	lower spine G FIR	pelvic G FIR
iliac creat	41.9	61.3
hip point	13.8	68.7

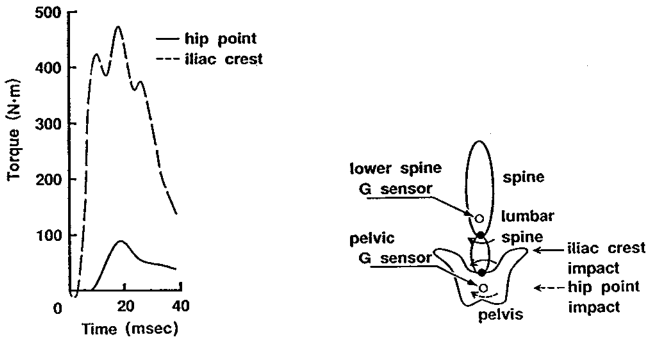
location is appraised. Fig. 14 shows that for the same reason as noted above, TTI has the minimum value when the thoracic pad is at the center of the jacket.

Under conditions of constant thoracic pad location, the effect of pelvic pad location is similarly evaluated. Table 6 shows that TTI is higher and pelvic G is lower on the upper half of the pelvic pad than those on the lower half.

Comparing the results of the studies between on pad deformation characteristics and on pad location, the former appears to be more sensitive to occupant injury indices than the latter.



(a) Impactor - to - pelvis
(c) Lumbar spine - to - spine



(b) Pelvis - to - lumbar spine
(d) Effect on dummy behavior

Figure 13. Effect of Impactor Location on Dummy Force and Torque (Pelvic Impact Model, Velocity 7 m/s)

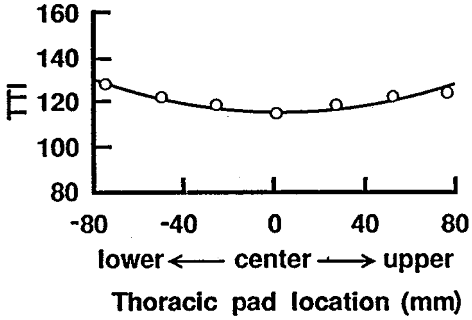


Figure 14. Effect of Pad Location on TTI (Hyge Sled Model, Velocity 9 m/s)

Table 6. A Trial of Improving Occupant Protection for a Small Vehicle

pelvic pad location	lower spine G FIR	upper rib G FIR	lower rib G FIR	TTI	pelvic G FIR
upper half	114.5	111.8	110.1	113.2	128.1
lower half	94.4	111.2	109.0	102.8	143.2

A Trial of Improving Occupant Protection for a Small Vehicle

Specification of Target Level of Door Stiffness. During the proposed NHTSA side impact test, a small vehicle experiences a door intrusional velocity of approximately 9 m/s at the time the door hits the dummy. Therefore, the tangible improvements for reducing occupant injury indices is studied utilizing the 9 m/s hyge sled model.

With respect to the thorax, the door belt-line (upper end of the door panel) hits the dummy jacket during the actual vehicle test. Utilizing the simulated ribcage impactor, Fig. 15 shows these belt-line deformation characteristics obtained from the dynamic impact test of the pre-crushed belt-line cut off from the door. Under conditions of constant pelvic pad stiffness, the effect of deformation characteristics of the belt-line with an additional 50mm of thickness is examined. The belt-line and pad deformation characteristics in this case are illustrated in Fig. 16(a) and (b). As can be seen in Fig. 17, the minimum value for TTI occurs when the belt-line is 6 to 10 times stiffer than the original, and the pad force of the point P is 10 to 15 kN.

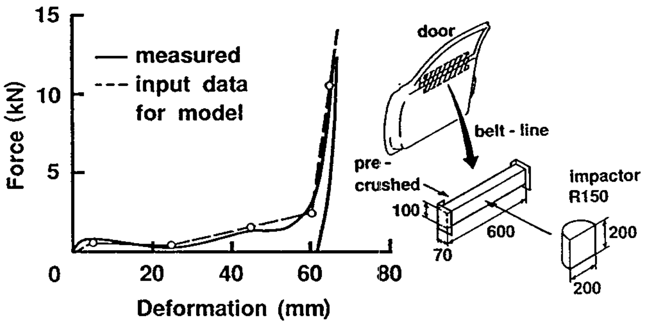
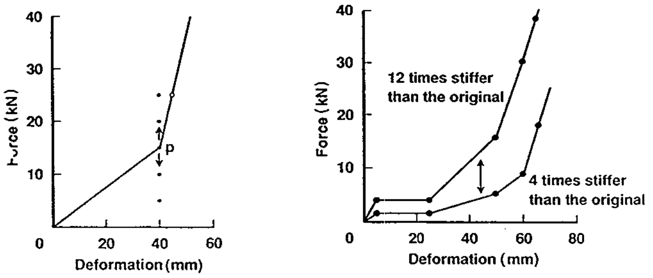


Figure 15. Belt-line Deformation Characteristics (Original)



(a) Pad (b) Belt - line

Figure 16. Pad and Belt-line Deformation Characteristics

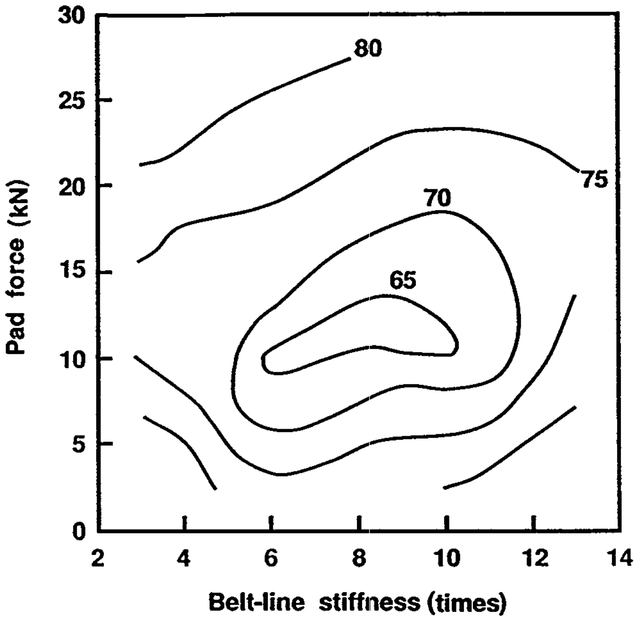


Figure 17. Effect of Pad and Belt-line Deformation Characteristics on TTI (Hyge Sled Model, Velocity 9 m/s)

With respect to the pelvis, it is the armrest that is involved. Fig. 18 shows the pad location describing that 100mm thickness hits the iliac crest and 50mm thickness hits the pelvis. Under constant thoracic pad stiffness conditions, the effects of thick and thin pads are evaluated. According to Fig. 19, pelvic G has the minimum value when the thick pad force of the point P is approximately 20 kN and the thin one at about 5 kN.

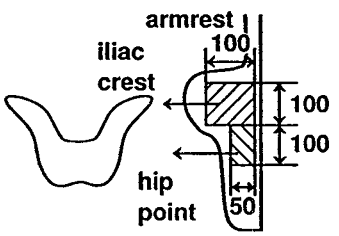


Figure 18. Pad Location into Armrest

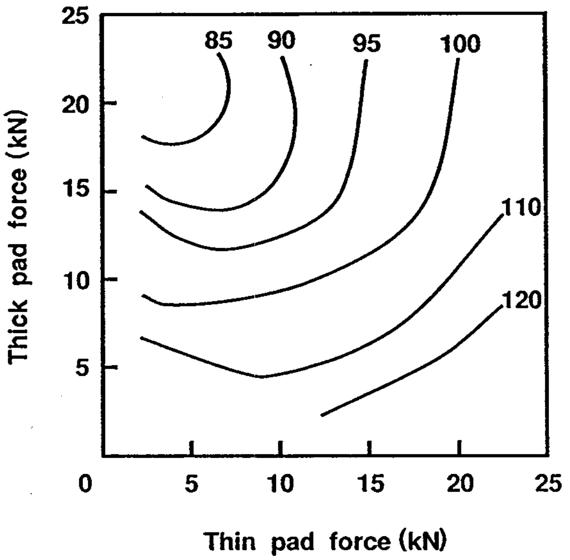
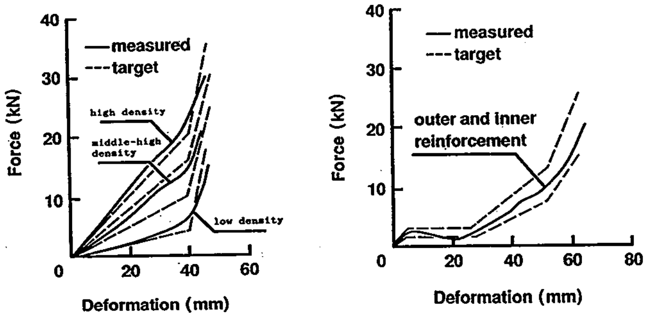


Figure 19. Effect of Armrest Pad Deformation Characteristics on Pelvic G (Hyge Sled Model, Velocity 9 m/s)

Specification of Door Structure. The addition of several types of reinforcement and several kinds of pad, specifications are clarified by conducting the dynamic impact tests on the belt-line. Fig. 20(a) and (b) show that the belt-line outer and inner reinforcement of thin thickness, belt-line pad of middle-high density, armrest thick pad of high density and thin pad of low density is optimal.



(a) Pad (b) Belt-line

Figure 20. Specification of Pad and Belt-line

Verification. The improvements suggested by the simulation cited above, are verified through several hyge sled tests. Table 7 shows belt-line and pad specifications, and in addition occupant injury indices obtained from hyge sled tests. From this table, it is found that the aforementioned specifications yields good values for occupant protection indices.

Table 7. Verification of the Improvement Given by Simulation (Hyge Sled Model, Velocity 9 m/s)

specification				test results	
thoracic		pelvic		TTI FIR	pelvic G FIR
belt-line	pad	upper half pad	lower half pad		
original	—	middle-low density 50mm thickness	middle-low density 50mm thickness	137.1	115.6
				140.1	122.8
reinforcement	middle-high density 50mm thickness	↑	↑	68.5	123.1
				67.7	118.4
rigid	rigid	rigid	rigid	179.2	150.8
				175.7	166.8
↑	middle-low density 50mm thickness	high density 100mm thickness	low density 50mm thickness	93.2	82.6
				94.9	83.5

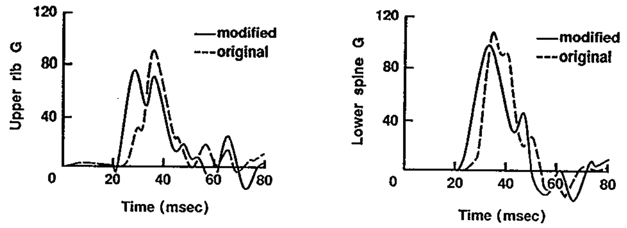
Further, the actual vehicle test is performed in order to demonstrate the improvements. Fig. 21(a), (b), (c) and (d) show comparisons of upper and lower rib G, lower spine G and pelvic G between the original and the modified vehicle, respectively. It should be noted, the only modifications completed are those that stem from the results of the computer simulation. These figures demonstrate dramatic improvements in occupant injury indices.

In developing a new type of vehicle, the above approach is very useful to clarify the target levels of door stiffness derive door specifications by which the target levels are achieved.

Conclusions

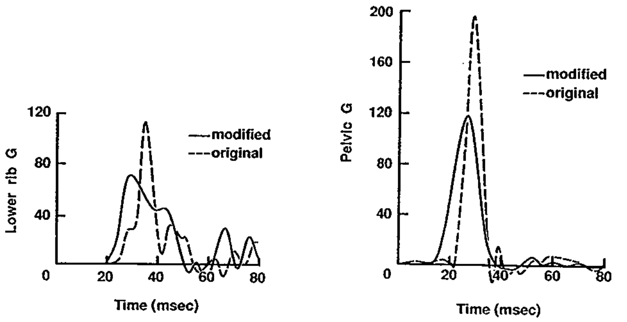
It has been demonstrated that crash victim simulation model can be effectively and conveniently used to evaluate the influence of the pad stiffness and location, and the door stiffness on effective occupant protection as follows:

1. Using the dummy impact model in conjunction with the hyge sled model, parametric studies on the effect of pad deformation characteristics reveal that there are optimal pad deformation characteristics, which result in the minimum value for TTI and pelvic respectively. In addition, the change in impact velocity leads to the change of the optimal pad deformation characteristics.



(a) Upper rib G

(c) Lower spine G



(b) Lower rib G

(d) Pelvic G

Figure 21. Comparison Between Original Vehicle and Modified One

2. Parametric studies on the effect of pad location reveal that TTI has the minimum value when the thoracic pad is at the center of jacket, and TTI is higher and pelvic G is lower on the upper half of the pelvic pad and not on the lower half.
3. Parametric studies on the definite improvement for decreasing occupant injury indices, for a small vehicle, clarify the optimal door specifications. The simulation results are verified by the actual tests as well as several hyge sled tests.

Acknowledgment

The authors would like to thank the related people of Ford Motor Company and Mazda Motor Corporation, who gave useful suggestions in preparing this paper.

References

(1) Yih-Charng Deng, "Design Considerations for Occupant Protection in Side Impact—A Modeling Approach," Proceedings of the 32nd Stapp Car Crash Conference, SAE Paper 881713, Atlanta, Georgia, October 1988.

(2) Yih-Charng Deng, "The Importance of the Test Method in Determining the Effects of Door Padding in Side Impact," Proceedings of the 33rd Stapp Car Crash Conference, SAE Paper 892429, Washington D.C., October 1989.

(3) John M. Cavanaugh, et al., "Biomechanical Response and Injury Tolerance of the Thorax in Twelve Sled Side Impacts," Proceedings of the 34th Stapp Car Crash Conference, SAE Paper 902307, Orlando, Florida, November 1990.

(4) F. Shokoohi, et al., "One-Dimensional Model for Predicting Side Intrusion Injuries Including Effects of Padding," SAE Paper 910600, International Congress and Exposition, Detroit, Michigan, February 1991.
(5) Tah Chuan Low, et al.,"Dynamic Response and Mathematical Model of the Side Impact Dummy," Proceedings of the 34th Stapp Car Crash Conference, SAE Paper 902321, Orlando, Florida, November 1990.
(6) MADYMO3D User's Manual, Version 4.2, TNO.
(7) J. Hasegawa, et al., "Side Impact Simulation Analysis Using an Improved Occupant Model," Proceeding of the 12th International Technical Conference on ESV, pp 1071 - 1077, Göteborg, Sweden, May 1989.

S5-O-04

Protection of Occupants Against Side Impact

Albert I. King, Yue Huang,
John M. Cavanaugh
Wayne State University

Abstract

Side impact protection through the use of padding is still somewhat controversial. Although it has been shown in a series of 17 cadaveric tests that paper honeycomb can reduce thoracic injuries dramatically, there are still concerns regarding the ability to provide protection for the thorax when there is no engagement of the shoulder with the intruding side structure of the car. There is also concern as to what effect the padding would have on the occupant if the width of the vehicle remained unchanged and the free air space between the padded surface and the occupant is decreased. This paper describes the development of a one-dimensional lumped parameter model to simulate the cadaveric experiments carried out at Wayne State University and its validation. The model is then used to study the protective effect of the shoulder on the thorax and the effect of the padding on the force and duration of impact sustained by the occupant when a thick padding is used. It was found that the shoulder can provide substantial protection to the thorax and without shoulder engagement, the force on the thorax can be approximately 45% higher. This calls for additional cadaveric testing since the existing side impact dummies are apparently too stiff to be representative of the human. As for the loss of free air space due to the padding, the model predicted an increase in the force level and in thoracic deformation if the padding is too stiff.

Introduction

The promulgation of the new Federal Motor Vehicle Standard (FMVSS) 214 has resulted in research and development activities to provide side impact protection to automotive occupants. The use of padding to reduce the severity of impact against the torso is one approach which can be both beneficial and detrimental to the near-side victim, depending on the type of padding used and the possibly on the space taken up by the padding between the door and the occupant.

Recent data obtained by Wayne State University show that the use of 100 mm of a cardboard honeycomb material can effectively reduce thoracic injuries and the maximum AIS sustained by the near-side occupant. However, the tests were conducted with full engagement of the shoulder with the simulated door panel which was stationary. It is not known what the thoracic force magnitude is if there was no shoulder engagement. It has also been postulated that the addition of padding which results in the decrease of the free air space between the occupant can be detrimental to the occupant. In view of the fact that cadaveric tests are expensive to conduct and that, in the opinion of the authors, current side impact dummies do not have the level of biofidelity necessary to predict injury with a high degree of accuracy, it would be advantageous to develop a computer model which can be used to study variations in impact conditions. After the model has been validated, such parametric studies can be used to cut down on the number of cadaver tests to be carried out and in the design of the side structure of automobiles which will provide maximum protection for the occupant.

The aim of this paper is to present a validated lumped parameter model of the human torso interacting with the side structure of an automobile in a broadside impact.

The Experimental Data Base

A total of 17 cadaveric side impact tests have been conducted so far. The data from these tests constitute the experimental base for the validation of the model. Details of how the tests were conducted have been reported by Cavanaugh et al (1990a, 1990b). A brief description of the test set-up and an updated summary of the test results is provided in this paper, for the sake of completeness.

The Experimental Test Set-up and Procedure

All of 17 the side impact simulations were conducted on the Wayne Horizontal Accelerator Mechanism III (WHAM III) which is a pneumatically powered deceleration sled. The deceleration distance was set to a very low value (about 200 mm) to ensure that the sled was completely stopped before the side impact occurred. The test subject was placed in a seated position, at one end of a

1-m long bench seat, the long-axis of which was parallel to the direction of motion of the sled. At the other end of the bench seat, an instrumented barrier was erected to stop the test subject and to measure the forces of impact at the level of the shoulder, thorax, abdomen, pelvis and knee. The cadaver impacted this barrier at approximately the same speed as the pre-impact speed of the sled. To minimize the loss of speed of the cadaver, the surface of the bench seat was made of Teflon and the cadaver sat on a piece of plastic sheet so that friction is minimized. Although the basic set-up was very similar to that described by Marcus et al (1983), it should be noted that separate forces were measured at each of the four levels of the torso for the first time, in side impact cadaveric simulations. These are, therefore, the only data that can be used to validate a model which seeks to simulate the response of the four regions of the torso individually. The deformation of the thorax was measured optically using photo targets and high speed cinematography.

In addition to the instrumentation of the barrier with 9 load cells, the cadaver was instrumented with head, chest and spinal accelerometers and photo targets on the shoulder and thorax to measure regional deformation, for both padded and unpadded impact with the barrier. Strategically placed high speed cameras were used to record the impact and to provide optical data for analysis.

Summary of Experimental Data

A summary of the experimental data from the 17 runs done so far can be found in Table 1. The first eight runs were impacts against a rigid wall and three of those were done with a 150 mm rigid pelvic offset. That is, the pelvis was stopped 150 mm before the rest of the torso by an offset rigid barrier. The remaining nine tests were padded impacts in which the principal padding used was a cardboard or paper honeycomb material, identified in the table as PHC. The stiffness of the honeycomb was given in terms of pressure rating in pounds per square inch (psi). There was also a change in the arm position in Runs 14 through 17 in which the arm was raised so that the thorax was completely exposed to the padded wall. Partial interaction of the arm occurred in Runs 1 through 13 since the arm was flexed anteriorly about 15 deg relative to the mid-axillary line. Table 1 also provides relevant data on the cadavers, the scaling factors to be used to scale the force and acceleration data and the maximum AIS seen in the neck (NE), shoulder (SH), thorax (TH), abdomen (AB) and pelvis (PE).

It can be seen from the injury data that, for the thorax, the AIS was 5 for rigid wall impacts and that it was reduced to 0 or 2, in four of the six tests in which 15 psi paper honeycomb was used. It should be noted that in Run 14, the 15 psi paper honeycomb used was a single piece from the shoulder to the abdomen, resulting in an AIS of 4 for the thorax. In the other runs, the padding was cut up into rectangular pieces 150 mm high and approximately 600 mm long. The thickness of the padding ranged from 100 to 150 mm.

Table 1. Summary of Side Impact Cadaveric Test Data

RUN N	RUN DATE	PELVIC OFFSET (IN.)	WALL PAD	PAD THICK (IN.)	SLED VEL. (MPH)	SLED VEL. (M/S)	CAD. NO.	MASS (KG)	HT. (M)	AGE	SEX	LAM-DA NO.	MAIS TO BODY REGIONS				
													NE	SH	TH	AB	PE
SIC01	1-20-89	6	NO	0	19.94	8.91	UM6	70.5	1.76	67	M	1.021	0	2	5	2	2
SIC02	1-30-89	6	NO	0	20.29	9.07	187	49.5	1.63	64	F	1.148	3	2	5	2	3
SIC03	2-03-89	6	NO	0	23.43	10.47	188	70.0	1.75	37	M	1.023	0	0	5	0	2
SIC04	4-03-89	0	NO	0	20.25	9.05	215	57.8	1.63	69	M	1.092	3	2	4	2	2
SIC05	4-10-89	0	NO	0	15.00	6.71	216	44.0	1.72	67	M	1.194	0	0	4	0	0
SIC06	4-27-89	0	NO	0	20.23	9.04	217	61.2	1.84	60	M	1.070	0	2	4	0	2
SIC07	5-16-89	0	NO	0	14.92	6.67	206	74.8	1.70	66	M	1.001	0	2	4	0	0
SIC08	8-10-89	0	NO	0	14.74	6.59	UM12	73.9	1.62	64	F	1.005	3	2	5	3	0
SIC09	10-26-89	0	ARSAN	3	20.5	9.16	280	54.9	1.65	61	F	1.110	3	2	5	0	3
SIC10	01-17-90	0	15 PHC*	6	19.56	8.74	317	62.1	1.71	60	M	1.065	0	0	2	0	0
SIC11	02-22-90	0	15,23 PHC*	4	19.98	8.93	330	55.3	1.65	54	F	1.107	0	0	2	0	0
SIC12	03-01-90	0	23,31 PHC*	4	19.85	8.87	335	54.4	1.43	68	F	1.113	0	0	5	0	0
SIC13	04-12-90	0	15,23 PHC*	4	18.50	8.27	338	66.7	1.81	62	M	1.040	0	0	4	0	0
SIC14	07-17-90	0	15,23 PHC*	4	21.10	9.43	360	55.3	1.74	72	M	1.107	3	2	4	2	0
SIC15	08-09-90	0	15,23 PHC*	4	20.00	8.94	386	68.9	1.54	43	F	1.026	0	2	0	0	0
SIC16	02-21-91	0	16,23 PHC*	3	19.84	8.87	462	56.7	1.70	58	F	1.098	0	2	4	4	2
SIC17	06-11-91	0	15,23 PHC*	6	19.92	8.90	503	93.0	1.80	65	M	0.931	0	2	2	0	0

* SIDEWALL PAD: PHC SIGNIFIES PAPER HONEYCOMB

▨ = PADDED WALL TESTS

15, 16, 23, 31 ARE MANUFACTURER'S RATED COMPRESSIVE STRENGTHS IN PSI.

NE = NECK
SH = SHOULDER
TH = THORAX
AB = ABDOMEN
PE = PELVIS

SIC 09: PADDING 3" THICK 0.9 PCF CLOSED CELL FOAM ENTIRE HEIGHT OF SIDEWALL.
SIC 10: 6" THICK 15 PSI PADDING USED ENTIRE HEIGHT OF SIDEWALL.
SIC 11: 4" THICK 15 PSI PADDING USED AT THORAX & ABDOMEN BEAMS,
23 PSI AT SHOULDER & PELVIC BEAMS.
SIC 12: 4" THICK 23 PSI PADDING USED AT THORAX & ABDOMEN BEAMS,
31 PSI AT SHOULDER & PELVIC BEAMS.
SIC 13: 4" THICK 15 PSI PADDING USED AT THORAX & ABDOMEN BEAMS, 23 PSI AT SHOULDER & PELVIC BEAMS.
SIC 14: ONE PIECE OF 4" THICK 15 PSI PADDING USED AT SHOULDER, THORAX, ABDOMEN BEAMS; 23 PSI AT PELVIC BEAM.
SIC 15: 4" THICK 15 PSI PADDING USED AT THORAX & ABDOMEN BEAMS, 23 PSI AT SHOULDER & PELVIC BEAMS.
SIC 16: 4" THICK 16 PSI VERTICEL USED AT THORAX & ABDOMEN BEAMS, 23 PSI HONEYCOMB AT SHOULDER & PELVIC BEAMS.
SIC 17: 6" THICK 15 PSI PADDING USED AT THORAX & ABDOMEN BEAMS, 23 PSI AT SHOULDER & PELVIC BEAMS.

SIC01–13: ARMS DOWN (ANGLE APPROXIMATELY 15 DEGREES ANTERIOR TO MID-AXILLARY LINE).
SIC14–17: ARMS UP TO EXPOSE LEFT SIDE OF THORAX TO DIRECT IMPACT.

The Mathematical Model

The model developed to simulate side impact is a one-dimensional lumped parameter model consisting of rigid masses, springs and dashpots arranged to have 5 degrees of freedom. Its configuration is shown in Figure 1. There are four smaller masses representing those of the shoulder, the rib cage, the abdominal casing, and the lateral aspect of the pelvis. A three-element model was used to simulate the soft tissue covering for these masses which are connected to the main torso mass by springs and dashpots. The interaction between the shoulder and the thorax is represented by another pair of elastic and viscous elements. The paper honeycomb padding was represented by a bilinear spring which basically gave a plastic response following a rather stiff elastic one.

Second order ordinary differential equations for the five masses were written and solved numerically, using a 4th order Runga-Kutta subroutine. The side impact experiment described above was simulated with appropriate initial conditions. Validation was carried out by comparing the response of the model with that of cadaver. However, averaged experimental data, normalized to a 75- kg male, were used for this purpose. For the rigid wall runs at 6.7 m/s, the average of Runs 5, 7, and 8 was used and at 9 m/s, the average of Runs 4 and 6 was used. Padded runs using the paper honeycomb were made at 9 m/s and the average of Runs 11 and 13 were used to validate the padded model.

Simulation Results—Model Validation

The model parameters were chosen to obtain responses that would match both the rigid wall as well as the padded wall tests. The force-time history was the

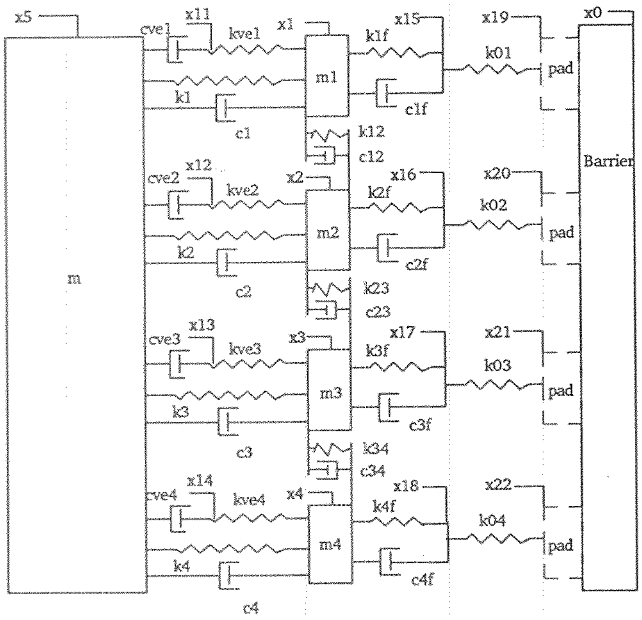


Figure 1. A Lumped Parameter Model for Side Impact

principal parameter for comparison because they were available for each of the four body regions. The other parameter used in the validation process was the deformation of the thorax.

The parameters that produced the best fit of model results to the averaged experimental response, in terms of force-time histories, are listed in Table 2. The values of the masses, m_1 through m_4, were adjusted to obtain not only the best force response but also to match the duration of impact observed experimentally. The total mass involved is 40.2 kg or 54% of the total body mass.

Table 2. List of Model Parameters Used in the Lumped Parameter Model for Side Impact

Parameters	Values	Units	Notes	Parameters	Values	Units	Notes
m1	2.5	Kg	Effective mass of shoulder	k01	500000	N/m	Stiffnesses of soft tissue,
m2	1.7	Kg	Effective mass of thorax	k02	400000	N/m	after it has bottomed out
m3	2	Kg	Effective mass of abdomen	k03	480000	N/m	
m4	4	Kg	Effective mass of pelvis	k04	900000	N/m	
m	30	Kg	Effective mass of torso and head	k01	10000	N/m	Stiffnesses of soft tissue,
k1	32000	N/m	Inter mass stiffnesses	k02	10000	N/m	before it has bottomed out
k2	25000	N/m		k03	10000	N/m	
k3	32000	N/m		k04	10000	N/m	
k4	15000	N/m		thick1	0.01	m	Thicknesses of soft tissue
c1	80	N*s/m	Inter mass damping factors	thick2	0.01	m	
c2	55	N*s/m		thick3	0.01	m	
c3	55	N*s/m		thick4	0.01	m	
c4	100	N*s/m		k12	40000	N/m	Interaction between
cve1	200	N*s/m	Damping factors of Maxwell model	k23	25000	N/m	shoulder and thorax,
cve2	100	N*s/m		k34	30000	N/m	thorax and abdomen,
cve3	270	N*s/m		c12	400	N*s/m	abdomen and pelvis
cve4	150	N*s/m		c23	300	N*s/m	
kve1	68000	N/m	Stiffnesses of Maxwell model	c34	300	N*s/m	
kve2	40000	N/m		kp1	140000	N/m	Stiffnesses of padding,
kve3	35000	N/m		kp2	200000	N/m	before it has crushed
kve4	70000	N/m		kp3	200000	N/m	
k1f	85000	N/m	Stiffness of shoulder	kp4	110000	N/m	
k2f	55000	N/m	Stiffness of thorax	fp1	2520	N	Crush forces of padding
k3f	72000	N/m	Stiffness of abdomen	fp2	1878	N	
k4f	145000	N/m	Stiffness of pelvis	fp3	2060	N	
c1f	80	N*s/m	Damping factor of shoulder	fp4	3980	N	
c2f	55	N*s/m	Damping factor of thorax				
c3f	55	N*s/m	Damping factor of abdomen				
c4f	100	N*s/m	Damping factor of pelvis				

This is somewhat less than the ideal value of 67% for the head and torso. However, the model does not simulate head and neck contact and the effective mass of those two body regions can be less than the estimated 7%. The occupant parameters listed in Table 2 were used in all of the runs presented in this paper. The results for rigid wall and padded wall impacts are compared separately.

Rigid Wall Impacts

At 6.7 m/s, the model and experimental results are shown in Figures 2 through 5 for force-time histories at the shoulder, thorax, abdomen and pelvis. There is a reasonably good fit at all levels with the largest deviation at the abdominal level. Since thoracic deformation was available experimentally, it is possible to compare this parameter. However, for the model, it was first necessary to define thoracic deformation. If the soft tissue was included in the deformation measured optically, then the thoracic deformation for the model would be relative motion of the center of the three-element model x16 in Figure 1 with respect to that of the torso mass, m, (x5). A comparison of thoracic deformation is shown in Figure 6. At 9 m/s, the match between experimental results and model predictions was equally good for both the force-time histories of all four body regions and the thoracic deformation-time history.

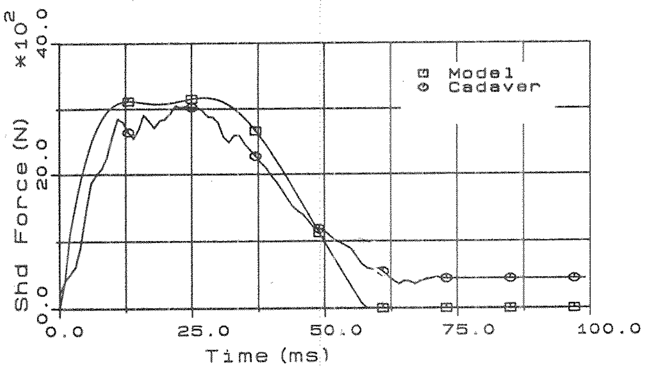


Figure 2. Comparison of Force-Time Histories at the Shoulder for Rigid Wall Impacts

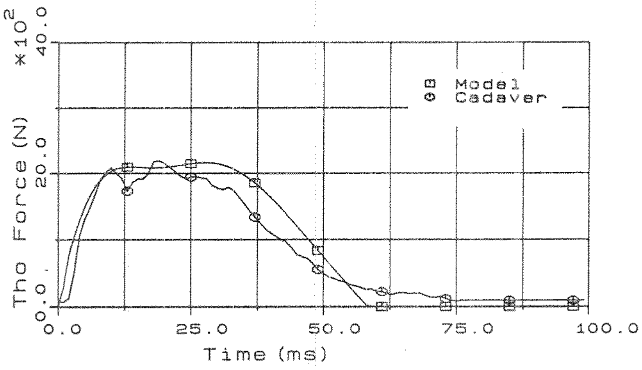


Figure 3. Comparison of Force-Time Histories at the Thorax for Rigid Wall Impacts

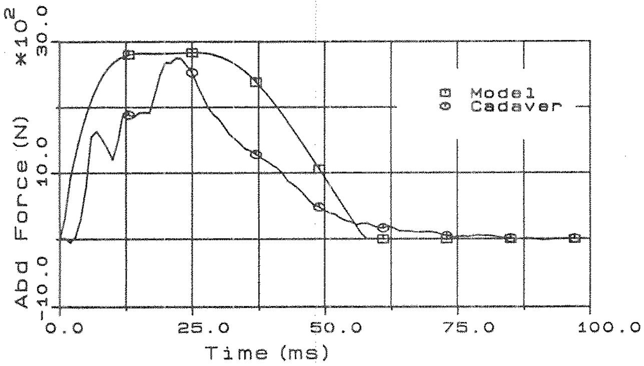


Figure 4. Comparison of Force-Time Histories at the Abdomen for Rigid Wall Impacts

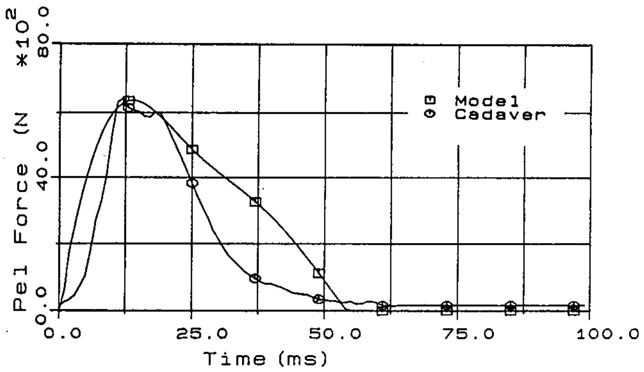


Figure 5. Comparison of Force-Time Histories at the Pelvis for Rigid Wall Impacts

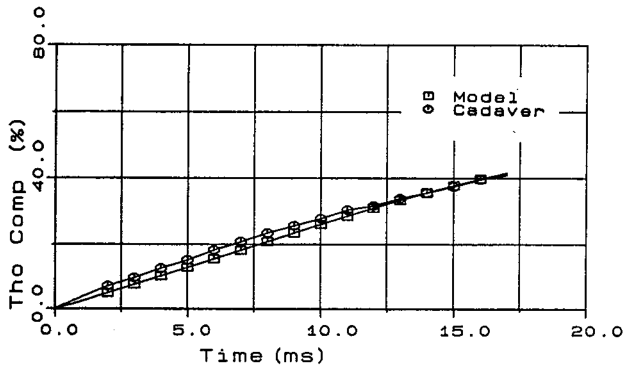


Figure 6. Comparison of Deformation-Time Histories of the Thorax for Rigid Wall Impacts

Padded Wall Impacts

The same comparisons are made for an analytical padded run made at 9 m/s with the averaged data from experimental Runs 11 and 13. The pads had a rated crush strength of 158.6 kPa (23 psi) for the shoulder and pelvis and 103.4 kPa (15 psi) for the thorax and abdomen. These crush characteristics were converted to a crush force for each body region. For the best fit to the experimental data, the constant crush forces used were 2520, 1878, 2060 and 3980 N for the shoulder, thorax, abdomen and pelvis respectively. These values are not consistent with the rated crush strengths but the areas of contact were not the same for each body region and it is therefore justifiable to select crush force values that are based on cadaveric force data and not on crush strength. The corresponding force-time histories are shown in Figures 7 through 10 for these body regions. The thoracic deformation-time histories are compared in Figure 11, using data from Test No. 13. Again there is fairly good agreement between the analytical and experimental results.

Simulation Results—Parametric Studies

The validation is sufficiently encouraging to continue with a short series of parametric runs to study the influence of padding on the force of impact if the space between the padding and the occupant is decreased by the thickness of the padding and the protective effect of the shoulder in side impact.

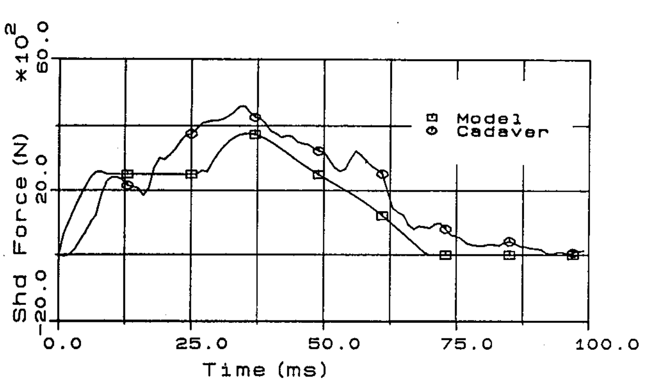


Figure 7. Comparison of Force-Time Histories at the Shoulder for Padded Wall Impacts

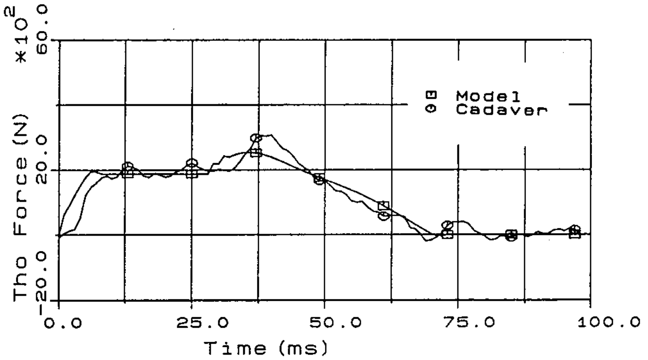


Figure 8. Comparison of Force-Time Histories at the Thorax for Padded Wall Impacts

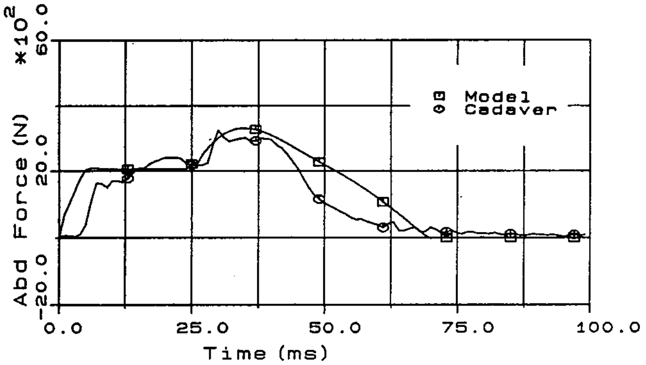


Figure 9. Comparison of Force-Time Histories at the Abdomen for Padded Wall Impacts

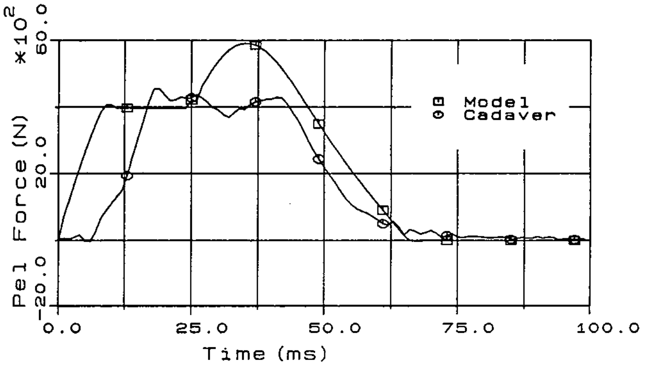


Figure 10. Comparison of Force-Time Histories at the Pelvis for Padded Wall Impacts

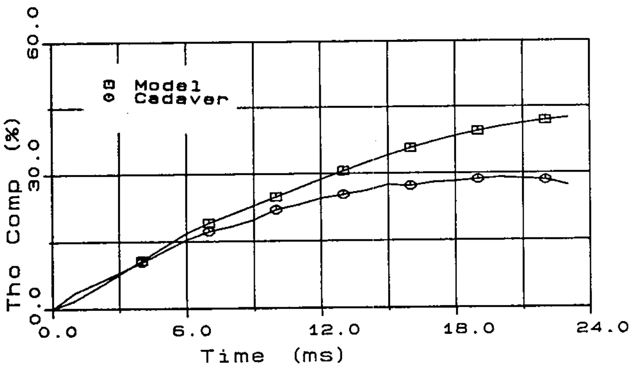


Figure 11. Comparison of Deformation-Time Histories of the Thorax for Padded Wall Impacts

Effect of Loss of Air Space between Occupant and the Side Door

To simulate the influence of air space between the door and the occupant. the initial conditions of the model were changed to simulate a stationary occupant impacted by a moving door. As a first approximation the door velocity was assumed to be constant across its entire surface. The velocity-time history was obtained from car-to-car test data and a typical trace is shown in Figure 12. The velocity-time history of the door relative to the occupant was computed and integrated to provide a relative displacement which was used as input to the model. The air space between the unpadded inner surface of the door and the occupant was assumed to be either 0 or 100 mm. When padding was used, there was also no air space since a 100-mm pad would take up all of the available air space. The model was run under these 3 conditions, rigid wall impacts with and without air space and a padded wall impact with no air space. Figures 13 through 16 compare the forces on the four body regions for a rigid door impact with and without the 0.1 m air space. The forces are higher when there is early contact but the duration is slightly less. With a 0.1 m space, there is a double peak in the force-time history but both peaks are less than that with no space at all. The double peak appears to be characteristic of the 0.1 m space since there is only one peak if the space was increased to 0.15 m.

When the paper honeycomb padding which produced minimal injury was used and the space was reduced to zero, the force on the occupant was higher than that due to impact with a rigid door with 0.1 m of air space. This is shown in Figures 17 through 20. However, if the crush strength was decreased by 40%, the thoracic force levels became comparable but the duration of the padded impact is still slightly longer. A 60% reduction in crush strength was needed to lower the thoracic peak force significantly, as shown in Figure 18. The same trends are seen in Figure 17 for the shoulder forces. The pad appears to be more effective at the pelvic level, as shown in Figure 20.

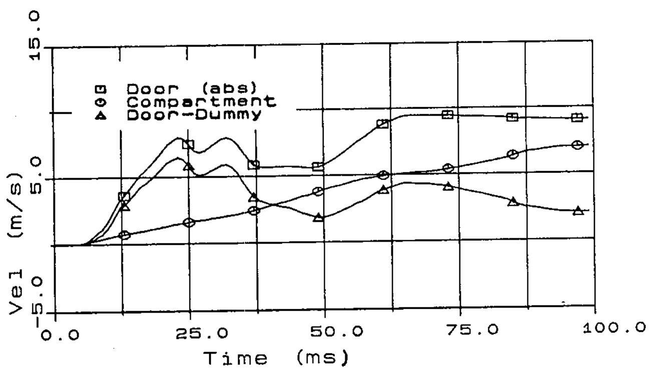


Figure 12. Typical Side Door Velocity Profile

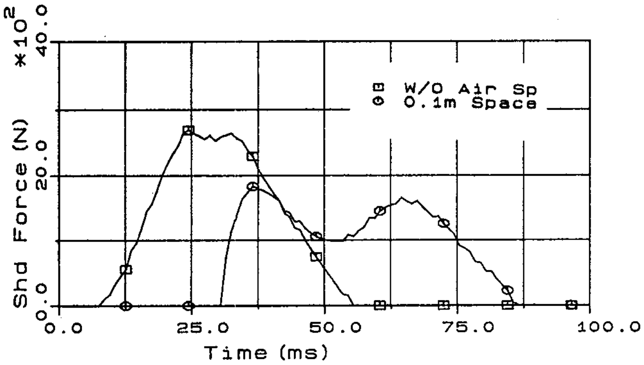


Figure 13. Comparison of Force-Time Histories at the Shoulder for a Moving Rigid Wall With and Without 0.1 m of Air Space

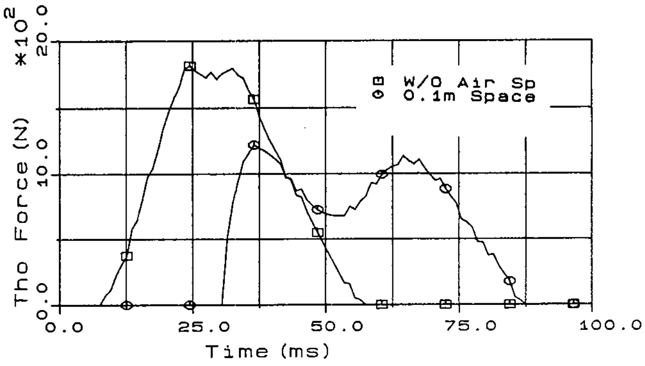


Figure 14. Comparison of Force-Time Histories at the Thorax for a Moving Rigid Wall With and Without 0.1 m of Air Space

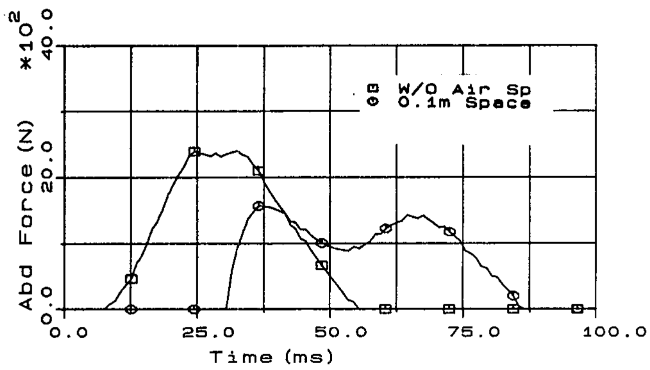


Figure 15. Comparison of Force-Time Histories at the Abdomen for a Moving Rigid Wall With and Without 0.1 m of Air Space

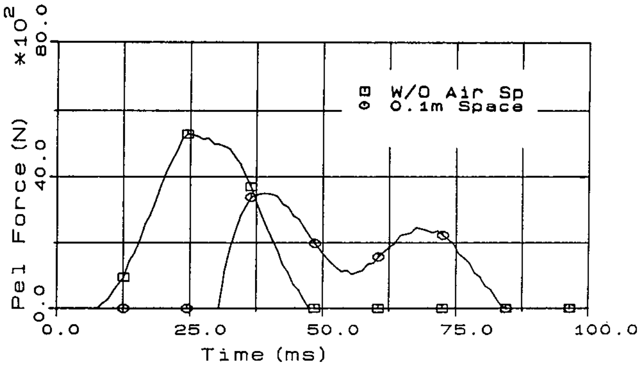


Figure 16. Comparison of Force-Time Histories at the Pelvis for a Moving Rigid Wall With and Without 0.1 m of Air Space

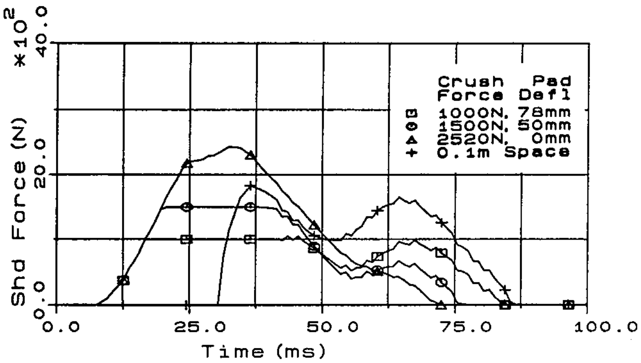


Figure 17. Comparison of Force-Time Histories at the Shoulder for a Moving Rigid Wall a Moving Padded Wall With No Space

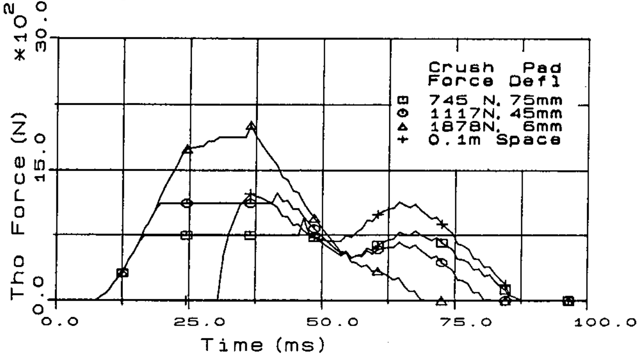


Figure 18. Comparison of Force-Time Histories at the Thorax for a Moving Rigid Wall With 0.1 m of Air Space and a Moving Padded Wall With No Space

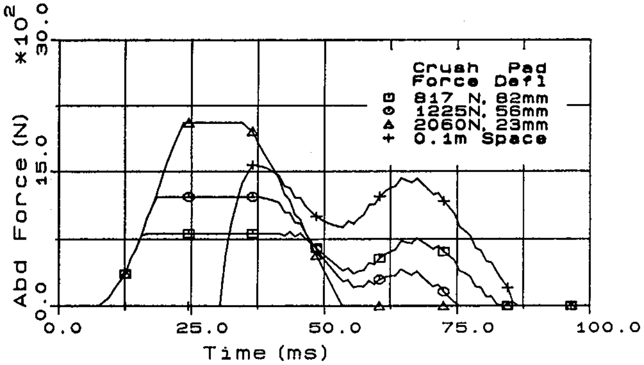


Figure 19. Comparison of Force-Time Histories at the Abdomen for a Moving Rigid Wall With 0.1 m of Air Space and a Moving Padded Wall With No Space

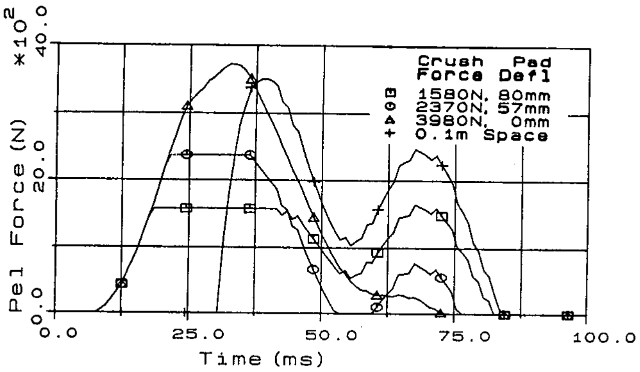


Figure 20. Comparison of Force-Time Histories at the Pelvis for a Moving Rigid Wall With 0.1 m of Air Space and a Moving Padded Wall With No Space

Since force was found to be not well correlated with injury, an analysis of the chest kinematics was made. Figure 21 shows a comparison of thoracic compression as a percentage of chest width for the unpadded rigid door with an air space of 0.1 m, the same door with no air space and three different padded doors with no air space. The padding would have to be more compliant than the 15 psi paper honeycomb before the maximum compression is less than that for a rigid wall with 0.1 m of air space. The same is true for the viscous or V*C criterion, as shown in Figure 22.

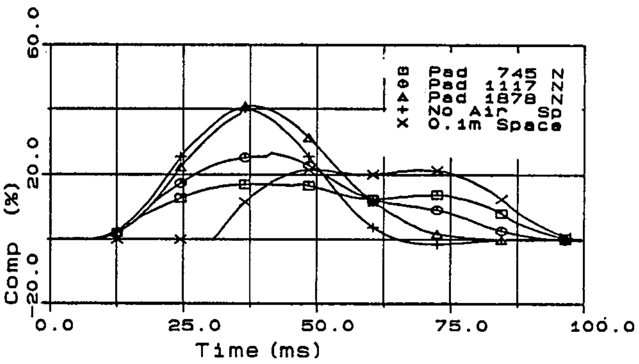


Figure 21. Comparison of Chest Compression for Moving Wall Impacts: Rigid Wall With No Air Space, Rigid Wall With 0.1 m of Air Space and Padded Walls with No Space

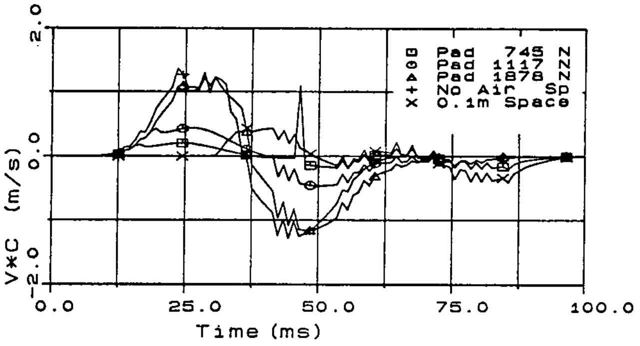


Figure 22. Comparison of the Viscous Criterion (V*C) for Moving Wall Impacts: Rigid Wall With No Air Space, Rigid Wall With 0.1 m of Air Space and Padded Walls With No Space

Side Impact with No Shoulder Engagement

Without engagement of the shoulder with the side door, there is a significant increase of 45% in the force sustained by the thorax, when the test subject was impacted by an intruding rigid side door. The model also predicted relatively smaller increases in force at the level of the abdomen and pelvis. The force-time histories for all four levels are shown in Figures 23 through 26. Thoracic compression increased by approximately 30% when there is no shoulder engagement.

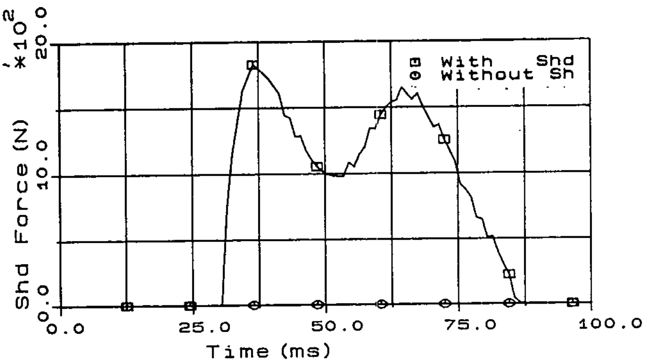


Figure 23. Shoulder Contact Force Due to an Intruding Rigid Wall Impacting an Occupant Seated 0.1 m Away from the Wall

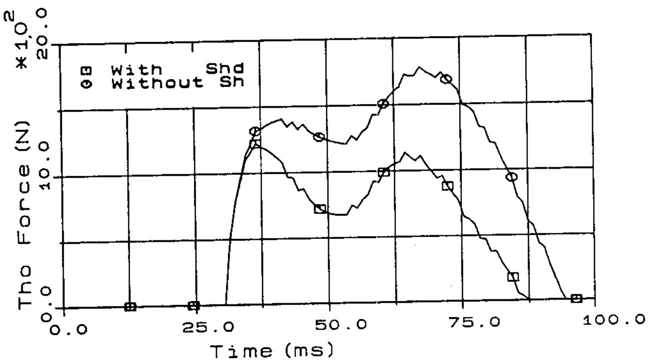


Figure 24. Thoracic Contact Force Due to an Intruding Rigid Wall Impacting an Occupant Seated 0.1 m Away from the Wall, With and Without Shoulder Engagement

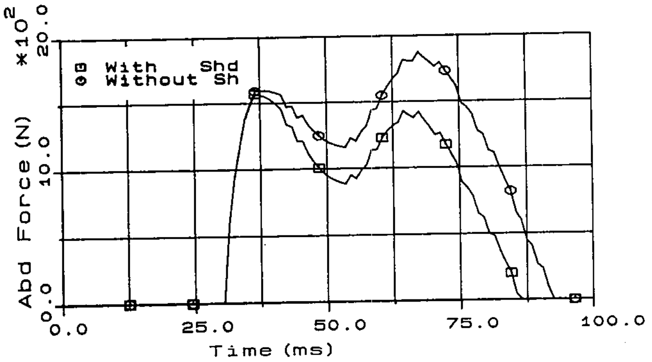


Figure 25. Abdominal Contact Force Due to an Intruding Rigid Wall Impacting an Occupant Seated 0.1 m Away from the Wall, With and Without Shoulder Engagement

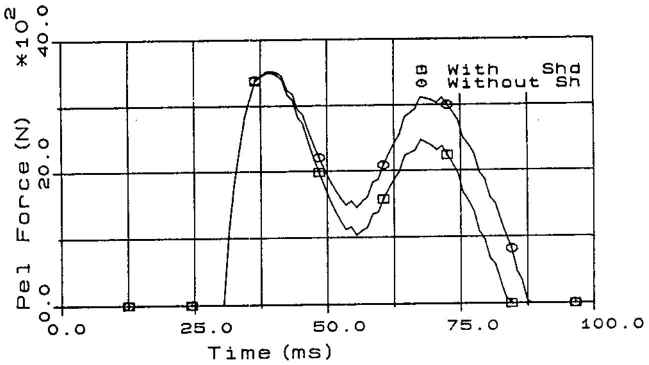


Figure 26. Pelvic Contact Force Due to an Intruding Rigid Wall Impacting an Occupant Seated 0.1 m Away from the Wall, With and Without Shoulder Engagement

Discussion

This model is a preliminary effort to predict side impact response of a near side occupant. It is based on cadaveric data obtained at the shoulder, thorax, abdomen and pelvis. The purpose of the model was to develop a surrogate which has human-like characteristics and which can be used to predict actual injuries rather than compliance with FMVSS 214. It was exercised to study two specific design problems—the type of padding that should be used and the potential for thoracic injury if there was no shoulder engagement with the side door.

The opinion that stiff padding would not reduce thoracic force and deflection if it occupied all of the air space available was confirmed by this model. It certainly should be verified experimentally since the model indicated that a softer padding could be effective in reducing thoracic response. Based on these results, the design implications are that the door structure should be strengthened to reduce door velocity and a soft padding should be used to further reduce the force and deformation levels. The predicted increase in thoracic response when there is no shoulder engagement renders these implications even more significant. If the window sills are to remain low in future vehicles, there is a need to confirm these results experimentally, preferably using more human-like anthropomorphic dummies. However, if such dummies cannot be made available soon, the testing should be done with cadaveric subjects.

The model can be exercised further to study the injury potential of using a variety of padding and the effect of changing door velocity profiles. The effect of shoulder interaction with the door can also be studied in greater detail. In particular, the combination of padding with a low window sill should be investigated.

Conclusions

1. A one-dimensional lumped parameter model has been developed to simulate near-side occupant response to a side impact.
2. Model parameters were determined to yield responses measured experimentally, using cadaveric subjects.

3. The response of the occupant in an actual impact appears to be different from that simulated experimentally, using the University of Heidelberg test set-up.
4. Padding that takes up all of the free air space between the side door and the occupant needs to be extremely compliant before it can be effective in reducing thoracic force and deformation levels.
5. A low window sill can increase thoracic response and experimental data are needed to confirm this model prediction.

Acknowledgment

This research was supported in part by CDC Grant No. CCR 502347-6.

References

Cavanaugh, J.M.; Walilko, T.J.; Malhotra, A.; Zhu, Y.; King, A.I., (1990) Biomechanical Response and Injury Tolerance of the Pelvis in Twelve Sled Side Impacts. Proc. of the 34th Stapp Conf., SAE Paper No. 902305.

Cavanaugh, J.M.; Walilko, T.J.; Malhotra, A.; Zhu, Y.; King, A.I., (1990) Biomechanical response and injury tolerance of the thorax in twelve sled side impacts. Proc. of the 34th Stapp Conf., SAE Paper No. 902307.

Marcus, J.H.; Morgan, R.M.; Eppinger, R.H.; Kallieris, D.; Mattern, R.; Schmidt, G., (1983) Human response to injury from lateral impact. Proc. 27th Stapp Car Crash Conf, SAE Paper No. 831634.

S5-O-06

The Protective Effect of Airbags and Padding in Side Impacts—Evaluation by a New Subsystem Test Method

Yngve Håland
Electrolux Autoliv AB
Bengt Pipkorn
Chalmers University of Technology

Abstract

The risk of being injured with life threatening or permanently disabling consequences is higher in side impacts than in frontal impacts. Occupants sitting on the struck side receive twice as many injuries as occupants on the non-struck side. Improved protection in side impacts can be achieved with car body/door reinforcements and padding/airbag on inside of the door. When side impact protective systems are being developed, there is a need for an economical subsystem test method, that simulates full scale test conditions. This study presents a new test method, where a car door mounted on a sled impacts a test dummy. The method takes into account the two main injury causing factors in side impacts, the door to dummy impact speed and the velocity history of the door inner wall, which will determine the door to dummy displacement/overlap. The new test method is then used to evaluate the effect of the padding/airbag in the chest area and the padding in the pelvis area. The chest airbag results in generally lower loadings to the head, neck and chest than chest padding (50 mm) and significantly lower loading than a stiff reference door. Soft pelvis padding (75 mm thick) effectively reduces the pelvic loads. The best configuration, chest airbag and pelvis padding, gave a considerable improvement in 48 km/h (30 mph) as well as 32 km/h (20 mph) side impact tests.

Introduction

The passive safety of cars has greatly improved during the last decades. The passenger compartment has been made more rigid and the frontal zone of the car has a better deformation characteristic. The introduction of the seat belt was a major step in the reduction of the number of occupants injured and killed in car accidents. The effectiveness of the seat belt has been documented in several investigations. Evans (1) found it to be 41% in preventing outboard occupant fatalities. Norin et al. (2) found it to be 24% for drivers and front seat passengers with minor and moderate injuries and as high as 68% in case of severe and fatal injuries.

The seat belt effectiveness is however lower in side impacts, but the belt is effective in preventing ejection out of the car (3). Otto et al. (4) showed that there was only a small protective effect offered by the seat belt in a right angle near side impact with door intrusion. For passengers seated on the opposite side to the impact, the effect of the seat belt was evident in all cases.

Frontal collisions are very frequent and account for more than 50% of all accidents. Side impacts come in second place with about 20%, but the portion of seriously injured is higher, at 35%. Injuries were found by Håland et al.(5) to be twice as common for occupants on the struck side compared with occupants on the non-struck side. It was also found that the head, chest and abdomen/pelvis are mainly exposed to life threatening injuries, whilst the neck and the legs mainly receive injuries with a risk of permanent disability. Moreover, the study showed that elderly people received significantly more chest injuries than young people on average four times greater. Based on these results Electrolux Autoliv, one of the major European suppliers of occupant restraint systems, is active in the research and development of a side impact protection system that improves the protection not only of the struck side occupant's chest but also of the head, neck, abdomen, pelvis and legs. A system with an airbag in the door was presented by Electrolux Autoliv the first time at the ESV Conference in 1989 (6).

The need to improve the passive safety of cars in lateral collisions has been recognized during recent years in both the United States and Europe. There are now two side impact test procedures, one American (7) and one European (8). The American procedure will be effective in a couple of years. 10% of sold MY (model year) 94 vehicles in the United States, 25% MY95, 40% MY96 and 100% MY97 must fulfill the new requirements. Each car model must pass a side impact test with a mobile deformable barrier of 3000 lbs (1360 kg) weight, which represents an average American car in size and frontal stiffness. The test simulates a road intersection crash in which the struck vehicle—the vehicle to be tested for compliance—is travelling at 24 km/h (15 mph) and the striking vehicle is moving at 48 km/h (30 mph).

It is not yet known, when the European proposal will be effective. The proposal prescribes a 50 km/h side impact test at right angles with a mobile deformable barrier of 950 kg weight that is lighter than the American one. The European barrier can however be more aggressive since it is not as wide as the American version and the frontal characteristic is different.

A typical 48 km/h (30 mph) car to car side impact is characterized by a rapid acceleration of the door adjacent to the struck side occupant. The door inner surface impacts the occupant very early, typically at about 20 ms, with a speed that can be as high as the speed of the impacting car. The impacted car has at this time barely started to move laterally (9,10).

There are two important injury causing factors in side impacts found by mathematical and mechanical simulations. The first is the door inner velocity at the time of impact with the occupant. The second is the door inner surface velocity history during the total period of contact with the occupant. This determines the door to occupant displacement/overlap (11,12,13).

The occupant protection in side impacts can potentially be improved by different measures. A reinforcement of the car body and the door will reduce the door inner velocity as well as the car body deformation (14). Padding on the inside of the door can reduce the chest loading, if the padding thickness and characteristics are tuned in an appropriate way (15). Viano has shown that the padding must be "soft" and rather thick.

The so called viscous response or viscous criterion, VC, is used as the most relevant injury criterion in side impacts (16). The chest of a struck side occupant is loaded by the intruding door with a speed that is higher than that of a belted occupant in a frontal impact. The injury causing mechanisms are therefore different. The speed of the intruding door, at the time of contact with the chest in a 48 km/h (30 mph) side impact, can be in the range of 8-12 m/s, at which speed the chest behaves with a visco (elastic) response. The viscous response is the instantaneous product of the chest deformation speed and compression during an impact. The proposed injury criterion is VC ≤ 1 m/s. This is included in the European side impact proposal, but not in the new American version. This latter procedure stipulates a chest criterion called TTI (thoracic trauma index), which is the average of the maximum spine acceleration and the near-side rib acceleration, both in g's. The calculated TTI-figure shall be below 85 g for four-door cars and 90 g for two-door cars (7). Which injury criterion that is most relevant to use, TTI or VC, is a controversial question. A side impact protection system, for example a certain padding, can reduce TTI but not necessarily VC (11).

To develop and evaluate potential improvements in side impact protection, suitable test methods are necessary. The American and European side impact test procedures both prescribe full-scale tests with cars. However during the research and development phases there is a need for less expensive subsystem test procedures.

Tsujimora et al. (17) developed a sled test method where parameters such as impact velocity, body side intrusion and collision angle can be controlled. A partial car body was used in each test. Preuss and Wasko (18) used a side impact test device representing the human thorax. A lot of effort has been expended by European car manufacturers, represented by CCMC, in the so called Composite Test Procedure (CTP). The method is a combination of testing and computer evaluation. There is no need for a mechanical test dummy. Richter (19) suggests that a mathematical dummy could be better suited in providing a humanlike behaviour. The CTP-method permits evaluation of dummy loadings at different impact speeds. However, there is still a need for a side impact subsystem test method that is both economical and gives a valid response pattern to all body regions. In such a method it is necessary to impact all the relevant body regions such as the shoulder, the thorax, the pelvis and the legs since the motion of these body regions will also affect the thorax response (11).

The aim of this study was to develop a new side impact subsystem test method that simulates full scale test conditions and then use the method to evaluate the effect of different padding and airbag configurations in order to reduce the loadings on the body regions exposed to injuries (head, neck, chest, abdomen and pelvis) at different velocities. The study was the first attempt to find the principles for an optimum protective system.

Method

The method described here has been developed and used by Electrolux Autoliv. The main objectives are, that the method shall represent full-scale testing conditions, have good repeatability and be economical.

A prerequisite for tests according to the method is that a full scale 48 km/h (30 mph) side impact test has been run and some essential parameters have been measured (fig. 1 and 2). The velocity history of the door inner wall at chest and pelvic levels, relative to the car, and the door to dummy clearance (distance A in fig. 1)will determine the violence of the energy transfer to the occupant.

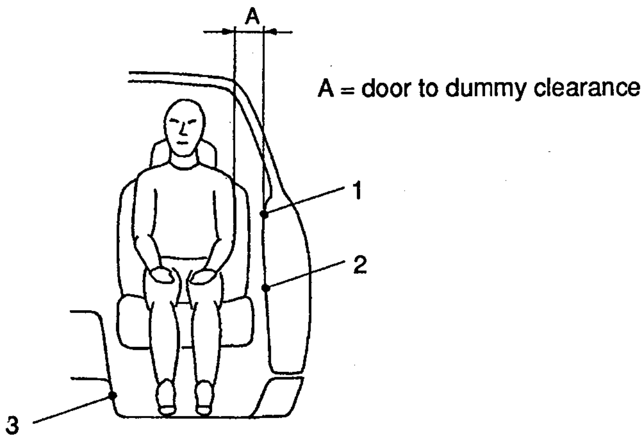


Figure 1. Three Different Accelerometer Locations

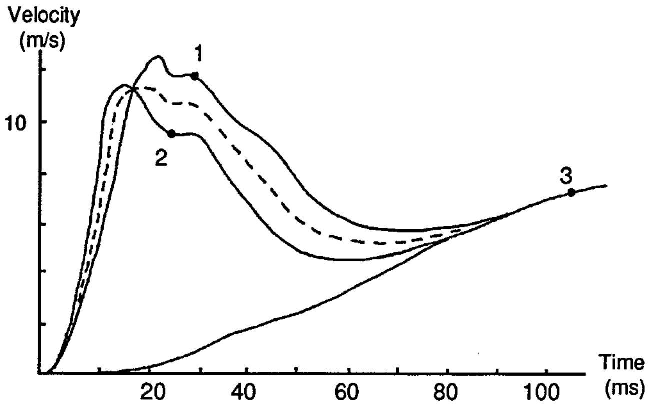


Figure 2. Typical Door and Car Velocities

(1,2,3 = locations from fig. 1)

Pelvic load cells (measuring forces) will give information, if the dummy is squeezed between the intruding door and the centre tunnel section of the car.

Lateral accelerations are measured at three different locations during the full scale side impact test (fig. 1). The first accelerometer is located at the upper part of the door interior at a mid lateral chest position for a 50 percentile male. The second accelerometer is located close to the H-point. The third accelerometer measures the lateral acceleration of the whole car. A suitable location is at the centre tunnel section. The signals from the three accelerometers are integrated and velocity-time curves are obtained (fig. 2). An average of the two door velocity curves is estimated (dotted line in fig. 2). (Different intrusion patterns caused by American and European mobile deformable barriers can be taken into account by preshaping the door.)

The difference in velocity between the door inner wall and an undeformed part of the car can then be obtained and a new velocity curve will be drawn (fig. 3). An integration of this curve gives the door to car lateral displacement.

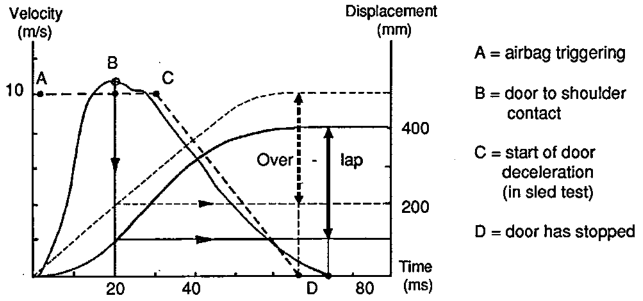


Figure 3. Door Velocity and Displacement Relative to the Car

The test method (fig. 4) comprises a reinforced door, mounted to the test sled, and a dummy sitting on a seat at right angle to the crash track. The door must be reinforced to give the inner structure the same support as the front of the impacting car (or the mobile deformable barrier) gives in the full scale test. The door approaches the dummy at a constant speed and is then braked at a constant deceleration, from C to D (fig. 3). The final overlap between the door inner wall and the original position of the dummy shoulder, shall be the same as in the full scale test. The door-shoulder contact starts at time B, which shall also correspond to the full scale test. Triggering of a side airbag (see below) takes place at time A, which is within a few milliseconds.

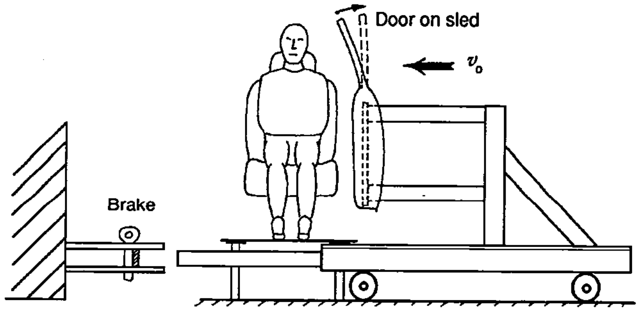


Figure 4. Door on Sled Impacting the Dummy

The head to side window impact can be analysed in an appropriate way if the window frame is bent to a vertical position (the position at the time of head impact in the full scale test).

Two series of tests were conducted, the first corresponded to a 48 km/h (30 mph) car to car side impact and the second to a 32 km/h (20 mph) side impact. The door test velocity in the first series of tests was 9 m/s. This represents a car with a good reinforcement of the body and door structure (14).

The overlap, before braking, between the door innerside and the original position of the dummy shoulder was chosen to be 100 mm and the deceleration 20 g. This resulted in a total overlap of 300 mm, when the sled had stopped. It corresponds to a car body lateral deformation of about 500 mm. Triggering of the airbag, when tested, took place at 2 ms (time A in fig. 5).

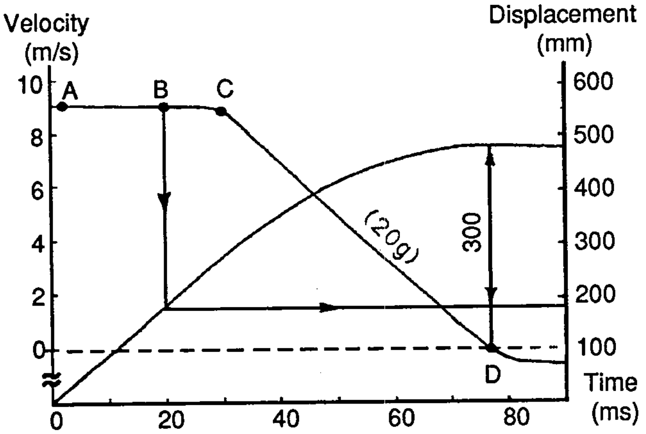


Figure 5. Door Velocity and Displacement "48 km/h (30 mph) Side Impact"

The door test velocity in the second series of tests was chosen to be 6 m/s. This should correlate to a 32 km/h (20 mph) car to car side impact. The car body lateral deformation at this impact speed was estimated to be about 150 mm less than for the same car at 48 km/h (30 mph). (The same car body stiffness was assumed). The door velocity and displacement curves can be found in fig. 6. The overlap between the door innerwall and the original position of the dummy shoulder, before braking, was 70 mm and the deceleration 20 g. This gave a total overlap of about 150 mm, when the sled had stopped, compared with the overlap of 300 mm at the 9 m/s tests. Triggering of the airbag (when tested) took place at 3 ms (time A in figure 6).

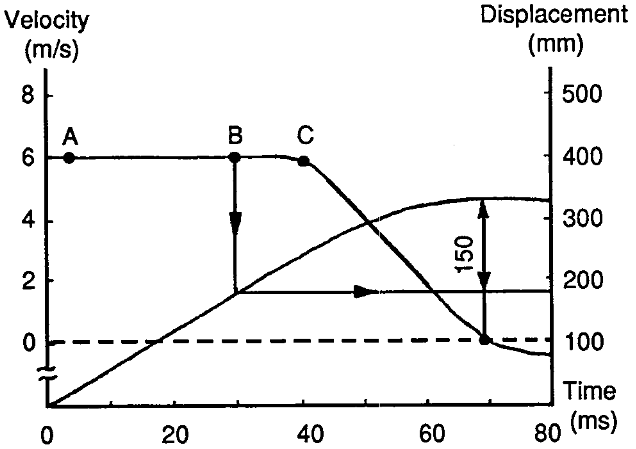


Figure 6. Door Velocity and Displacement "32 km/h (20 mph) Side Impact"

The test dummy used was the BioSid. The tests were run at the Electrolux Autoliv sled test facility in Vårgårda, Sweden. The following test dummy parameters were measured and calculated:

- Head linear accelerations (a_x, a_y and a_z); HIC-calculation
- Head angle (ϖ_x) (from high speed film)
- Head angular velocity (ϖ_x) (derivative of ϖ_x)
- Head angular acceleration (ϖ_x)
- Transverse neck forces, upper and lower (Fy)
- Neck bending moment, upper and lower (Mx)
- Upper and lower spine accelerations (a_y) at T1 and T12 for TTI calculation
- Thorax rib accelerations, 3 ribs, (a_y) for TTI calculation
- Thorax rib displacements, 3 ribs (y-direction) for VC-calculation
- Abdominal rib displacement, 2 ribs (y-direction) for VC-calculation
- Pelvic accelerations (resultant of a_x, a_y and a_z)
- Pelvic forces, sacrum and pubic (Fy)
- Bag pressure (when airbag was used)

The coordinate directions were those normally used by car makers. An angular accelerometer was put into the head as extra instrumentation (Endevco Model No 7302 BM2). It was fitted to a special adapter and located at the head inertia point to measure the angular acceleration around the x-axis.

All measured signals were filtered according to SAE CFC 180. For the calculation of chest and abdominal VC the unfiltered (CFC 1000) rib-to-spine deflection signal was differentiated to obtain rib-to-spine velocity. Both rib-to-spine deflection and velocity were then filtered by CFC 180, multiplied and divided by 175 mm to obtain the viscous response (VC).

Three basic configurations (A, B and C) were tested and compared at the 9 m/s test velocity. The A and C configurations were also tested at 6 m/s.

A. *A reference door.* A 10 mm thick and stiff polyethylene padding (Termolon 80) covered the flat rigid door inner-side and the B-pillar.

B. *50 mm chest and 75 mm pelvis paddings.* The chest padding was 100 mm high and 500 mm long, and located at the upper part of the door to protect the chest. The pelvis padding was 200 mm high and 600 mm long and located beneath the chest padding to protect the lower part of abdomen, the pelvis and the thigh. The material was polyethylene foam with open cells and a density of 30 kg/m^3 (Termolon30).

C. *Chest airbag and 75 mm pelvis padding.* The airbag had an inflated volume of about 8 litres. Height and width were 170 mm and 120 mm respectively. The length was 450 mm. The bag material was a typical rubber coated polyamide fabric used for airbags. Two small gas generators, of the same type employed for pyrotechnical pretensioners, were used. The pyrotechnical charge was in total 3.5 grams. The same 75 mm thick pelvis padding as in configuration B was used.

All three configurations can be found in fig. 7 and a picture of each configuration in fig. 8 (conf. A), fig. 9 (conf. B) and fig. 10 (conf. C). The position of the dummy can best be seen in fig. 7. It was positioned so that the head should not hit the B-pillar. (The most common side impact force direction, for a struck side occupant, is 10 o'clock. Even a tall occupant, sitting in the most rear seat position in a 4-door car, will normally not hit the B-pillar).

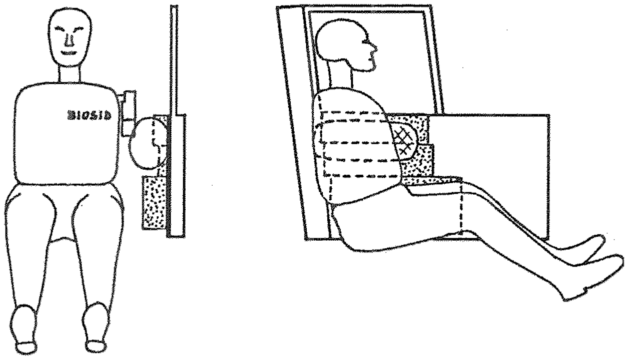


Figure 7. Test Configurations

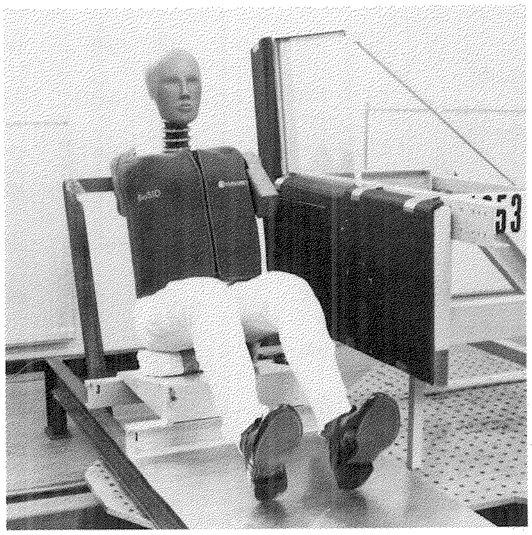


Figure 8. Conf. A, Ref. Door

It has been found in contacts with carmakers that there is only space for a maximum of 50 mm padding in the chest area and a maximum of 75 mm in the pelvis area. The pelvis padding can be made thicker, since it is located below the armrest level. The chest airbag is normally hidden behind the door panel. It can be considered as thick soft padding, when it is inflated.

The chosen padding material, polyethylene foam with open cells of 30 kg/m^3 density, is almost as soft as can be obtained. It has a progressive characteristic to also give protection in lower speeds. A soft material should have a better possibility to protect the weaker elderly portion of the population than a stiffer material.

The reference door (conf.A) and the door with a chest airbag and pelvis padding (conf.C) were also tested with a 6 mm (3+3 mm) side window in polycarbonate to study the effect of head impact.

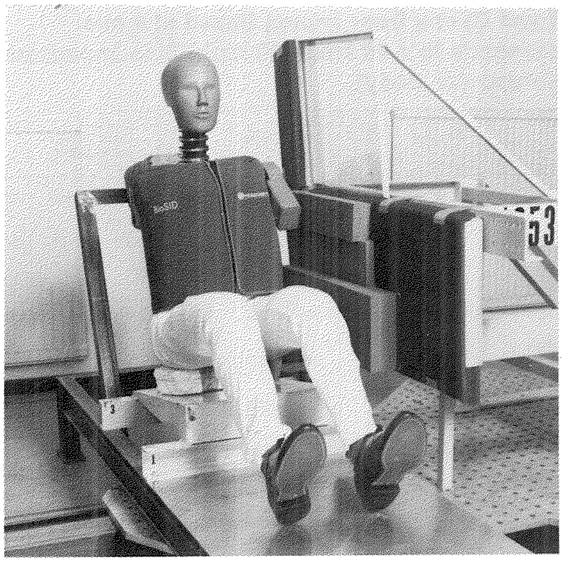


Figure 9. Conf. B, Chest and Pelvis Padding

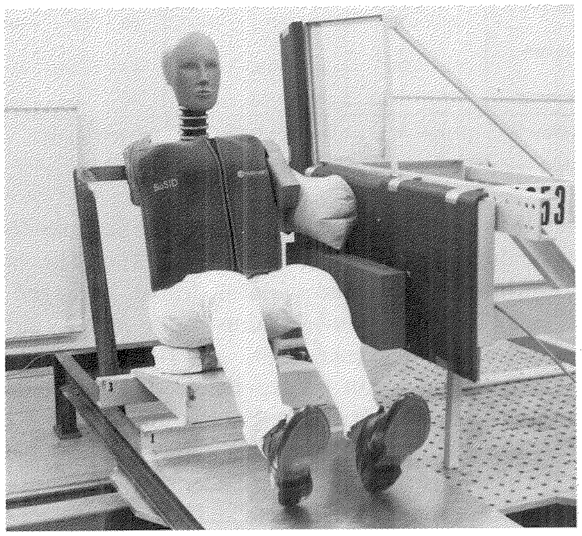


Figure 10. Conf. C, Chest Airbag and Pelvis Padding

Results

The test results of the three configurations at 9 m/s are summarized in table 1. The mean of the maximum values from N tests and the 95% confidence limit of the mean value for each parameter are shown.

The bag pressure (conf. C) just after inflation and before chestloading averaged 80 kPa (0.8 bar). The bag had no ventilation. It was close to bottoming out in the test but didn't. However, the 50 mm chest padding in conf. B did bottom out (i.e. fully compress).

The pelvis padding in configurations B and C bottomed out at about 30 ms, a few milliseconds before the pelvis acceleration reached its maximum.

The upper neck force was always higher than the lower neck force and the lower neck moment was also

Table 1. Results of Sled Tests With Three Configurations (A, B and C) at a Door Impact Speed of 9 m/s (Corresponds to a 48 km/h (30 mph) Side Impact into a Reinforced Car Body)

Parameter	Config. A Ref. door (N=5)		Config. B Chest + pelvis padding (N=3)			Config. C Chest airbag+ pelvis padding (N=5)		
HIC	92	(±9)	74	(±7)	-20% 3)	65	(±7)	-29% 3)
Head ang.acc. (rad/s²)	1170	(±90)	890	(±80)	-24%	560	(±70)	-52%
Head ang. vel. 4) (rad/s)	43	(±4)	33	(±7)	-23%	30	(±2)	-30%
Head angle (rad) 4)	1.0	(±0.1)	0.9	(±0.1)	-10%	0.9	(±0.1)	-10%
Upper neck transv. force (kN)	0.7	(±0.0)	0.6	(±0.0)	-14%	0.6	(±0.0)	-14%
Lower neck moment (Nm)	62	(±3)	56	(±2)	-10%	52	(±3)	-16%
Upper spine acc. (T1) (g)	51	(±3)	47	(±3)	-8%	42	(±2)	-18%
Lower spine acc. (T12) (g)	83	(±1)	68	(±3)	-18%	58	(±1)	-30%
TTI (g)	123	(±7)	80	(±11)	-35%	75	(±6)	-39%
Thorax rib deflection (mm)	67 1)	(±3)	61 1)	(±2)	-9%	55 2)	(±4)	-18%
Chest VC (m/s)	1.5	(±0.2)	1.1	(±0.1)	-27%	0.8	(±0.1)	-47%
Abdomen VC (m/s)	2.1	(±0.1)	1.0	(±0.1)	-52%	0.8	(±0.1)	-62%
Sacrum force (kN)	6.5	(±0.5)	4.6	(±0.4)	-29%	4.2	(±0.1)	-35%
Pelvis acc. (g)	233	(±7)	128	(±13)	-43%	125	(±3)	-44%

1) Upper rib 2) Lower rib 3) Change relative to conf.A 4) Relative to spine

No side window. (mean±95% conf. limit).

higher than the upper neck moment. The sacrum force was the highest of the two pelvis forces. The head ejection, outside the side window frame, averaged 30 mm less for the configuration with chest airbag compared to the reference door.

Differences in mean values between parameters of configurations A and B and between A and C respectively are all statistically significant, p<0.05 or better (comparison of two means, independent samples, t-distribution) except for the head angle and upper spine acceleration (conf.B). The significance is high (p<0.001) for differences of 24% and larger.

A comparison between the three configurations showing some parameters for head, neck, chest, abdomen and pelvis, that are in the neighborhood of injury criterion or tolerance levels, are indicated in fig. 11.

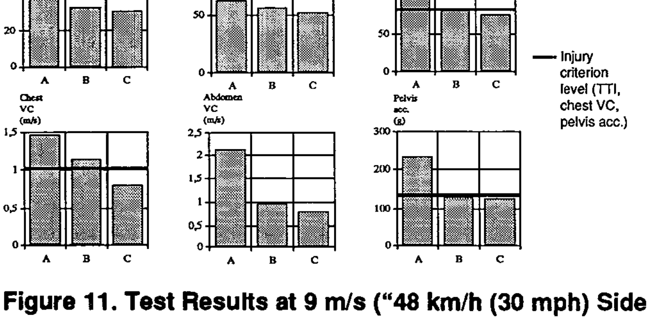


Figure 11. Test Results at 9 m/s ("48 km/h (30 mph) Side Impact") for A, B and C Configurations

The introduction of the side window in 6 mm polycarbonate only changed the head load, due to impact, in the reference door case. The HIC value increased from 92 to 133 units (mean values). The head velocity into the side window, the component in the y-direction, was derived from high speed film evaluation. It averaged 6.4 m/s for the reference door, (conf. A), and 3.7 m/s for the door with chest airbag and pelvis padding, (conf. C). The reference door window flexed about 15 to 20 mm when struck by the dummy head, compared to only 5 mm, when there was an airbag between the dummy and the door. (Conf. B was not tested with a side window).

The second series of tests, at 6 m/s, was run with configurations A and C only. The results are summarized in table 2. The mean of maximum values of each parameter from three tests of each configuration are shown.

Table 2. Results of Sled Tests with Two Configurations (A and C) at a Door Impact Speed of 6 m/s (Corresponds to a 32 km/h (20 mph) Side Impact into a Reinforced Car Body)

Parameter	Config. A Ref. door (N=3)		Config. C Chest airbag+ pelvis padding (N=3)		
HIC	12	(±3)	12	(±9)	±0% 1)
Head ang.acc. (rad/s²)	640	(±460)	310	(±210)	-52%
Head ang. vel. 2) (rad/s)	23	(±11)	19	(±4)	-17%
Head angle (rad) 2)	0.5	(±0.1)	0.6	(±0.4)	+20%
Upper neck transv. force (kN)	0.4	(±0.1)	0.4	(±0.1)	±0%
Lower neck moment (Nm)	31	(±4)	33	(±10)	-6%
Upper spine acc. (T1) (g)	27	(±8)	21	(±1)	-22%
Lower spine acc. (T12) (g)	38	(±3)	30	(±1)	-21%
TTI (g)	79	(±30)	47	(±15)	-40%
Thorax rib deflection (mm)	32	(±2)	25	(±5)	-22%
Chest VC (m/s)	0.5	(±0.1)	0.2	(±0.0)	-60%
Abdomen VC (m/s)	0.4	(±0.1)	0.2	(±0.0)	-50%
Sacrum force (kN)	3.5	(±1.0)	2.9	(±0.3)	-17%
Pelvis acc. (g)	75	(±16)	73	(±4)	-3%

1) Change relative to conf. A. 2) Relative to spine

No side window (mean ±95% conf. limit).

The differences in lower spine accelerations, chest VC and abdominal VC between the two configurations are statistically significant (p<0.05 or better).

Evaluation of the high-speed films revealed that the dummy never reached the side window plane.

A comparison of the two configurations for head, chest and pelvis are shown in fig. 12, all well below injury criterion or tolerance levels.

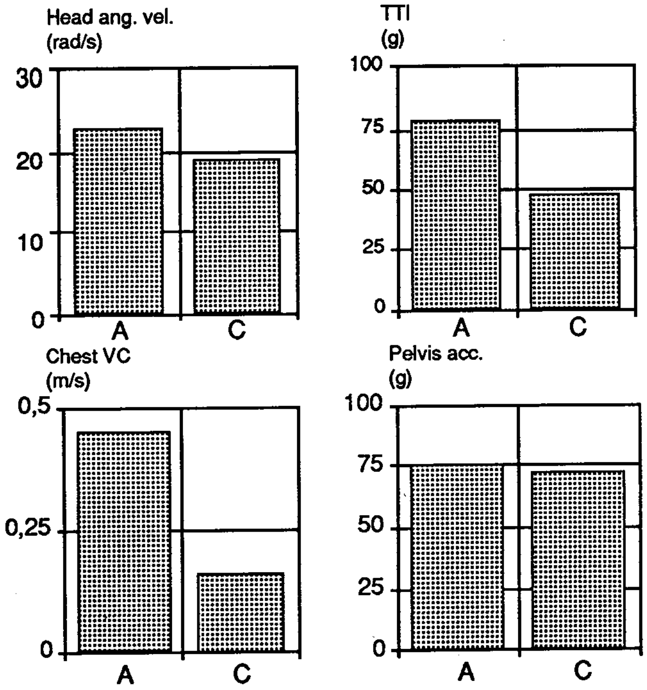


Figure 12. Test Results at 6 m/s ("32 km/h (20 mph) Side impact") for A and C Configurations

Discussion

The test method used takes good account of the two main injury causing factors in side impacts, the door inner velocity at the time of impact with the occupant and the inner wall velocity history during the total period of contact with the occupant. This velocity history determines the door to occupant displacement/overlap.

With this test method the inside of the door has the same vertical profile during the whole impact sequence. This corresponds better with the deformation pattern given by the American mobile barrier than with the European. The American barrier has on average the same stiffness at different heights, whilst the European one is stiffer in the lower half of the front face. Fig. 2 shows typical curves from a test with a European barrier. The pelvic area of the door is deformed earlier than the chest area. This effect can be taken into account in the test method by using a pre-shaped door.

The impacted car starts to move after 10-15 ms in a full scale test. Transverse lateral forces are transmitted to the dummy through the seat cushion. This can not be achieved in the sled test. However, this effect is negligible at the time viscous response, VC, reaches its maximum. The car then has moved less than 30 mm laterally.

The head to window impact takes place at around 50 ms with a window frame which has been bent to a vertical position, or even to a slightly over-bent position in a full scale test (20). The tests with a side window in this study had the frame therefore in a vertical position.

If pelvic loads of more than 10 kN have been recorded in the full scale test, a deformable plate can be mounted at the inner pelvic side of the dummy, to give the same loading. This is an indication that the pelvis has been squeezed. In the tests reported in this paper, it was assumed that the car was well reinforced. Any squeezing of the pelvis should therefore not have taken place. This problem is however probably found with smaller cars.

The subsystem test method, used in this study, is a valuable supplement to full scale testing during the research and development phases of a side impact protection system. However, verifying full scale tests must be performed, before the system can finally be released for production. The great advantage with the subsystem test method is that it permits evaluation of different parameters at a reasonable cost. A combination with mathematical simulations will improve the efficiency of the research and development work even further.

The spread of the measured test values at 9 m/s according to table 1 was small when five tests (N = 5) had been run of conf. A and conf. C respectively. At three tests (N = 3) the spread was still acceptable for the conf. B values. However, at the 6 m/s tests the spread of the test values in general increased. To be able to show statistical significance in the difference of two mean values it is recommended to run at least five tests based on these results.

The tests were run in three blocks to see if there was any systematic changes in the dummy readings. These changes were small with a typical range of ± 3%.

The stiffness of the front structure of the impacting car (the bullet car) and the strength of the door and the side of the impacted car (the target car) determine the velocity by which the occupant is hit by the intruding door (21). If the target vehicle door is weak and the frontal structure of the bullet car is strong, the door will impact the occupant at approximately the speed of the bullet vehicle. If, on the other hand, the target car is strongly reinforced and the bullet car has a soft front the impact with the occupant will take place with a velocity which approaches the "momentum velocity." For cars of approximately equal mass this velocity is about one-half of the impacting car's velocity. At a 48 km/h (30 mph) side impact the door to occupant impact velocity therefore can vary from about 13 m/s down to 7 m/s. The chosen test velocity of 9 m/s represents a reinforced car. To come down to 7 m/s the reinforcement would probably be so extensive that the car will not be practical to produce.

The chest to door clearance is normally in the order of 100-150 mm. An airbag must be fully inflated in about 10-12 ms, before the gap between the door and the occupant has been closed more than 50%. The full bag inflation takes 7-8 ms with the type of gas generators used in the airbag system in this study. This leaves a time of 2-4 ms for the sensor to trigger. At both door velocities, 9 m/s and 6 m/s, the sensor triggering time was chosen to correspond to about 30 mm of door penetration under full scale conditions.

When padding is placed on the inside of the door, the contact with the occupant will take place earlier in a side impact with an intruding door. More energy will be transferred to the occupant. The padding material will rather easily reduce the chest rib accelerations, which will lower the TTI. However there is a risk that the rib deformation and the viscous response, VC, will increase (11). These tests have shown that the negative effect of the increased energy transfer will be more than compensated for by the favourable load transfer and distribution. The reason for this is probably the soft and progressive characteristic of both the bag and the padding material and that they both give a certain energy absorption. The bag absorbs more energy than the 50 mm thick chest padding. The final lateral speed, of the dummy's chest spine, was 10.2 m/s for the reference door (conf. A), 10.5 m/s for the chest padding (conf. B) and 10.2 m/s for the chest airbag (conf. C). The time to reach the maximum spine acceleration, after initial chest contact, was about 15 ms for conf. A, 20 ms for conf. B and 25 ms for conf. C. The 75 mm pelvis padding used in conf. B and C increased the final lateral speed of the pelvis from about 15 m/s (conf. A) to about 17 m/s. This means that the lower part of the dummy was subjected to a larger portion of the energy transfer, when the pelvic padding was used. This was favourable for the chest.

There are at present time three side impact dummies available; USSid, EuroSid and BioSid. The first one is prescribed in the new US regulation and the second one in the European version. However, BioSid, which is the latest of the three dummies has the best biofidelity according to a comparative evaluation performed in 1990 (22). The BioSid has a chest, which is similar to the Hybrid III dummy used for frontal impacts. Beebe (23) has described the BioSid including tests to compare it with the ISO requirements (24). The BioSid was chosen for the tests because of its proven biofidelity. The repeatability of the dummy was also very good during the tests.

Pendelum tests, to determine the dynamic force deflection characteristics of different padding materials and of small airbags with different internal pressures, preceded the tests performed in this study. Some sled tests, similar to those reported here, were also run. Partly based on data from mathematical simulations reported by Viano (15) a padding/airbag characteristic of about 60 kN/m (at an impact area of 175 cm^2) was chosen. Both the polyethylene foam with a 30 kg/m^3 density and the chest airbag with a 80 kPa internal (over) pressure have this stiffness over a certain range of compression. The bag is softer during the initial compression. When the padding or the airbag bottoms out the stiffness rapidly increases.

The conf. C, chest airbag and pelvis padding, gave the lowest loads to all body segments. The improvements in relation to the reference door (conf. A) for head angular acceleration were -52%, angular velocity -30%, neck moment -16%, TTI -39%, chest VC -47%, abdominal VC -62% and pelvis acceleration -44%.

50 mm of chest padding gave the same reduction of TTI as the airbag but there was a significant difference in chest VC, -27% versus -47%. The reduction of TTI is achieved mainly by a reduction in the chest rib acceleration. The use of thin padding will give this reduction. The viscous response, VC, is considered by most researchers to be the most relevant chest parameter in side impacts. 50 mm of padding seems to be insufficient to come below the 1 m/s injury criterion level. The airbag, which can be considered as thick and soft padding, has a much better possibility to come below this value. The mean VC-value in the tests was 0.8 m/s (lower rib). The abdominal VC was at the same acceptable level.

The reduction in pelvis acceleration was the same for configurations B and C, down to about 125 g from 235 g for the reference door (conf. A). The 75 mm pelvis padding was the same for both configurations. 130 g is the pelvis acceleration criterion in the new US regulation. It therefore seems possible to meet this criterion with 75 mm padding.

The C-configuration had the lowest head and neck loadings. The HIC values were very low (< 100 units), since there were no head impacts. The proposed European regulation has a criterion level of 1000 units (the same level for frontal impacts according to FMVSS 208).

There are no existing injury criteria for head angular acceleration, head angular velocity and neck moment. Aldman and Chapon (25) and Gennarelli and Thibault (26) indicate a level of 2000-2500 rad/s^2 for the head angular acceleration and 30-40 rad/s for the head angular velocity for frontal rotation, which also seems conservative to use for lateral rotation. All three configurations showed acceptably low head angular accelerations. It is however interesting to note the considerable reduction for conf. C (-52%) in relation to conf. A. The head angular velocities recorded were close to the 30-40 rad/s mentioned above. The C-conf. had the lowest level, 30 rad/s versus 43 rad/s for conf. A.

In an ISO document (27) an injury assessment value of 57 Nm has been proposed for the neck extension moment. If this is used as a reference, the measured neck moment was slightly above for conf. A, at 62 Nm, and somewhat below for conf. C, 52 Nm.

The head velocity into the side window plane averaged 6.4 m/s for the reference door and only 3.7 m/s for the door with chest airbag and padding. The head ejection, outside the side window frame, was reduced by 30 mm on average. These reductions are of great importance if external objects are impacting the car in the head area.

The measured values in the 6m/s impact tests were in general much lower than those in the 9 m/s tests.

The TTI seems to have a linear relationship with the door impact speed, while the viscous response, VC, seems to have a relationship with both the door speed and the door to shoulder overlap.

In order to get a better understanding and to predict these relationships a mathematical BioSid dummy model was developed in the crash victim simulation program MaDyMo. The mathematical BioSid dummy is a 2 dimensional lumped mass model (fig. 13).

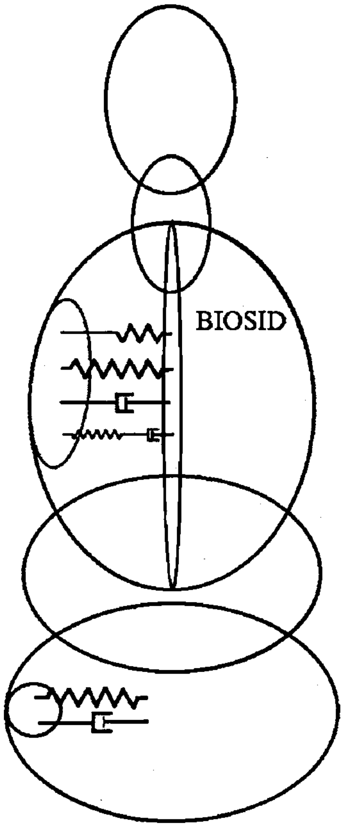


Figure 13. Mathematical BioSid Dummy

The masses are connected by non-linear springs and dampers. The model was validated by comparing predictions of the model with results from pendulum- as well as sled tests (28). The force/penetration characteristics of the airbag used in the calculations with the mathematical model were obtained by impacting an inflated airbag with a 23.4 kg pendulum. In the simulations it was decided to evaluate the performance of the C - conf. (chest airbag and pelvis padding) with respect to overlap (fig. 14) at different impact speeds. Door velocity histories, corresponding to the sled test conditions, were used.

At all impact velocities (6, 9 and 11 m/s) the chest VC with respect to overlap showed a tendency to increase. The VC also increased with the door to dummy impact speed.

The solid dots in the diagram (fig. 14) are the results from the sled tests (average from the three thorax ribs). Predictions from the model showed good agreement with the results from the sled tests.

In the conf. C simulations, at all impact velocities, the chest VC stays well below 1 m/s, which is the proposed injury criterion included in the European side impact proposal.

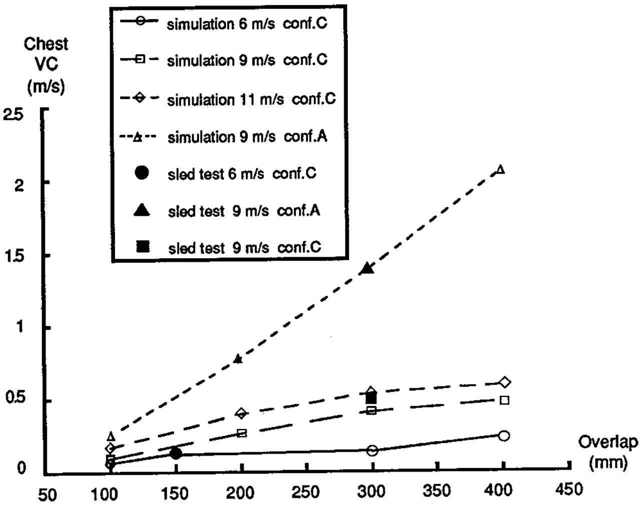


Figure 14. Simulation Results

However, for the reference door (conf. A) the VC increased past 1 m/s at an overlap greater than 230 mm and at a door impact speed of 9 m/s.

The mathematical simulation shows that an improvement to the side impact protection for the chest region requires both car body reinforcements, to reduce the lateral deformation, and a soft progressive cushion for the chest as well as for the pelvis. An airbag for the chest seems to be very suitable, which was also the result from the mechanical simulation (by sled tests).

The optimization of the chest airbag and pelvis padding configuration will follow this study. Both mathematical and mechanical simulations, as described above, will be used in this work.

Summary

The new side impact subsystem test method simulates the main injury causing factors in full scale tests. The dummy parameters measured in tests according to this new method are all sensitive to the door to dummy impact speed. There is also a relationship with the door to dummy displacement/overlap. A validated mathematical simulation model has shown this for the chest VC. The chest airbag in general gives lower loadings to head, neck and chest, than the chest padding and significantly lower loadings than the stiff reference door. The 75 mm thick and soft pelvis padding effectively reduces the pelvic loads. It also plays a roll in reducing the chest loads. The best configuration, chest airbag and pelvis padding, gave a considerable improvement in 48 km/h (30 mph) as well as 32 km/h (20 mph) side impact tests.

It seems possible to meet both the American and the European regulation requirements by a chest airbag and pelvis padding side impact protection system (which also assumes a reinforced car).

References

(1) Evans, L., "Motorized Two-Point Safety Belt Effectiveness in Preventing Fatalities," Proceedings of the 34th Conference, Association for the Advancement of Automotive Medicine, 187-201, 1990.

(2) Norin, H., Carlsson, G., Korner, J., "Seat Belt Usage in Sweden and Its Injury Reducing Effect," SAE Special Publications P-141, SAE Technical Paper 840194, 1984.

(3) Thomas, C., Henry, C., Harteman, F., Patel, A., Got, C., "Injury Pattern and Parameters to Assess Severity for Occupants Involved in Car-to-Car Lateral Impacts," Proceedings of the 11th International Technical Conference on Experimental Safety Vehicles, Washington, D.C., 49-61, 1987.

(4) Otte, D., Suren, E.-G., Appel, H., Nehmzow, J., "Vehicle Parts Cousing Injuries to Front-Seat Car Passengers in Lateral Impact," Proceedings of the 28th Stapp Car Crash Conference, SAE Technical Paper 841651, Warrendale, PA, 1984.

(5) Håland, Y., Lövsund, P., Nygren, Å., "Estimation of Fatalities and Disabilities in Car to Car Side Impacts—An Evaluation of Different Risk Factors," Proceedings of the 34th Conference, Association for the Advancement of Automotive Medicine, 275-287, 1990.

(6) Olsson, J.A., Skötte, L.-G., Svensson, S.-E., "Air Bag System for Side Impact Protection," Proceedings of the 12th International Technical Conference on Experimental Safety Vehicles, Göteborg, 976-983, 1989.

(7) National Highway Traffic Safety Administration, "Side Impact (FMVSS 214)—1993 Phase-In Implementation—Final Rule, Docket No. 88-06, Notice 8," 1990.

(8) Economic Commission for Europe, "Proposal for Draft Regulation: Uniform Provisions Concerning the Approval of Vehicles with Regard to the Protection of the Occupants in the Event of a Lateral Collision, Document TRANS/SC1/WP29/GRSP/R.48/Rev. 1," 1991.

(9) Warner, C.Y., Strother, C.E. Wooley, R.L., "Application of Kinematic Concepts to Side Impact Injury Analysis," SAE Technical Paper 900375, Warrendale, PA, 1990.

(10) Håland, Y, "Airbags to Reduce Injuries in Car to Car Side Impacts," Proceedings of 1st International Akzo Symposium on Occupant Restraint Systems, Cologne (Köln), 1990.

(11) Deng, Y.-C., "The Importance of the Test Method in Determining the Effects of Door Padding in Side Impact," Proceedings of the 33rd Stapp Car Crash Conference, SAE Technical Paper 892429, Warrendale, PA, 1989.

(12) Watanabe, K., Yamaguchi, T., "Analysis of Factors Affecting Dummy Readings in Side Impact Tests," Proceedings of the 12th International Technical Conference on Experimental Safety Vehicles, Göteborg, 1104-1114, 1989.

(13) Nilsson, M., Andersson, K., Korner, J., Nilsson-Ehle, A., "Volvo Side Impact Testing," Proceedings of the 10th International Technical Conference on Experimental Safety Vehicles, 649-658, Oxford, 1985.

(14) Mellander, H., Ivarsson, J., Korner, J., Nilsson, S., "Side Impact Protection System—A Description of the Technical Solutions and the Statistical and Experimental Tools," Proceedings of the 12th International Technical Conference on Experimental Safety Vehicles, Göteborg, 969-976, 1989.

(15) Viano, D.C., "Evaluation of the Benefit of Energy-Absorbing Material in Side Impact Protection: Part 11," Proceedings of the 31st Stapp Car Crash Conference, SAE Technical Paper 872213, Warrendale, PA, 1987.

(16) Lau, I.V., Viano, D.C., "The Viscous Criterion—Bases and Applications of an Injury Severity Index for Soft Tissues," Proceedings of the 30th Stapp Car Crash Conference, SAE Technical Paper 861882, Warrendale, PA, 1986.

(17) Tsujimura, H., Isobe, H., Maeda, K., "Dummy Injury Values Obtained in Side Collision Tests," Proceedings of the 9th International Technical Conference on Experimental Safety Vehicles, Kyoto, 494-503, 1982.

(18) Preuss, C.A., Wasko, R.J., "Motor Vehicle Manufacturers Association Subsystem and Full Vehicle Side Impact Test Procedure Development Program," Proceedings of the 11th International Technical Conference on Experimental Safety Vehicles, Washington, D.C., 124-133, 1987.

(19) Richter, B., "The Composite Test Procedure (CTP) —State of the Art," Proceedings of the 12th International Technical Conference on Experimental Safety Vehicles, Göteborg, 1077-1087, 1989.

(20) Klaus, G., Sinnhuber, R., Hoffmann, "Mobile Deformable Barrier for Lateral Collision Testing—A Contribution Toward a Harmonization of Future Side Impact Performance Requirements." SAE Technical Paper 840888, Warrendale, PA, 1984.

(21) Shokoohi, F., Breed, D.S., "One-Dimensional Model for Predicting Side Intrusion Injuries Including Effects of Padding," SAE Technical Paper 910600, Warrendale, PA, 1991.

(22) International Organization for Standardization, "ISO/TC22/SC12/WG5, Document N 281," 1990.

(23) Beebe, M.S., "What is Bio Sid?" SAE Technical Paper 900377, Warrendale, PA, 1990.

(24) International Organization for Standardization, "Technical Reports ISO 9790-1 to 6," 1989.

(25) Aldman, B., Chapon, A. (editors), "The Biomechanics of Impact Trauman, International Center for Transportation Studies, Elsevier Science Publishers, p. 161 and p. 179, 1984.

(26) Gennarelli, T.A., Thibault, L.E., "Clinical Rationale for a Head Angular Acceleration Criterion," Proceedings of the Head Injury Mechanisms Seminar, Association for the Advancement of Automotive Medicine and Volvo Car Corporation, Washington, D.C., 1989.

(27) International Organization for Standardization, "ISO/TC22/SC12/WG5 Document N 123," 1984.
(28) Pipkorn, B., "A Mathematical Approach to Evaluate the Benefit of Energy Absorbing Material in Side Impact Protection," Department of Injury Prevention Report R015, Chalmers University of Technology, Göteborg, 1991.

S5-O-09

Air Bag System for Side Impact Occupant Protection

Toru Kiuchi, Kenji Ogata
Toyota Motor Corporation
Charles Y. Warner
Collision Safety Engineering
John Jay Gordon
GMH Engineering

Abstract

Pilot and prototype designs of a door-mounted air bag system for occupant protection in side impact have been assembled and tested. The primary goal of the designs was to take advantage of the improved space utilization offered by the air bag when combined with the padding and structural benefits that are contemplated for torso injury. Another important goal of the project was the demonstration of the head-protection potential of such a system, attempting to interpose a pad between the head and side structures and intruding objects likely to cause impact injury.

The pilot design was subjected to a test program, providing a preliminary evaluation of a system which incorporates both head and torso protection in a single air bag system. The pilot design showed sufficient promise that a preliminary prototype design program was undertaken.

Full-scale crash tests of recent production 4-door sedans were conducted to establish baseline performance over a range of side-impact conditions. Design objectives were analyzed and subsystem performance goals were established and proven by component testing. The prototype system incorporated two kinds of sensor switches, a production steering wheel air bag inflator module, a large, flat, tethered air bag, and a fabric air bag cover, all mounted in a modified production door. The complete prototype system was evaluated in laboratory tests and full-scale crash tests, including FMVSS 214 crabbed moving deformable barrier (CMDB) tests employing the DOT/SID side-impact dummy. A very satisfactory performance was achieved, as demonstrated by comparison of dummy indices measured in baseline and air bag-equipped vehicles in full-scale crash tests. This paper outlines the designs and system configurations and discusses the results of the pilot and preliminary design test series.

Introduction

Fatalities and Injuries in Side Impact Accidents

Many head injuries occur in side impacts, due to contacts with interior structures or exterior intruding objects. According to accident data collected by the National Crash Severity Survey (NCSS) and the National Accident Sampling System (NASS), side impact accidents cause about 30 percent of all traffic accident occupant fatalities. Head injuries account for 40 percent of all fatalities to near-side front-seat occupants in side impacts, with chest injuries at 32 percent. Objects exterior to the vehicle are involved in about 40 percent of head injuries, presumably due to partial ejection or intrusion, while impacts with A-pillar (19%) and roof side rail (17%) structures make an almost equal contribution [DOT/NHTSA, 1990-1; Viano, 1987-1,2,3; Strother, 1990].

NHTSA Safety Rulemaking Activities

The most recent "Final Rule" of revised FMVSS 214 was issued in October, 1990, aimed at reducing thorax and pelvis injury indices, as measured in CMDB crashes. The test procedure includes the use of the DOT/Side Impact Dummy (DOT/SID) and the Thoracic Trauma Index (TTI(d)). The rule currently applies to passenger cars produced after September, 1993 for sale in the U.S. [DOT/NHTSA, 1990-2]. NHTSA is rightly considering means to reduce not only thorax and pelvis injuries but also head injuries in side impacts. The Advanced Notice of Proposed Rulemaking (ANPRM) issued in August of 1988 suggested head protection by the use of pads on pillars and rails, glass-plastic glazing in compartment sides, strengthened door hardware, etc. [DOT/NHTSA, 1988].

Upgraded Occupant Protection in Side Impact

It is extremely difficult to provide adequate stroke for the absorption of occupant second collision energy in side impacts [Warner, 1989; 1990-2]. Attempts to upgrade occupant protection in this crash mode have generally involved modifications of vehicle body side structure and imposition of paddings between occupant and interior for thorax, abdomen, and pelvis protection. The improvement of body side structure and interior padding configurations appears to be somewhat effective for reduction of chest injuries [Warner, 1990-1; Lau, 1989; Viano, 1989-2; Ridella, 1990]. It may also be partially effective for reduction of head injuries, but it is unresponsive to injuries caused by partial ejection or foreign body intrusion through the side glass. Our studies were directed at the feasibility of using air bags as supplemental side impact protection, with particular emphasis on head protection.

Toyota/CSE Pilot Study of Side Air Bags

A joint pilot study was initiated by Toyota and CSE in 1989, to investigate the potential of improved side impact occupant protection by use of supplemental air bag systems [Warner, 1988], with demonstration tests in Toyota production vehicles, and injury index comparisons with baseline FMVSS 214 tests and DOT/SID dummy.

Configuration of Pilot Side Air Bag System

The pilot system shown in Figures 1 and 2 was configured as an extension of findings from the early preliminary testing in 1980 Citation automobiles [Warner, 1988, 1990-3]. The bag and inflator were attached to a backup plate in the door inner panel, and covered with an energy-absorbing inner foam pad meant to reduce thoracic injury. The inflator was selected from among those already available for steering wheel air bags. The bag was designed to deploy inward and upward rapidly, in order to accommodate the limited distance available. It included distributed venting and tethers to control lateral expansion and encourage vertical deployment over the window space, with a width of about 100 mm and a volume of about 60 liters (Figures 3 and 4). Mechanical intrusion sensors were mounted at two levels near the door outer skin. Switch closures resulting from small deflections of the door provided the inflation signal for the bag system (Figure 5). Loadpath foams were included to support reaction forces and help with energy absorption. For the pilot study, no conventional interior trim was included on the door.

Performance Evaluation of Pilot System

The pilot system was evaluated in full-scale side impact test, using the FMVSS 214 procedure with the addition of a Hybrid-III dummy neck and head to the DOT/SID; results from the pilot system were compared with baseline tests from the same vehicle and procedures. Figure 6 shows ratios of the comparative dummy index values. While the TTI(d) reduction of 5% is not very significant, other body areas show impressive reductions ranging as high as 65%.

Prototype Air Bag System Performance Requirements

The potential of the air bag system for the reduction of occupant injuries in side impacts and the technology for the bag upward deployment were confirmed in the pilot system study. Since the top priority of the pilot study was given to questions of overall technical feasibility, some of the basic door functions were ignored, making necessary further prototype design studies regarding the application of this type of system in mass production vehicles.

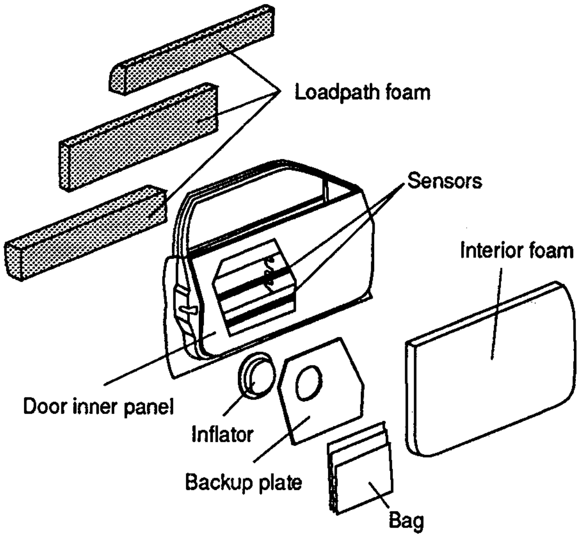


Figure 1. Configuration of the Pilot Air Bag System

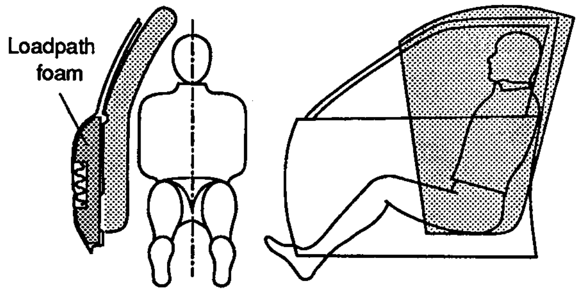


Figure 2. Frontal and Lateral Views of the Deployed Pilot Air Bag System

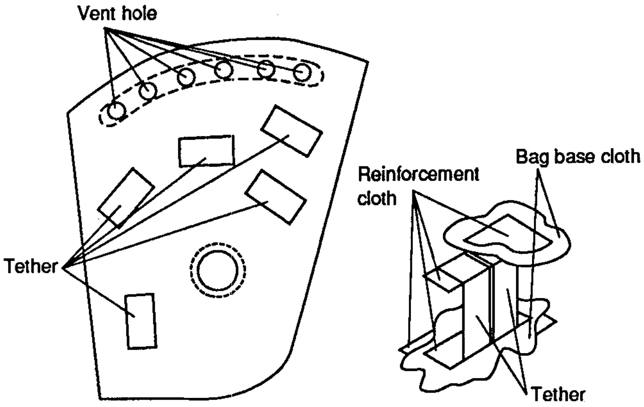


Figure 3. Shape of the Pilot Air Bag and Tether Configuration

Baseline Full-Scale Impact Tests

Various types of side impacts, in terms of speed, angle and impact position may be observed in actual traffic accidents. Development of improved occupant protection

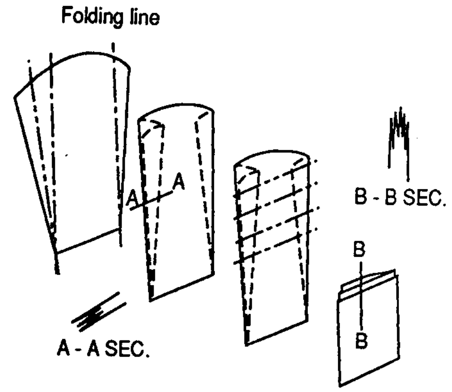


Figure 4. Pilot System Bag Folding Method

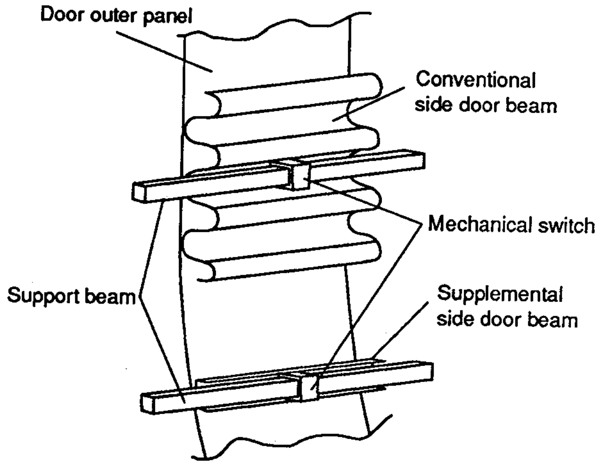


Figure 5. Structure of the Pilot System Sensor

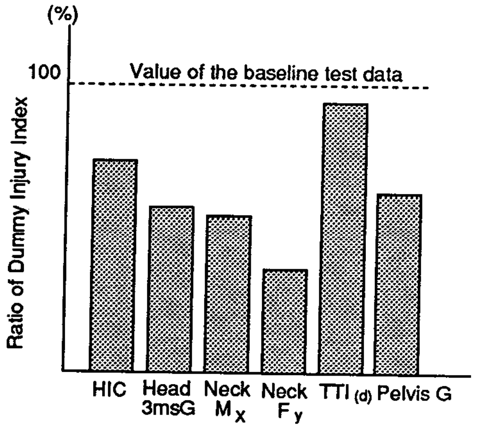
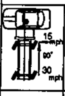
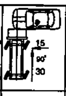
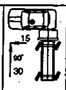
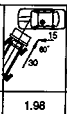
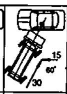
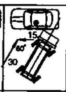
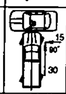
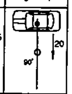


Figure 6. Dummy Injury Indices from Full-Scale Side Impact Test

suggests the need for consideration and evaluation of dummy occupant behavior over a wide range of side impact accident conditions. A matrix of eight typical side impacts representing some prominent types of injurious side impacts was selected for comparative evaluation of the prototype side impact air bag system, and full scale impact tests were carried out to evaluate them. Impact angles of 60 degrees and 90 degrees were selected for seven vehicle-to-vehicle tests, with striking and struck vehicle speeds of 30 mph and 15 mph, respectively. Three relative positions along the struck vehicle side were evaluated, including the front and rear corner "L" configurations and the compartment "T" position specified in FMVSS 214. As in the pilot program, comparisons were directed at that baseline condition, and tests were set up to conform with its dummy, CMDB concepts, and injury indices for the six tests representing car-to-car exposures. For the last two tests, the CMDB was replaced with a light truck and a fixed pole, respectively, with the pole impact carried out with the car moving laterally into the pole at 20 mph.

Table 1 depicts the test configurations and presents important results, expressed as ratios of the result obtained in the baseline FMVSS 214 test shown in the first column of data. Dummy kinematics and secondary impacts between dummy and interior were studied in detail by high-speed cinematography. Partial head ejections out the window area were observed in some cases, as noted below. Observe that head injury indices are greater than the NHTSA baseline in six of the seven alternate tests, and that all indices are greater in the 60 degree compartment impact and the perpendicular light truck impact. Head injury indices are particularly high in the concentrated pole impact, resulting from direct contact of the head against the pole.

Table 1. Conditions and Results from Baseline Series of Full-Scale Crash Tests

		Test condition							
		Side impact against MDB						Side impact against truck	Side impact against pole
									
Dummy Injury Index	HIC	Ratio 1.0	0.43	1.56	1.98	4.80	2.07	2.84	16.79
	Head 3msecG	1.0	0.71	1.34	1.20	2.69	1.66	1.46	1.60
	TTI(d)	1.0	0.42	0.48	0.39	2.34	0.42	1.28	0.90
	Pelvis G	1.0	0.16	0.17	0.17	1.87	0.09	1.14	0.86
Ejection		YES	YES	NO	NO	NO	NO	YES	YES
Interior contact		NO	NO	YES	YES	YES	YES	NO	NO
Exterior contact		NO	NO	NO	NO	NO	NO	YES	YES

Target Air Bag Performance

During the pilot study, bag occupant protection performance was given top priority at the expense of the normal door functions. Since the presence of an arm rest is considered essential, and since it has proven to be very difficult to deploy the bag both above and below the arm rest, it was decided to deploy the bag only above the arm rest. The pelvis portion of the occupant was thus excluded from the intended direct coverage area of the bag. Relationships among door intrusion, dummy motion, and elapsed time were determined by analysis of high speed films. The most stringent intrusion rates among the six baseline vehicle tests was found to occur under the FMVSS 214 test conditions, so that test was chosen for comparative evaluation of design goals. The relationship among bag thickness, deployment time and impact sensing can be approximated as shown in Figure 7, where door intrusion D (t) and bag thickness W (t) are plotted against time. The intrusion of the deploying bag surface B (t) can be expressed by Equation 1.

$$B(t) = D(t) + W(t) \qquad (1)$$

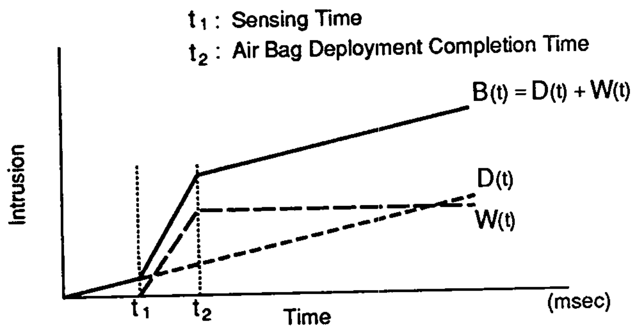


Figure 7. Intrusion of Air Bag Surface

It is of course desirable that contact between the air bag and the occupant occur at or after completion of air bag deployment, so that bag thickness may be used for energy management and its area may be used for force distribution over the occupant. As the initial distance between the door inner panel of the vehicle used in this study and the normally-seated DOT/SID occupant is 130 mm, Equation 1 becomes:

$$130 \leq D(t2) + W(t2) \qquad (2)$$

Figure 8 plots Equation 2, using the actual door intrusion determined by the baseline FMVSS 214 test, and demonstrates that bag thickness and deployment completion time must be traded off against one another. The bag should be as thick as possible in order to use it as effectively for occupant energy absorption stroke, so the bag thickness at chest height was given top priority. A target deployed thickness of 100 mm was selected to accommodate door intrusion, and tether length was set accordingly. Figure 9 shows the configuration of the bag at complete deployment, giving coverage from the arm rest to the roof side rail for head protection, as suggested by observed dummy kinematics and expected seating positions for a range of occupants.

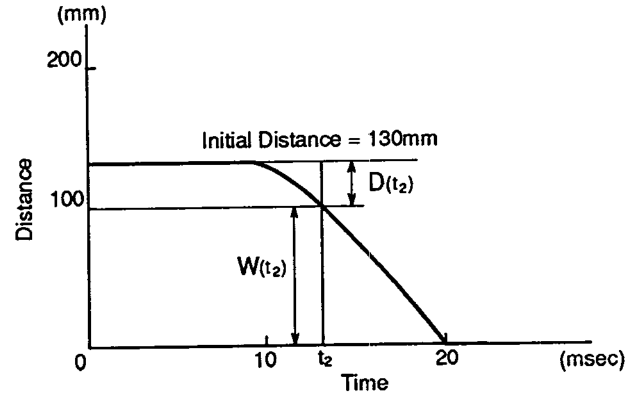


Figure 8. Relationship Between Door Intrusion and Air Bag Thickness

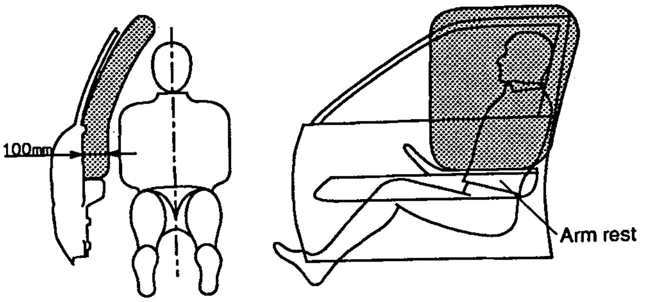


Figure 9. Frontal and Lateral Views of the Deployed Bag

The amount of energy to be absorbed in the secondary impact speed between the dummy chest and the door was calculated as 1000 J from the baseline FMVSS 214 test. Figure 10 shows the conceptional load-displacement characteristics of the door with and without the bag. A target energy absorption value of 500 J (50% of the total energy) was selected, assuming that the reduced door deformation by the bag will suppress the maximum load somewhat. With the bag thickness set at 100 mm, the bag must complete its deployment within 13 msec.

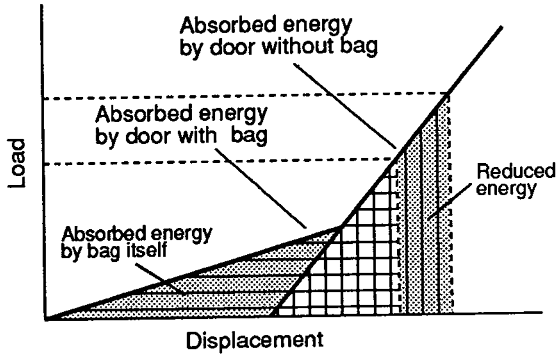


Figure 10. Load-Displacement Characteristics of Door Without and With Bag

The total time to 100 mm deployment was arbitrarily divided into 2 to 3 msec. for sensing and 10 to 11 msec. for bag deployment. Bag actuation duration to give adequate protection was targeted at 100 msec., based on dummy behavior in the tests, so that inflator characteristics and venting behavior were balanced around that goal.

The most important requirement for the sensors is to discriminate the need for bag deployment for occupant protection in side impact conditions, while avoiding inadvertent deployment in more normal conditions. The targeted 2-3 msec. sensing time is part of the 13 msec. deployment time, suggesting that G-sensors are impractical for this system. Another type of sensor capable of more rapid sensing is required.

Design of Prototype Side Air Bag System

Individual components that constitute the side air bag system were designed to be assembled into a front door, as shown in figure 11.

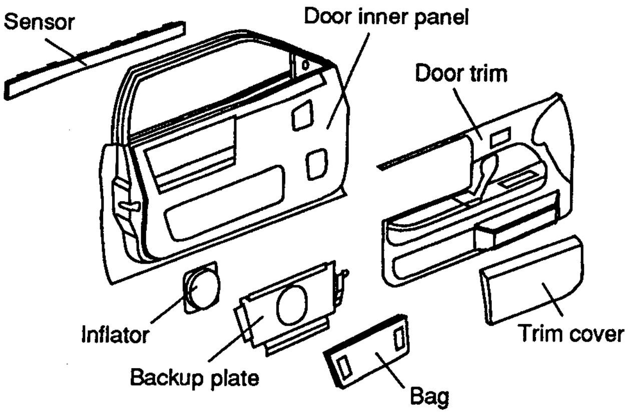


Figure 11. Configuration of the Air Bag System

Air Bag, Inflator and Backup Plate

The system consists of bag and inflator combined with backup plate, sensor, door panel and door trim, including air bag cover. Individual components were carefully designed to be compatible with all normal door functions. The bag was designed to meet the thickness and coverage ranges decided, with tether length set at 100 mm, as shown in Figure 12. Bag volume is about 40 liters.

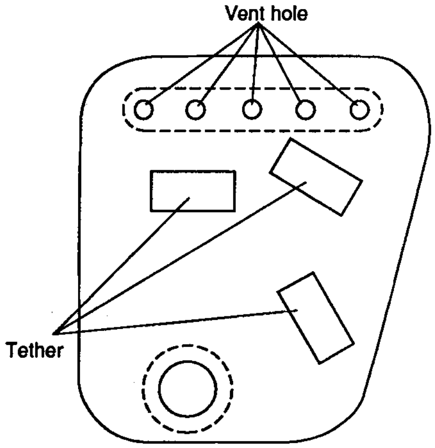


Figure 12. Shape of the Bag and Locations of the Tether

Development of a custom-designed inflator would require a much longer time than available under the prototype project, so it was decided to use an existing or modified inflator designed for frontal air bag systems.

Estimates of bag contact area with the occupant (500 cm^2), bag thickness (100mm) and the energy (500 J), suggest a dynamic internal pressure requirement of about 10 N/cm^2. An optimal inflator was selected from among several available inflators by means of a series of inflation tests. The backup plate to which the bag and the inflator were assembled was designed so that the bag and the inflator were positioned within the limited inner space of the door without sacrificing normal door and window functions.

Door Structure and Trim Modifications

A large opening was provided within the door inner panel for the installation of the backup plate, with a compensating window sill reinforcement. This allowed the system to function without major changes in overall door deformation characteristics. The door trim was similar to that of the baseline production vehicle, but a newly-designed trim cover for the air bag module was added.

The upper portion of the trim cover was intended to break away inward, encouraging upward bag deployment.

Sensor Design

In place of an ordinary G-sensor, contact switch sensor system to be installed to the outermost location of the door was considered to sense impacts as quickly as possible. According to the results of the preliminary study regarding the characteristics of the contact switches, it was found that the activation pressure of such switch should be set rather high level to avoid an inadvertent air bag deployment when, for example, the door was opened and hit against a pole, tree, etc. where the relatively high load was concentrated around the narrow contact area. And it was also predicted that such a switch with higher activation pressure might not activate even when an ordinary vehicle collided into the side door. Therefore, it was decided to develop a contact switch sensor system consisting of two switch systems—the primary switch system to sense the impact with some other vehicle, and the secondary switch system that would not be activated in the impact on the pole when opening the door, but to be activated by a more severe side impact against a pole.

The primary switch system consists of plural contact switches installed at given intervals, and each one of them turns on easily by relatively low activation pressure. The primary switch system itself turns on only where two or more contact switches are turned on simultaneously, but it remains off where only one of the contact switches is activated by a mischievous action, etc.

The secondary switch system was installed in the longitudinal direction of the door, which would not be turned on when the door hit a pole or a tree, even if the door was accidentally and strongly opened, but turns on in a side impact against a pole, tree, etc., where the air bag deployment is required to reduce the occupant injury.

The total contact switch sensor system was so constructed that it would turn on if either the primary or secondary switch system described above turned on. Figure 13 shows the sensor configuration and the installation. The sensors were installed immediately inside the door outer panel along the pipe-wise side door beam so that they sense impacts as quickly as possible.

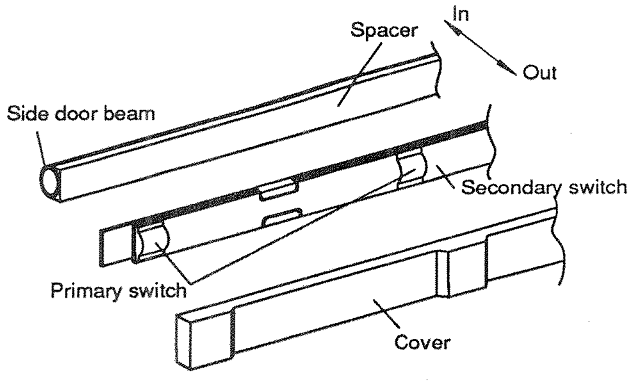


Figure 13. Configuration of the Sensor

Evaluation of Bag Performance in Static Bench Testing

Deployment tests were carried out to evaluate folding techniques, internal pressure, venting, and overall bag performance, leading to design modifications in an effort to optimize performance within the criteria outlined above. Figure 14 shows the final configuration of the prototype bag. Figure 15 presents the dynamic bag thickness at occupant chest height, taken from test films. Local bulging is obvious, extending locally beyond 100 mm, which gives the bag surface a mattress-like surface. This is fully acceptable, so long as the 13 msec. deployment time is achieved. Figure 16 shows the bag internal pressure vs. time, as recorded in a static deployment. The average pressure is lower in this static test than the 10 N/cm^2 dynamic pressure target, but pressure will be higher due to occupant contact forces in a dynamic deployment.

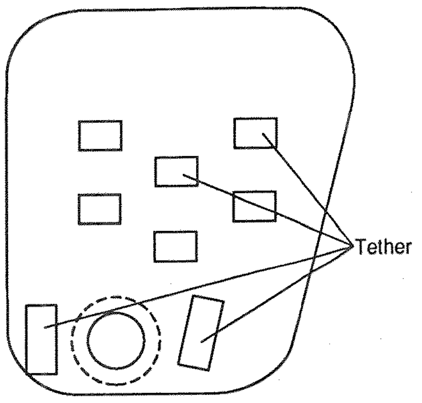


Figure 14. Final Configuration of the Bag and Tether Locations

Subsystem Deployment Tests on Vehicle

The prototype bag system was installed in a vehicle equipped with DOT/SID for a series of static deployments. Figure 17 represents the developing configuration during static deployment at various times after ignition; Figure 18 is a photograph taken at 25 msec. No unfavorable interactions with dummy or seat were noted, except that the motion of the trim cover induced a 70 g rib acceleration in the dummy. A subsequent test without the trim cover showed a reduction to 30 g. The trim cover was removed for the remainder of testing in the prototype project, with the idea that minor trim cover redesign efforts could resolve this dummy rib overload.

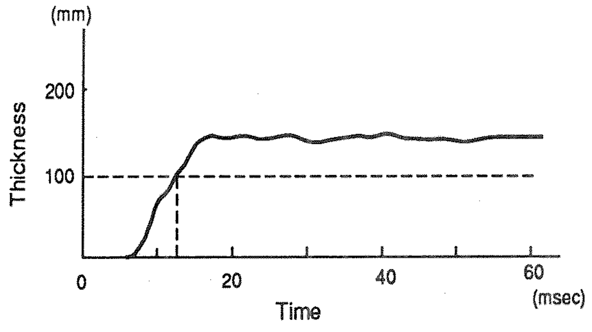


Figure 15. Bag Thickness at Occupant Chest Height

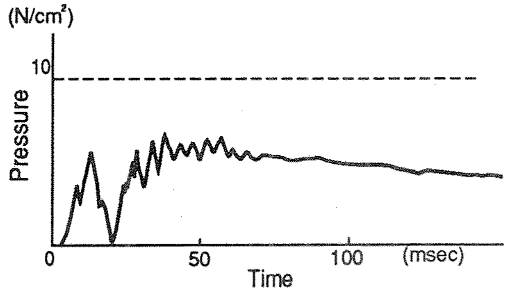


Figure 16. Bag Internal Pressure vs. Time

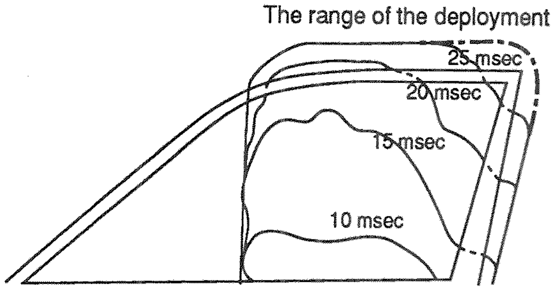


Figure 17. Process of Bag Deployment

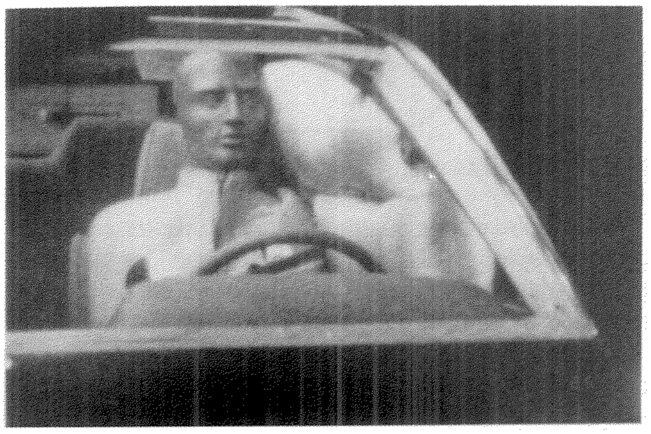


Figure 18. Condition of the Bag at 25 msec

Impact tests were carried out to study the load-displacement characteristics of the air bag system as installed in the door. The door was supported against a rigid barrier face while the inflating bag was struck at full thickness from the inside by an impactor which simulated the occupant. The result was the load-displacement curve depicted in Figure 19. Target values of air bag energy and door energy were achieved.

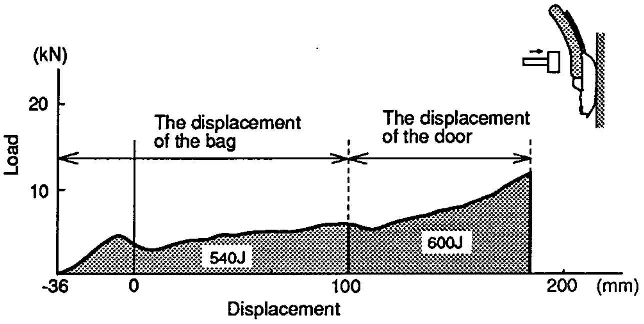


Figure 19. Load-displacement Characteristics of the Door With the Side Air Bag

Evaluation of Sensor Performance

The primary system used to sense striking vehicle side impact into the compartment must activated within 2 to 3 msec. Therefore it was decided to use switches which would be activated by a specified small activating stroke and load as the primary switch system.

Primary sensor performance was evaluated to demonstrate abilities to achieve sensing within 2-3 msec, by impacting a switch system subassembly attached to the rigid barrier by a FMVSS 214 moving barrier face at a speed of 3 m/s, with a resulting sensing time of 9 msec. Assuming an approximate inverse relationship of sensing time with speed, the required sensor performance was indicated. It was also verified that the primary switch system would not be activated when only one switch was turned on. Tests of the secondary sensor subsystem verified that it would not activate when impacted by a 160 mm diameter pole at maximum foreseeable occupant door opening force, while other tests verified that the secondary sensor system will activate when struck by a barrier-mounted 305 mm pole system having the same mass as the vehicle and a speed of 2.8 m/s, yielding a sensing time less than the selected target of 7 msec. This speed was selected as an appropriate threshold for deployment in pole side impact.

Full-Scale Side Impact Tests of the Prototype System

Full-scale FMVSS 214 side impact tests were carried out to evaluate the overall performance of the prototype system. The sensor system activated within 2 msec., and the bag deployed properly, with the dummy acceleration results shown in Figure 20. The most significant difference in the upper rib acceleration was that the first peak occurred earlier than in the baseline test, coinciding with the contact between dummy and air bag. The second peak occurred when the dummy contacted the door inner panel through the bag, the third by bottoming of available door structure deformation. The highest peak was reduced by 20 percent, compared with the baseline test. Accelerations of the lower spine do not show much differences from the baseline, except for timing. This is attributable to the reduction of the rib acceleration and the reduction of the pelvis acceleration which will be described later. Overall thoracic trauma should have been reduced by the air bag, as suggested by the ten percent reduction in TTI(d) provided. Notably, pelvis acceleration was decreased by 24 percent compared to baseline test results, despite the fact that the bag did not contact the pelvis directly, probably due to pelvis motion in response to transmission of thorax accelerations through the spine, moving the pelvis away from its later door contact. Figure 21 shows reductions achieved by the prototype air bag system in several dummy injury indices.

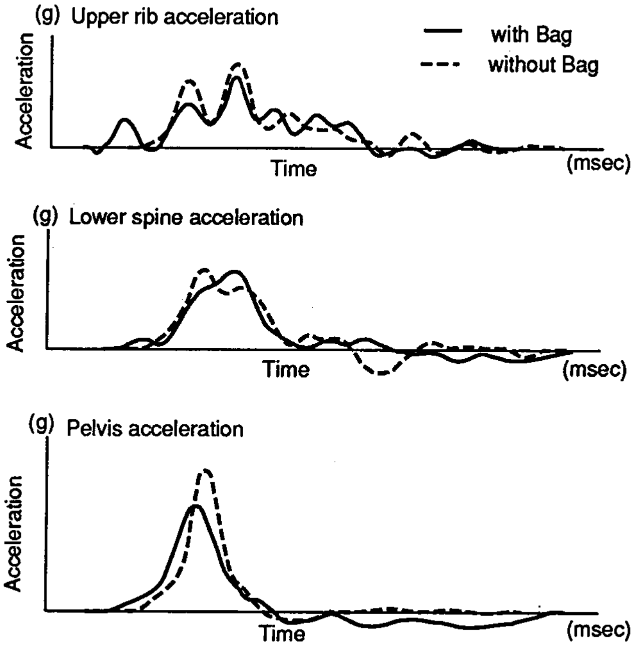


Figure 20. Dummy Acceleration from Full-Scale Side Impact Test With the Side Air Bag

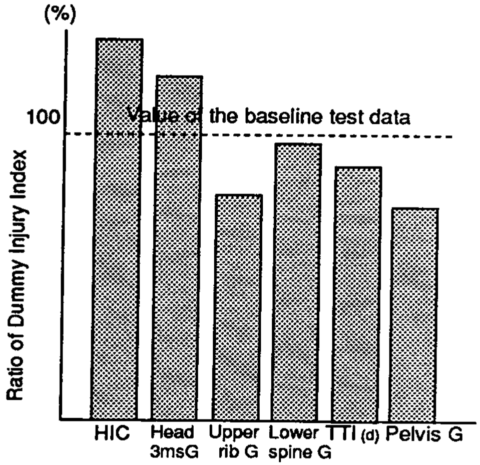


Figure 21. Dummy Injury Indices from Full-Scale Test: Prototype Side Impact Side Air Bag Compared to Baseline

Although head injury indices in the prototype system test are slightly higher than baseline, they are well below injury levels of concern. No head contact occurred with anything in the baseline test, nor with anything other than the air bag in the prototype system, so this comparison is somewhat mute regarding head injury effectiveness. Figure 22 compares head position at 80 msec., with and without the bag. Note the risk suggested by the partial ejection of the head in the baseline test and the protection provided by the bag. As a comparison, Figure 23 shows similar views from the baseline tests at the 30/15 mph condition with a light truck and with the pole at 20 mph. In both of these test cases, the dummy head contacted objects from outside the vehicle with serious injuries indicated.

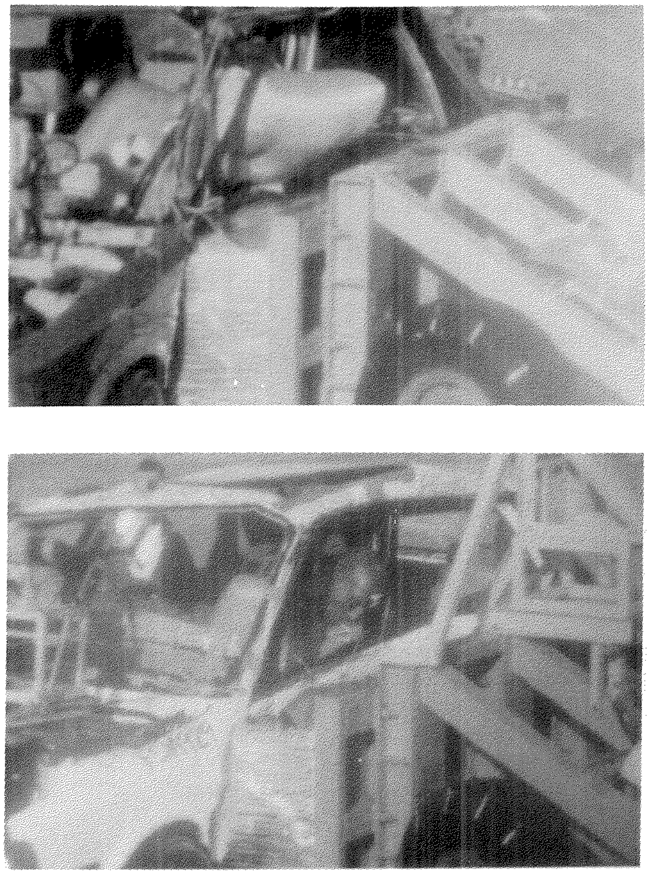


Figure 22. Comparison of Dummy Head Behavior With Bag (Top) and Without Bag (Bottom)

The dynamic tests confirmed that the air bag system can be effective in overall occupant protection in side impact. Although the head protection potential has not yet been fully evaluated in a numerical sense, it is clear that the prototype air bag system can provide substantial and meaningful protection from this important injury source as well.

Conclusions

1. A pilot design and a more sophisticated preliminary prototype design for air bag systems for side impact protection from torso and head injuries have been assembled and evaluated in side impact testing conducted with the DOT/SID dummy and FMVSS 214 CMDB procedures and criteria.
   - Folding methods and tether locations for deployment of the head-protection aspects of the bag have been clarified.
   - Two kinds of sensor switches have been incorporated into a successful side impact intrusion sensing system.
2. A preliminary prototype system was developed by careful refinement of the design principles embodied in the pilot design. As compared to baseline vehicles, this improved design demonstrated substantial improvements in dummy injury measures in various vehicle-to-car and car-to-barrier crash testing.
   - Thoracic injury risk is reduced by ten percent as measured by the DOT/SID and the TTI(d) criteria.
   - While not specifically addressed as a design goal of the prototype air bag system, reductions in pelvic injury seem to be indicated by the test results.
   - The test results have provided a clear demonstration of the potential effectiveness of the prototype system in the prevention of head injury in side impacts due to contact with vehicle interior surfaces and objects near or protruding inward through the side glass.

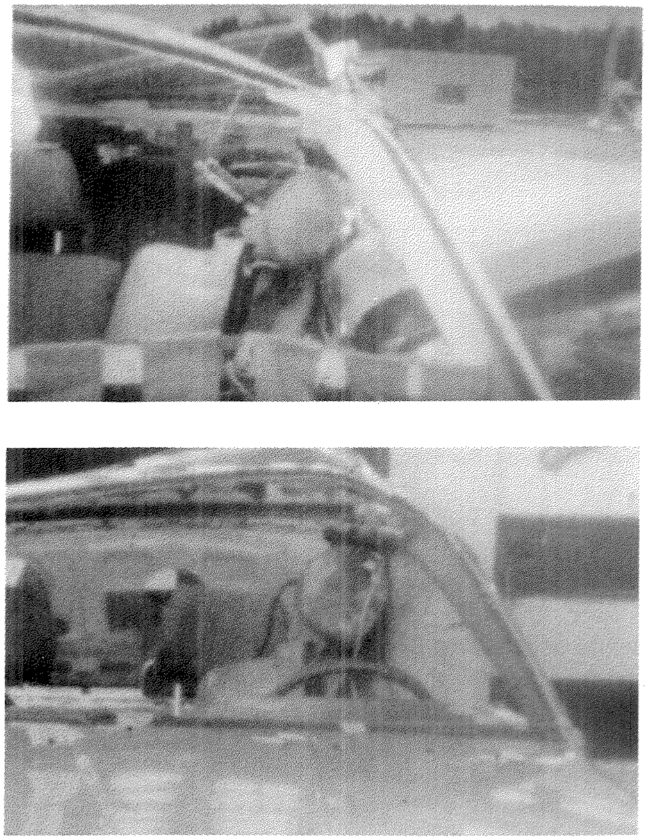


Figure 23. Impact of Dummy Head Against Harmful Objects: Against Light Truck (Top), Against Pole (Bottom)

Future Research Objectives

The prototype side impact air bag system tested and studied in this project has demonstrated promise for further research in the following areas:

- The effect of interposition of an inflating bag on head injuries deserves further study in various impact modes. This may well prove to be the greatest potential benefit of the side impact air bag system.
- A complete study of the trade-offs in injury presented by other effects is called for, including: potential hearing damage due to the near proximity of the inflating bag, potential arm damage for the reported minority of occupants who may lean an arm on the window sill [Viano, 1989], potential arm or chest damage due to rapid opening of the air bag cover, etc. These concepts must be considered carefully for both intended and inadvertent deployment situations.
- Sensing strategies and hardware must be refined somewhat before proceeding to production. This will require careful study of the various impact situations and great effort to shorten the sensing time.
- Inevitable weight and cost penalties of incorporation of the side impact air bag system will need careful study before introduction of such systems in production vehicles.

References

DOT/NHTSA, 1990-1: Final Regulatory Impact Analysis: New Requirements for Passenger Cars to Meet a Dynamic Side Impact Test, FMVSS 214, U. S. Department of Transportation, Washington, D.C., August 1990.

DOT/NHTSA, 1990-2: CFR 49 Part 571. Docket No. 88-06, Notice 8, Federal Motor Vehicle Safety Standards: Side Impact Protection. U. S. Department of Transportation, Washington, D.C., October 1990.

DOT/NHTSA, 1988: CFR 49 Part 571. Docket No. 88-06, Notice 3, ANPRM FMVSS 214 Amendment to Side Impact Protection - Passenger Cars, U. S. Department of Transportation, Washington, D.C., August 1988.

Lau, 1989: "Design of a Modified Chest for EUROSID Providing Biofidelity and Injury Assessment" Ian V. Lau, David C. Viano, Clyde C. Culver and Edward Jedrzejczak, GMRL, [SAE Paper # 890881] SAE International Congress and Exposition, Detroit March, 1989.

Ridella, 1990: "Determining Tolerance to Compression and Viscous Injury in Frontal and Lateral Impacts" Stephen A. Ridella and David C. Viano, [SAE Paper # 902330] Thirty Fourth Stapp Car Crash Conference Proceedings Orlando, Fla. November 4-7, 1990.

Strother, 1990: "Reconstruction and Side Impact Societal Benefit" Charles E. Strother and Charles Y. Warner, SAE International Congress and Exposition, Detroit [SAE Paper # 900379], March, 1990.

Viano, 1987-1: "Evaluation of the SID Dummy and TTI Injury Criterion for Side Impact Testing" David C. Viano, GMRL [SAE Paper # 872208] Thirty First Stapp Car Crash Conference Proceedings New Orleans La. November 9-11, 1987

Viano, 1987-2: "Evaluation of the Benefit of Energy Absorbing Material in Side Impact Protection: Part I" David C. Viano, GMRL [SAE Paper # 872212] Thirty First Stapp Car Crash Conference Proceedings New Orleans La. November 9-11, 1987

Viano, 1987-3: "Evaluation of the Benefit of Energy Absorbing Material in Side Impact Protection: Part II" David C. Viano, GMRL [SAE Paper # 872213] Thirty First Stapp Car Crash Conference Proceedings New Orleans La. November 9-11, 1987

Viano, 1989-1: "Patterns of Arm Position During Normal Driving" Research Note: Human Factors, 1989, 31(6).

Viano, 1989-2: "Biomechanical Responses and Injuries in Blunt Lateral Impact" David C. Viano, GMRL [SAE Paper # 892432] Thirty Third Stapp Car Crash Conference Proceedings Washington, D.C. October 4-6, 1989.

Warner, 1988: "Inflatable Structures for Side Impact Crash Protection," Final Report, SBIR Phase I, Contract # DTRS-57-86-C-00089, U.S. Department of Transportation, Washington, D.C., April, 1988.

Warner, 1989: "Crash Protection in Near-Side Impact: Advantages of a Supplemental Inflatable Restraint," Charles Y. Warner, Charles E. Strother, Michael B. James, Donald E. Struble, and Timothy P. Egbert, SAE International Congress and Exposition, Detroit [SAE Paper # 890602], March, 1989.

Warner, 1990-1: "A Perspective on Side Impact Occupant Protection" Charles Y. Warner, SAE International Congress and Exposition, Detroit [SAE Paper # 900373], March, 1990.

Warner, 1990-2: "Application of Kinematic Concepts to Side Impact Injury Analysis," Charles Y. Warner and Charles E. Strother, SAE International Congress and Exposition, Detroit [SAE Paper # 900375], March, 1990.

Warner, 1990-3: U.S. Patent No. 4,966,388, "Inflatable Structures for Side Impact Protection," Charles Y. Warner, Charles E. Strother, Donald E. Struble & Milton G. Wille, U. S. Patent Office, Washington, D.C., October 30,1990.

S5-O-10

"Renault VSS" Safety Vehicle: Occupant Safety in Side Impacts

J. Rio, D. Pouget, N. Casadei
Renault

Abstract

Renault's ambition is to achieve a vehicle design meeting requirements that go well beyond the requirements of the regulations at present proposed or in effect in Europe, and compatible with both actual road conditions and industrial realities. Our research model is the RENAULT 19, modified to obtain safety conditions by a now conventional procedure involving the following two aspects:

- for those of the body in white components which are subjected to the greatest stresses in an impact, improvement of component performance and improvement of the strength of component connections;
- fitting out the passenger-compartment walls in accordance with the occupant's characteristics.

Due to the lack of a suitable dummy for the ISO biofidelity criteria, evaluation is being performed using the EUROSID 1 dummy.

Introduction

In this paper the fitting-out arrangements are described and the test results are discussed. As a follow-up to the EPURE, Renault has decided to present the COVER, a safety synthesis vehicle obtained by modifying a production line vehicle, with the intention of achieving a degree of occupant safety beyond the legislative framework at present proposed or in effect. These changes must lead to designs which can be applied in future Renault cars. They must be industrially feasible and pertinent to actual road conditions.

The RENAULT 19 was justifiably chosen as the demonstration vehicle as its well-designed, homogeneous body structure offers good, passive safety and body side structural simplicity:

- two-piece body side frame, with the junction between the two-piece body side frame and the rear of the car located at the rear portion of the door entrance,
- relatively thick body side frame (body side frame: 1.1 mm, inner rocker panel: 1.8 mm)
- significant hollow member cross section size,
- available space for modifications to the rocker panel and B-pillar.

Therefore, significant improvements in safety during side impact can be considered technically possible.

Tests were carried out according to the draft European procedure for side-impact collision:

- use of an EEVC[1] Moving Deformable Barrier (MDB) with a total mass of 950 kg, and ground clearance of 300 mm,
- perpendicular impact (90° angle) with the impact point centered on the R-point
- use of a EuroSID 1 dummy in a front seat

We can justify our choice of the draft European procedure as it best represents real life road conditions, especially because of the MDB specifications. Impact velocity went beyond regulatory requirements in that an initial impact velocity of 56 Km/h was chosen.

To improve occupant safety in side impact collisions involving two passenger cars, the collision configuration found in the draft regulation procedures, three possible study approaches can be considered:

A. limit velocity of impact between striking wall and occupant
B. adapt the striking v. all to occupant characteristics
C. control the timing of occupant contact with the striking wall

The assumption behind approach A is that door intruding velocity over 10 m/s at the time of contact with any part of the occupant's body must be avoided. Approach B involves determining the force/deflection characteristic of the striking wall directly next to the occupant (a EuroSID 1 dummy in this case) which would minimize injury criteria. Approach C involves improving occupant to striking wall coupling by adjusting relative displacement amplitudes and timing of contact between the inner striking wall with the different body areas: thorax, abdomen and pelvis.

Approach A: Reduce Door Intrusion Velocity

As the coupling between the occupant and the vehicle is low during the beginning of impact, we can break down the closing velocity between striking wall and occupant into the following:

- lateral velocity of vehicle center of gravity in relation to the ground
- relative door intrusion velocity

It does not seem feasible to try to greatly reduce the first, given the standard impact sequence:

- vehicle movement begins progressively, beginning around 10 to 20 ms after impact, and reaching less than 1 m/s during the following 10 milliseconds

---

[1] The EEVC Mobile Deformable Barrier is chosen for the ECE and CEE draft procedures.

- occupant/striking wall contact is made around 12 to 20 milliseconds after impact
- maximum intrusion velocity is observed between 20 to 50 ms after impact, depending on the test
- cross-over of MDB velocity and striking vehicle velocity occurs between 50 to 70 ms after impact.

Thus the striking vehicle's lateral velocity remains very low, at least throughout a good deal of the striking wall/occupant interaction.

In order to diminish maximum intrusion velocity, two possible measures can be taken:

- lower velocity peaks
- reduce maximum-intrusion

Reduction in Striking Wall Velocity Peaks

These measures are taken to avoid any abrupt collapse in body structure which might be the result of buckling of any part, or breaking of a part or a connecting point.

The different parts making up the Renault 19 are sufficiently resistant in order that no such breaking upon side impact occurs at either 50 km/h or 56 km/h. Nevertheless, the addition of new structural parts could ease stress on certain sections which are highly strained during impact. For example, anti-bursting devices between the side doors and the side frame would help ease stress on the door latch.

To increase the critical loads possible to certain structures before buckling, the following structural reinforcements have been made (see Figure 2):

- a central roof crossmember connected to the roof side rail with a connecting bracket
- B-pillar inner reinforcement, forming a hollow member (*these elements form a complete arch without any important fall of mechanical properties*)
- rocker panel reinforcements (*connected to the B-pillar reinforcement*)
- various transverse reinforcements to the central part of the floor:
  - reinforcements of crossmembers under front seats
  - reinforcement under the tunnel in line with the front seat's rear crossmember
  - reinforcement of the total height of the central floor rearmost crossmember at both ends
  - reinforcement of the upper edge of the central floor rearmost crossmember in the central portion.

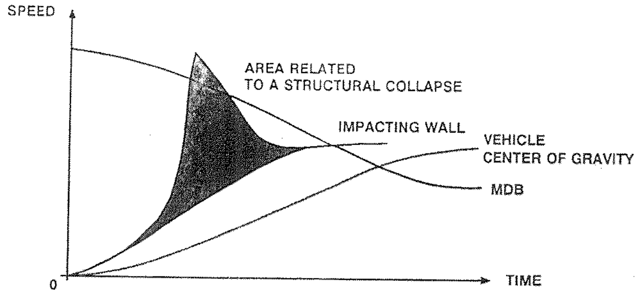


Figure 1. Kinematics Elements. Illustration of the Influence of Collapse on Striking Wall Intrusion Velocity

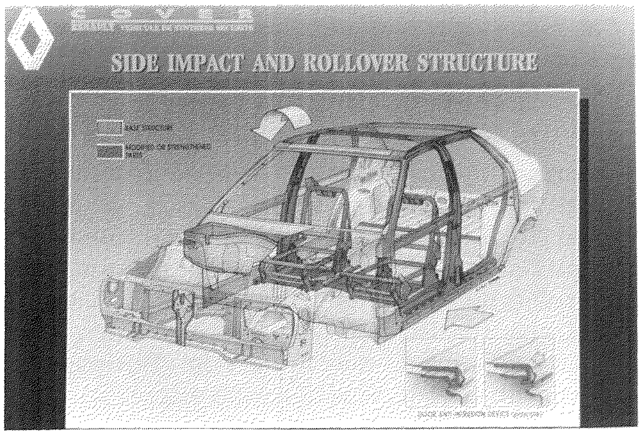


Figure 2. The COVER Reinforcements Especially Designed for Side Impact

By increasing the thickness of certain parts, their critical buckling load can be increased. This was necessary in the case of the roof rail inner panel because of weakening caused by space through the central roof crossmember passes. Without making production line manufacturing unfeasible, the aim was to give priority to the connection between the central roof crossmember and the B-pillar instead of to roof side rail resistance. To avoid injury to the occupants' heads due to jutting of the connecting bracket, it was necessary to insert the member through a space cut out in the roof rail inner panel.

Moreover, all these reinforcements aid in effectively reducing the maximum intrusion by increasing vehicle stiffness (see further). The influence of these reinforcements on intrusion velocity were quantified through full-scale tests and computer simulations. This influence is explained in Mr. Steyer's paper.

Reduction of Maximum Intrusion

Let's now look at the area between the curves (Figure 3) representing striking wall velocity and the vehicle's center of gravity velocity as a function of time. This area's value indicates the level of striking wall intrusion. Reducing intrusion results in the reduction of striking wall velocity.

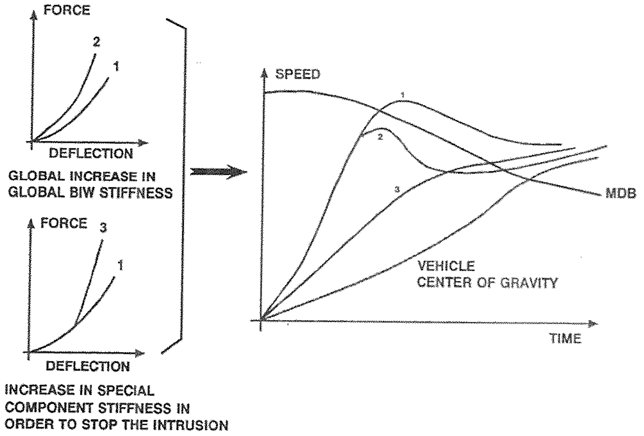


Figure 3. Influence of Structural Modifications on Striking Wall Velocity

The following two measures can be carried out at the same time:

- increase the overall structural rigidity
- stiffen considerably certain structures to stop thrust.

Increasing overall rigidity, leads to reducing the *average* relative intrusion velocity during the crucial interval (10 to 40 ms or 50 ms after impact). However it is important that the relative intrusion velocity goes down before the dummy's criteria reach too high a level.

Stiffening considerably certain structures also seems to be an interesting measure to carry out. This was done by equipping the vehicle with a front seat whose resistance to lateral forces was much higher than the original Renault 19 model, both for the seat bottom and back. This measure involved a rather large (roughly 20 kg for the 2 front seats) weight increase, but we shall notice that this non optimized design did not necessitate expensive materials or technology.

Test results (intrusion and striking wall velocity) are shown in Figures 4 to 7.

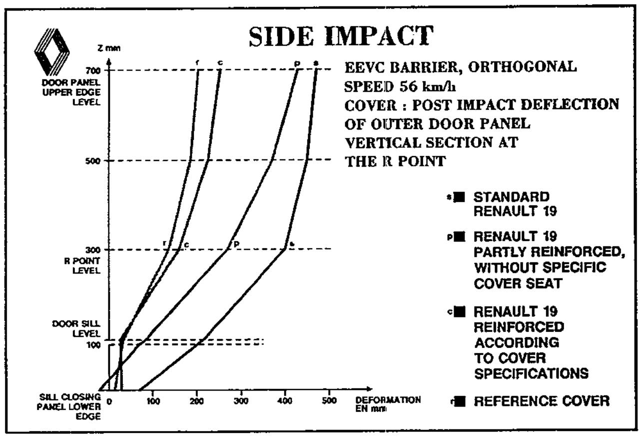


Figure 4. Post Impact Exterior Displacement of the Front Door. Vertical Section at the R Point

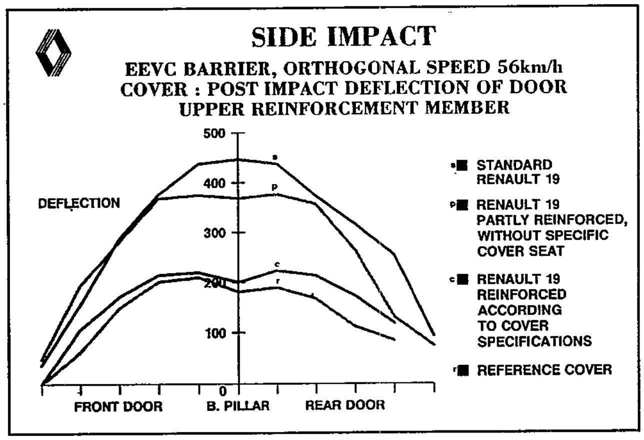


Figure 5. Post Impact Upper Door Reinforcement Member Deformation

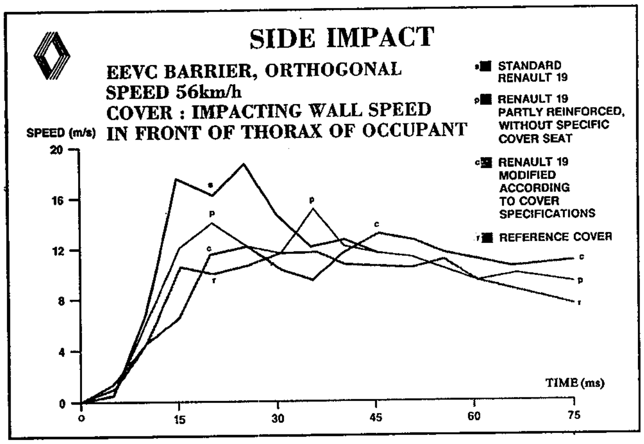


Figure 6. Comparison of Striking Wall Velocities at the Thorax Level

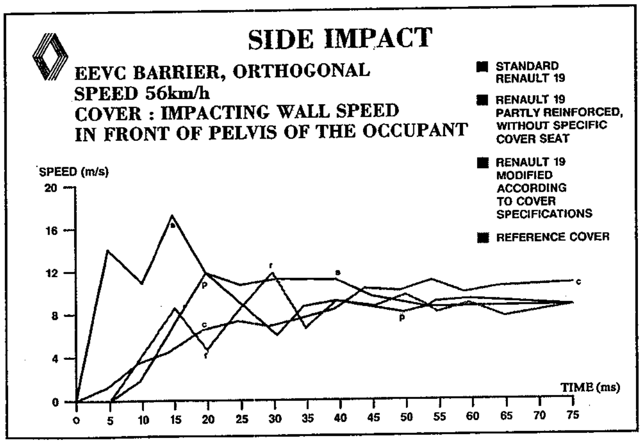


Figure 7. Comparison of Striking Wall Velocities at the Level of the Pelvis

All structural modifications carried out under approach A resulted in a significant increase in weight, an increase of 60 kg, distributed as follows:

chassis: + 17 kg
superstructure: + 23 kg
seats: + 20 kg

Influence of Structural Modifications on Overall Vehicle Kinematics

The aforementioned modifications result in increased vehicle stiffness. Given this increased rigidity, the characteristics of impact between the MDB and the vehicle change, resulting in the following:

- earlier velocity cross-over
- velocity upon cross-over is higher
- the ratio of energy absorbed by the MDB to that absorbed by the vehicle through permanent deformation is modified
- overall, when there is an increase in vehicle rigidity, the total MDB and struck vehicle deformation energy diminishes only slightly.

To reveal the influence of these modifications on the kinematic characteristics, the following E coefficient is appropriate:

$$E = (V_{MDB} - V_{Veh})_{(t=150ms)} / (V_{Veh} - V_{MDB})_{(t=0)}$$

It is not necessary to take into account MDB and struck vehicle mass because they have a secondary effect in this case.

The E coefficient values found in Table 1 show that all these impacts are soft impacts. With different structural modifications to the vehicle, the overall kinematic characteristics may be changed, but only slightly.

Unrealistic modifications would be necessary, given the desire to maintain manufacturing feasibility in the COVER project, to greatly change the overable kinematics of the struck vehicle.

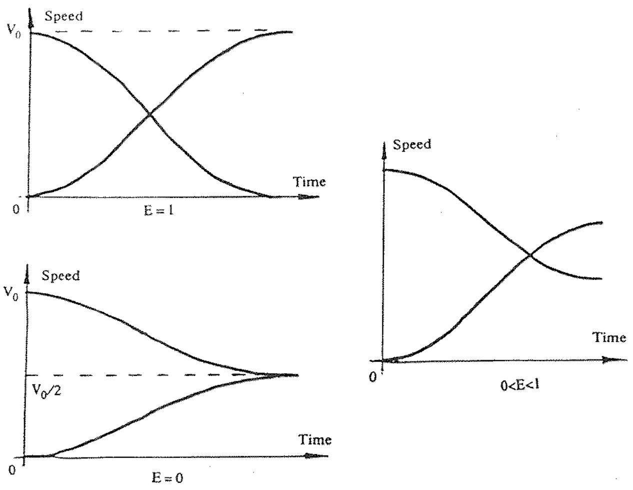


Figure 8. Examples of Kinematics with Their Corresponding E Coefficients

Table 1. E Coefficient Values Illustrating Overall Kinematic Characteristics

Impacted car type	R19 V0	R19 V1	R 19 V2	COVER R	COVER B
Impacted mass (Kg)	1042	1046	1086	1149	1144
Impactor type	Véhicle	EEVC	EEVC	EEVC	EEVC
Impactor Mass (Kg)	1290	950	950	950	950
Initial speed of impactor (m/s)	13,8	14	14,1	15,6	15,4
Cross-over speed (m/s)	7	7,5	7,25	7	8,25
Final speed of impacted car (m/s)	8	8	8,6	9,5	9
Final speed of impactor (m/s)	7	5	4,6	5	5
Intitial speed difference (m/s)	13,8	14	14,1	15,6	15,4
Final speed difference (m/s)	1	3	4	4,5	4
E	0,07	0,21	0,28	0,32	0,29

R19 V0 & V1 are standard vehicles (with EuroSID 0)
R19 V2 is a standard vehicle (with EuroSID 1)
COVER R is the reference version
COVER B has a modified door upper reinforcement member

Approach B: Adaptation of the Striking Wall to the Occupant Characteristics

Modifications to the mechanical characteristics of the striking wall in relation to the occupant can be considered. These modifications can be carried out by modifying the following:

- interior paddings
- mechanical characteristics of the side frame inner panel and side inner door structure.

Interior Paddings

Given the desire to maintain manufacturing feasibility in the COVER project, modifications to the interior paddings is done by adding a layer of padding to the door trim panel without any modifications to the door structure. The choice of padding was made after a series of sled tests using a EuroSID I dummy against a foam padded wall.

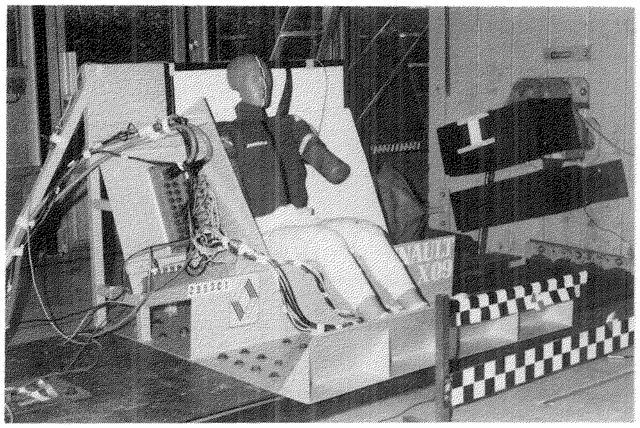


Figure 9. Photo of Sled Test Set Up

A combination of padding to be used at the thorax and pelvis level has been selected. Results with this combination were very satisfactory at impact speeds of 30 km/h. This kind of sled test, at this speed, is comparable in severity to a MDB / vehicle test. A sled test at 40 km/h confirms the correctness of this choice. Test results are presented in Table 2.

Table 2. EuroSID 1 Dummy Responses in Sled Tests

test reference		C1		C2		C3		C4		C5		C7		C8		C9		C10	
test speed (mm)		40		41		31		29		29		29		30		29		40	
padding definition	THorax / PElvis	TH	PE	TH	PE	TH	PE	TH	PE	TH	PE	TH	PE	TH	PE	TH	PE	TH	PE
	material	LP1	SP	LP2	SP	RF	SP	RF	SP	RF	SF	RF	NP	NP	SP	SP	SP	RF	SP
	thickness (mm)	35	30	35	25	30	25	30	15	30	15	30	15	30	15	20	15	40	30
peak rib deflection (mm)	upper	**51**		**54**		34		31		38		38		**48**		**49**		41	
	middle	**49**		**49**		30		29		37		38		**43**		**48**		37	
	lower	**50**		**50**		27		25		36		29		38		**48**		37	
peak rib accelera-tions (G)	upper	130		140		48		42		49		52		55		76		75	
	middle	213		216		108		106		105		115		115		188		144	
	lower	214		262		96		108		84		95		149		172		139	
peak accelera-tions (G)	T1	73		73		25		24		31		22		44		47		43	
	T12	107		108		58		53		43		46		77		84		71	
	PElvis	150		172		123		104		91		59		110		88		152	
Peak Pubic Force (DaN)		449		492		381		374		304		251		355		384		427	

NB: bold-faced values are higher than limit; all accelerations are filtered with cfc 180

Protection of the thorax was given priority. This involves choosing one of the stiffest paddings tested, the one giving the lowest thorax criteria, to be used at the pelvis level. The padding used at the abdomen level was the same as the one chosen for the thorax.

Table 3. Stiffness of Tested Paddings

Padding reference	LP1	LP2	SP	SF	NP	RF
Stress corresponding to 30% compressive strain (N/cm2)	26	26	25	20	15	6,5

Padding volumes were chosen based on the following:

- passenger comfort,
- accessibility of seat adjustment controls,
- sufficient space for the seat belt.

Padding thicknesses chosen were of course thinner than those used in the sled tests. But the dynamic stiffness of the striking wall struck by the occupant, is far less than that found in the production line vehicle, as indicated by the maximum accelerations, especially for ribs. These figures are given in Table 4. Paddings were installed only to the door trim panel. To install padding to the B-pillar is more problematic as room must remain for the safety belt.

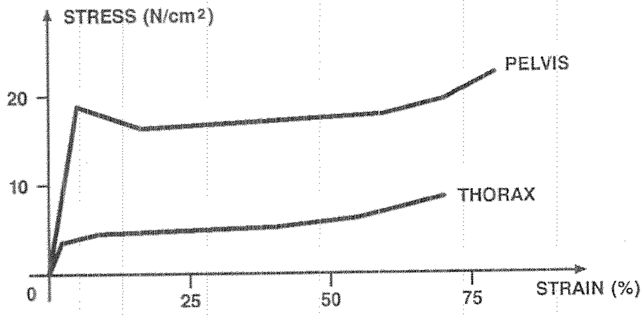


Figure 10. Static Compressive Behaviour of Chosen Paddings

Table 4. Full-scale Test Results with a EuroSID Dummy

impacted car type	R19 V1	R19 V2	COVER R	COVER B	COVER C		
impacted mass (Kg)	1046	1086	1149	1144	1176		
impactor type	EEVC	EEVC	EEVC	EEVC	EEVC		
impacted mass (Kg)	950	950	950	950	950		
initial speed of striking vehicle (m/s)	14	14,1	15,6	15,4	15,6		
dummy	EuroSID 0	EuroSID 1	EuroSID 1	EuroSID1	EuroSID 1	filter	Criter
HIC	352	188	578	340	419		1000
Deflections (mm)							42
upper rib	40,5	45	44	43	46	cfc 180	
middle rib	41	41	46	36	40	cfc 180	
lower rib	37	37	43	30	31	cfc 180	
Max accelerations (G)							
upper rib	129	253	94	104	111	cfc180	
middle rib	141	265	117	111	86	cfc180	
lower rib	133	265	103	106	77	cfc180	
T1	111	93	111	67	67	cfc180	
T12	135	111	98	50	54	cfc180	
TTI (G)	not comput	161	88	73	70	FIR	85 G *
Abdom. efforts (DaN)				sum 103			230
forward cell	Left199	23	24	22	18	cfc 180	
middle cell		12	42	40	21	cfc 180	
rearward cell	Right 30	45	44	52	22	cfc 180	
Pelvis accel (G)	68	64	68	52	43	cfc 180	130
Pubic Stress (DaN)	377	141	174	163	168	cfc 180	1000

* maximum value for 3 ribs
R19 V1 & R19 V2 are standard Renault 19
COVER R is the reference COVER, COVER B has a modified door upper reinforcement member
COVER C is a COVER B modified in order to comply to approach C

The necessity of complying with a certain production line vehicle structural volume made it impossible to reduce inner panel stiffness under normal force as this would lower the overall structural resistance. This is particularly true of the B-pillars resistance to bending which would fall far below the acceptable levels for various demands, especially its intrusion resistance which is a major factor for approach A.

Modifications to the upper front door reinforcement member allowed an increase in its flexibility under exertion of cross forces, thereby reducing door stiffness at the thorax level. This results in favorable changes in the injury criteria, particularly when all the padding's energy absorption potential is used. Nevertheless, if the stiffness of this member is high compared to the occupant's thorax, its stiffness is nonetheless rather low in comparison to the other structural parts which are part of overall side frame resistance. Consequently its contribution to limiting intrusion is relatively secondary, and its weakness does not cause problems from this point of view. Dummy criteria are given in Table 4.

Approach C: Control of the Timing of Contact Between the Occupant and the Striking Wall

Parallel to approach B, in which a better striking wall impedance is sought, it is important to make sure that the timing of striking wall movement in relation to the occupant does not lead to one body area receiving too high a load. For example, when thorax to striking wall contact occurs before pelvis to striking wall contact. When maximum residual intrusion (measured at the B-pillar inner panel level) is at the level of the door upper reinforcement member, one can observe very high thoracic injury criteria, but not necessarily high pelvic injury criteria. This effect is even more pronounced when the difference between intrusion at the thorax level and pelvis level is greater.

When B-pillar bending is the main structural deformation resulting in intrusion, and the displacement of B-pillar ends reaches only a low value, maximum intrusion is found at the door upper reinforcement member level.

Thus, it is necessary to modify the order of contact between the occupant and the striking wall so that pelvic to striking wall contact occurs before, or at least as early as possible, that of thorax to striking wall contact. Two possible courses of action are possible:

- adjust the distance between the occupant and the striking wall before impact
- re-balance the structural characteristics of the body in white

Adjust the Distance Between the Occupant and the Striking Wall Before Impact

Between the inner door structure and the occupant, it is possible to insert bulky elements without modifying the door structure. Adopting a minimum space between the striking wall and the pelvis can be done without seriously harming passenger comfort. Occupant closeness to the striking wall prior to impact can, however, not be obtained for all body sizes. However, interference between seat and striking wall must be avoided, as well as seat adjustment accessibility.

Next to the B-pillar, adjusting striking wall to occupant distance is more difficult as it requires reconsidering the interior layout (for example the path of the safety belt).

Modify the Structural Characteristics of the Body in White

The aim is to have the first contact between the occupant and the striking wall take place at the pelvic level, if this is not possible, then to have pelvis to striking wall impact occur shortly after thorax to striking wall contact. In order to do this, a more vertical deformation of the side frame than in Figure #4 is sought.

Re-working of the distribution of the stiffness of different side frame parts can be considered in order to:

- considerably limit displacement along the Y-axis of the junction between the B-pillar and the roof side rail by means of a central roof crossmember
- increase as much as possible (given the space constraints and the need to avoid injury to occupants) the angular rigidity along the X-axis of this junction between the B-pillar and the central roof crossmember
- obtain clean rocker panel bending before that of the B-pillar, if possible without lowering rotation stiffness around the X-axis of the junction between the B-pillar and the rocker panel.

This will preferably lead to reinforcing the B-pillar, peculiarly at the upper door reinforcement member level, and the central roof crossmember first.

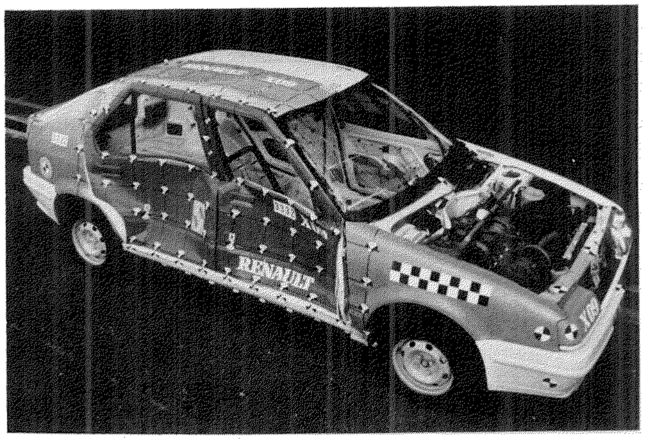


Figure 11. Side Impact Test with the COVER

Approach C Validity

A series of computer simulations using RADIOSS, was carried out using the EuroSID 0 schematization established by the ACEA for calculations of Composite Test Procedure. These simulations lead one to propose the hypothesis of approach C. A simpler impact configuration which is easier to analyze than the MDB/vehicle collision was considered. This simpler configuration involves sled tests with EuroSID 0 impacting a padded wall at 30 km/h.

By taking into account the characteristics of the paddings mentioned earlier, and padding thicknesses used during experimentation, the influence of the distance between the impacted surfaces could be evaluated.

The simulation results can only be considered indicative in comparison to test results for the following reasons:

- simplified model of padding behavior,
- tests carried out with EuroSID 1 while simulations were based on EuroSID 0, the only simulation model available at the time of this study,
- a very simplified model of the connection between the pelvis and spine box.

Nonetheless, the correlation between simulation and tests is reasonably good, as can be seen in curves 12 to 15. The simulation model responses however show some temporal shift at the beginning of impact which has little consequence during the important phase of impact. These shifts can be explained by the lack of a simulation of the arm and the shoulder.

Further dummy sled testing will be necessary to confirm or invalidate the simulation results for various geometric configurations of padding: *Thoracic injury criteria are highest when contact at the thorax level occurs before contact with the pelvis, and much lower when thorax impact is delayed in comparison to pelvis impact.*

Future Direction of Study

None of the three approaches, A, B, or C, taken alone can ensure compliance with the required criteria limits. Only by *combining* these approaches can we find solutions to the side impact problem.

Consequences of According Too Much Importance to Approach A

Major structural reinforcements (approach A) can result in the following:

- increase the striking wall mechanical impedance which is directly opposed to the approach B
- go contrary to the best intrusion profile sought in approach C and therefore result in no improvement, and perhaps even deterioration in the timing of occupant to striking wall contacts.

Consequences of According Too Much Importance to Approach B

Adapting the striking wall by adding paddings (approach B-(ii)) can lead to earlier thorax contact if too much padding is installed between the inner door panel and the occupant without care being taken (a situation

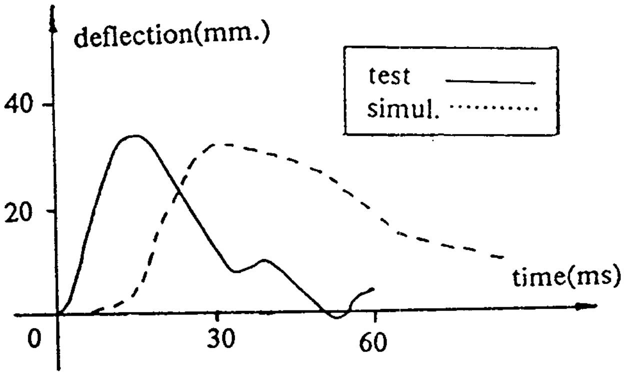


Figure 12. Comparison of Rib Deflections

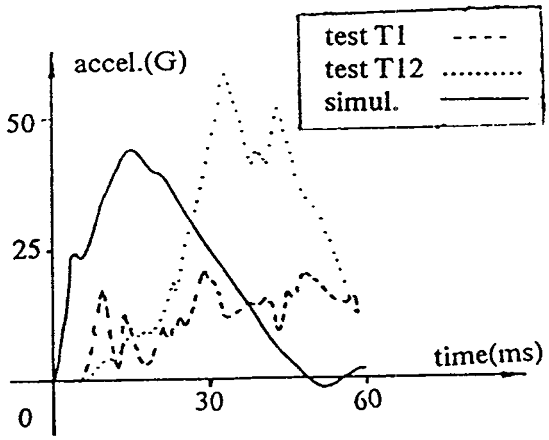


Figure 13. Comparison of Spine Accelerations

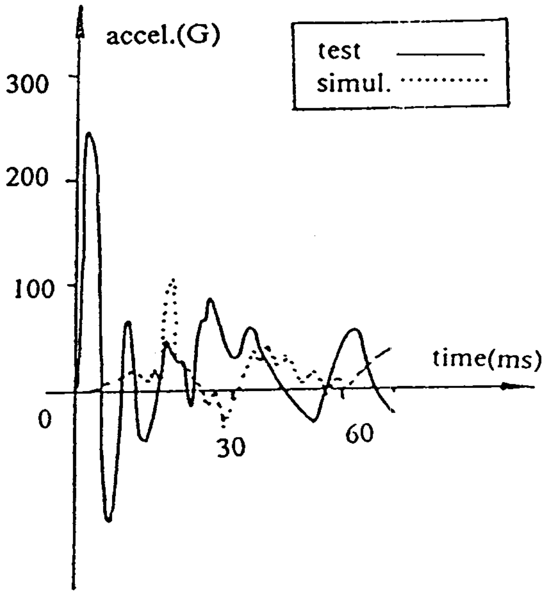


Figure 14. Comparison of Rib Accelerations

contrary to approach C). As well, the energy absorption capacity of these paddings, in particular the padding directly next to the thorax, can be insufficient if striking wall intrusion velocity is too high (approach A).

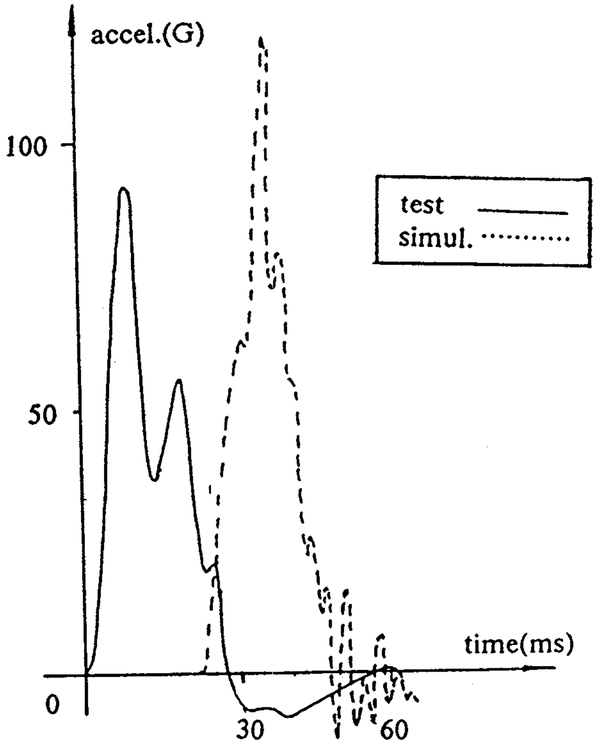


Figure 15. Comparison of Pelvis Accelerations

Limits of Approach C

If a redistribution in side frame resistance is considered, in order to have maximum intrusion take place at the pelvis level, or if not maximum intrusion, at least intrusion equal to that at the thorax level, then it is necessary to maintain high overall structural stiffness in relation to the striking MDB.

Conclusions

Obtaining good thorax protection in side impact is difficult. Given the more severe side impact procedure specifications for the COVER, its performance in terms of thorax protection in side impact remains marginal despite the considerable 75 kg weight increase—mainly for the lateral protection—and reduced roominess in comparison to the production line RENAULT 19 (the loss in elbow room in the front seats being 120 mm).

References

1. "Proposal for a directive on the protection of car occupants during side impact collision," ERGA S65 Final, June 1989.
2. TRANS/SC1/WP29/GRSP/R.70: "Draft regulation concerning the approval of vehicles with regard to the protection of the occupants in the event of a lateral collision; proposal for draft annex 9," 02 August 1991.
3. R.P. Daniel: "Biomechanical design considerations for side impact," Ford Motor C^y, SAE Paper 890386, 1989.

4. G. Walfisch, F. Chamouard, A. Fayon, C. Tarrière: "Etude expérimentale de matériaux amortissants pour assurer la protection en cas de choc latéral," APR, SIA 83-2, March 83.
5. H. Mellander, J. Ivarsson, J. Korner, S. Nilsson: "Side Impact Protection System—A description of the Technical Solutions and the Statistical and Experimental Tools," Volvo Car Corporation, 12th ESV Conference, May 1989, paper 89-SA-O-028.
6. C.A. Hobbs: "The Influence of Car Structures and Padding on Side Impact Injuries," TRRL UK, 12th ESV Conference, May 1989.
7. F. Brun-Cassan, F. Chamouard & alii: "Final report on Modelization of EuroSID 0 dummy by CTP software," LPB-APR, March 90.
8. N. Casadei, D. Pouget: "V.S.S. Safety Synthesis Vehicle," Renault, 13th ESV conference, November 91, paper 91-S4-O-08.
9. C. Steyer, R. Najchaus: "Parametric study on the side impact simulation of RENAULT Safety Synthesis Vehicle," Renault, 13th ESV conference, November 91, paper 91-S5-O-11.

S5-O-11

Parametric Study on the Side Impact Simulation of Renault VSS

C. Steyer, R. Najchaus
Renault

Abstract

The advantages of numerical simulation for study of impacts in general, and in particular for side impacts are already well known. In a previous publication we presented a finite-element numerical simulation of a side impact in which a barrier impacted a vehicle (1). The simulation takes account of the complex deformation, internal vehicle contacts and contacts between the vehicle and the barrier which occur during impact. This model is now applied in a new context. This article covers a series of numerical studies aiming to optimize structural reinforcement for the series-production Renault 19. The project breaks down into two main parts. The first phase is that of validation of the numerical simulation in two extreme cases of vehicle-structure stiffness. Once these results were obtained, the model then allowed for a hierarchical arrangement of reinforcement zones based on criteria of car side intrusion speed.

Introduction

Experimental testing of side impacts, although producing a wealth of significant data, cannot, on its own, provide explanations of all of the complex phenomena which occur during impact. Modifications to vehicle structures often necessitate new tests requiring costly new prototypes given the risks involved in extrapolating results from one test to another.

A major advantage of numerical simulation is the provision of a shorter response time for these modifications, while also allowing investigations which are greater in number and more complete than traditional types of testing. Numerical methods also provide the possibility of access to values which cannot be found from experiments such as the amount of energy absorbed, contact forces, etc. which contribute to the understanding of the phenomena involved. Furthermore, the credibility of such calculations has now been sufficiently established by passed correlations. All of these elements are illustrated in the study described and justify development of its widespread use in the future.

In the previous article, a conclusive validation of side impact was presented for a series-production vehicle (1). This model is now to be applied to the Renault 19. Before discussion of the subject proper, we will briefly set the problem in its context.

Before producing global impact models, a number of local studies have to be completed to ensure full mastery of the calculation tool. A suitability-for-modelling study was thus carried out in this project on two center pillar structures. Adequately limited conditions simulate a mode for application of a bending load to the pillar representative of global impact behaviour.

Two extreme versions of the structure were considered for complete modelling of side impact. The first consists of a series production vehicle which, similar in terms of stiffness to the vehicle studied in the previous article, constitutes an application for the model. The second version was based on the previous vehicle which was reinforced in the floor, roof and body sides and with a considerably stiffened seat. This new structural context required a certain number of investigations into the simulation to arrive at a satisfactory validation.

Finally, from the vantage point of these two validations, optimized reinforcement was produced based on the criteria of the speed of intrusion of car sides in areas opposite the thorax and pelvis of a dummy. This work illustrates how calculation can integrate with the method proposed by J. Rio (3) whose first line of investigation was the reduction of the relative speed of the body panel. The importance of the contribution of the seat in controlling deformation of body sides is revealed initially. The study then shows that from the reinforcements proposed, that for the roof provides the weakest contribution. However, other increases in stiffening have a very direct effect on the speed of the panel at the level of segments.

Experiment Conditions

The stationary test vehicle is impacted orthogonally by a deformable CEVE type barrier weighing 950kg and moving at a speed of 56 kph. The barrier consists of a trolley equipped a block of foam divided into six portions and two aluminum plates on the front (1). Contact is established via the two plates. This assembly reproduces an impacting vehicle in terms of weight and stiffness, from the point of view of the impacted vehicle. The degrees of stiffness of the foam blocks is representative of the front part of an average vehicle. The force/movement law for each of the six areas and of the entire barrier is determined during a calibration test on a rigid wall and must remain within a given bracket.

This experimental context is very close to that described in the article presented in 1989 (1). There are however, important differences; an increased impact speed (from 50 to 56 kph) and a new vehicle model.

Calculation Method

The phenomena occurring during impacts are far from linear in nature and are on extremely limited time scales; less than 100ms. They involve local buckling, plastification of steels and multiple interactions due to contact. Fortunately, thanks to the ductile nature of steel (unlike composites), this behaviour does not go as far as failure which would considerably complicate and burden the numerical models.

The Radioss calculation software method is based on an explicit type of formulation integrating geometric non-linearity and materials. Contact is modelled by a weighing method which introduces a force proportional to the intrusion detected. For further information, refer to references (1) and (2).

Study on Suitability for Modelling of Collapse Threshold of Central Pillar

Suitability for modelling is a question which underlies any calculation using the finite element method. Suitability studies applied to the vehicle in its entirety resulted in two versions of meshing. Given the time required for discretization (2 to 3 man/months), this type of study cannot reasonably be integrated into a project. Furthermore, this type of approach applied to a complex structure would have given an average estimation of the influence of fineness of the mesh but would not allow for quantifying of the variation in responses to the type of loading mode and to the intrinsic nature of the structure. On the other hand, application to sub-structures, which may be instructive, are possible for the opposite reasons to those mentioned above. In fact, the two approaches are complementary in the sense that a suitability study for meshing applied to a vehicle completes those realized on the sub-structures.

Two factors influenced the choice of the central pillar. It is directly involved in the process of side impact, and simulation of its environment appeared manageable. With regard to this last point, we were concerned to define the limit conditions reflecting the working mode of the central pillar. It was not so much there exactitude as a realistic context which governed our choice. This context was applied in identical fashion to the two models of the pillar representing series-production and reinforced versions.

The sub-structure includes the central pillar and a part of the cant rail as well as reinforcements which it contains in the second definition of the vehicle. Loading of the pillar is in the form of a localized transverse force. Limit conditions for embedded and simply supported surfaces are imposed for the ends of the cant rail and central pillar.

To study suitability for meshing, each element is divided into four. The Figure 1 shows the force-vs-movement curves, the collapse force for the central pillar for two mesh sizes, for the two versions of the central pillar. The relative differences for the collapse threshold are less than 10%, (6% for the serie version and 9% for the version reinforced precisely).

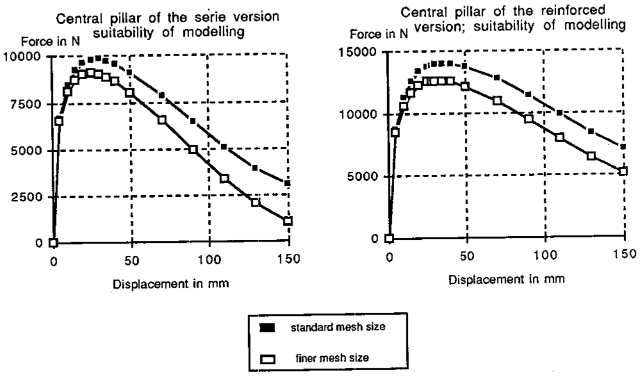


Figure 1. Suitability of Modelling

Another parameter, specific to the field of automobiles, is the influence of simulation of weld points. These, concealed by flanged edges, are the places where forces are transmitted from one part to another and are therefore of particular interest for modelling. In order to test sensitivity to this phenomena, each weld was replaced by two coincident nodes while retaining the same weld pitch. This is a model which, on average, must be stiffer than the real situation.

Figure 2 represents the force-vs-movement curves, the central pillar collapse force for the different configurations. Stiffness in the simulation of weld points increases by 13 and 9% the collapse threshold for the central pillar for reinforced and series-production versions respectively.

These results show that the basic model provides sufficiently correct behaviour to be integrated into the global model and also illustrates the limits of this type of modelling which requires management of approximations.

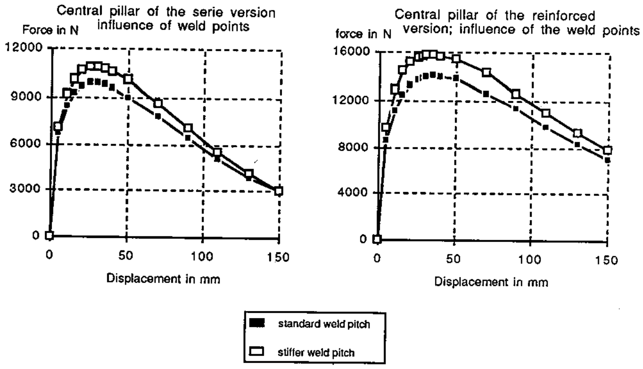


Figure 2. Influence of Weld Points

Model for Series-Production Vehicle

The creation of a mesh for the series-production vehicle is based on the discretization used for the statical analyses. The fineness of this type of mesh is well suited to areas of the vehicle which are not deformed or are only slightly deformed. This is the case for the side not subjected to impact and the front and rear extremities of the structure. On the other hand, the car side, sub-frame and doors on the impacted side are re-meshed in their entirety, more regularly and with a finer mesh.

The fact that the barrier can be deformed during impact is a fundamental parameter requiring particular care when constructing its model. In the case of impact on series-production vehicle, the model used for previous simulations (1) was re-applied and proved satisfactory. One of the guarantees of success of modelling is based on the prior definition of contacts which will occur during crushing of panels. Two types of algorithms allow these to be taken into account. Contact between two objects, an example of this is the interaction between the barrier and the vehicle via the doors; and contact within an entity, e.g. the doors or door/body side interaction.

The limit conditions are such that the vehicle is free in space. Friction between surface and tyres is negligible in relation to the forces transmitted to the vehicle by the barrier. Similarly, the vertical suspension forces are very weak compared with inertia effects.

17,000 finite elements were used to discretize the vehicle. Sixteen hours of CPU time were required on a Cray-YMP computer to simulate the sixty milliseconds of impact. After that time the barrier and vehicle have the same speed and there is therefore no further transfer of energy between them.

The knowledge acquired during earlier work made it possible to avoid certain pitfalls and to arrive at a solution rapidly. In particular, mastery was rapidly gained over the principal source of error which could have arisen from the definition of areas of contact and their management, and which would have been costly in terms of CPU time and real time.

Numerical Results and Comparison with Experiment for Series-Production Vehicle

Comparison of numerical simulation results with experimental data was satisfactory. Only kinematic data was compared. The elements for comparison concern intrusions and the speeds of intrusion into the cabin on the impacted side of the body. They are represented on the undeformed mesh of the series-production vehicle (figure 3). Correlation was good (see annex 1).

Analysis of deformation of the vehicle at the end of impact shows that the calculation is a reasonably faithful reproduction of the phenomena observed during testing, i.e.: collapse of the roof, local plastification of central pillar, crushing of door sill and doors, collapse of sub-frame.

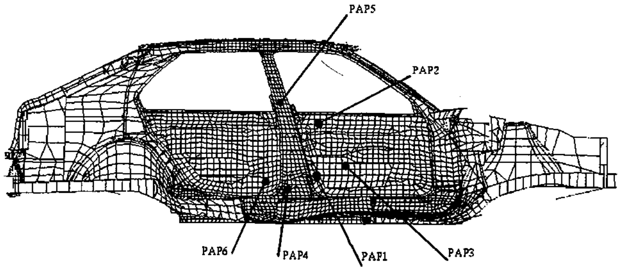


Figure 3. Position of the Points for the Correlation on the Undeformed Series-Production Vehicle

Model for Reinforced Vehicle

The reinforcements built into the vehicle are described in detail in the article by J. Rio (3). A first set were located at the door sill, a second in the central pillar and finally in the roof. A non-standard seat with considerable reinforcement was placed in the front of the vehicle on the impact side. All of these modifications considerably increased the global lateral stiffness of the structure. The consequence of this was to apply a higher load to the barrier with different modes of application. Given this new context, the barrier model had to be revised. A program of testing of the barrier on rigid non-flat walls was started. These more severe conditions made it possible to modify the force/movement laws and extend validity of the model.

3000 finite elements were added to the 17,000 from the previous model; 1500 for the seat and 1500 for the other reinforcements. Of course the internal vehicle interactions were re-defined and new seat/central pillar interaction created.

Two types of problems arose during the final development phase of the calculation. Firstly, modelling of the link between the seat back and its lower frame required investigations in order to arrive at a satisfactory simulation. Secondly, the introduction of reinforcers modify certain contacts and led to a new definition of numerical management.

Numerical Results and Comparison with Experiment for Reinforced Vehicle

Correlation proved to be conclusive with regard to all of the experimental data. The figures in Annex 2 of this document show this.

The reinforcements provide very significant reduction in intrusion and wall speeds on body side. It can be seen the relative homogeneous deformation of the body sides of the vehicle and the stability of the roof (Figure 4). The results show a small deformation of the seat and a good behaviour of the floor, too. All of these phenomena are an acceptable faithful reproduction of those observed during testing.

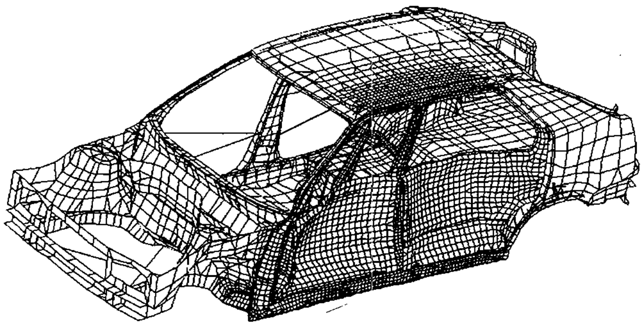


Figure 4. Final Deformed Mesh of the Reinforced Vehicle

The reinforcements radically alter the distribution of energy absorbed (Figure 5). These diagrams require a few comments. Verification is provided that increase in overall rigidity of the vehicle reduces the loads upon it and increases loading of the barrier. The effects of the reinforcements led to a transfer of the deformable energy from the body sides, the floor and the rear door to the front door and the seat. Particularly, the contribution of this type of seat in the side impact is emphasized.

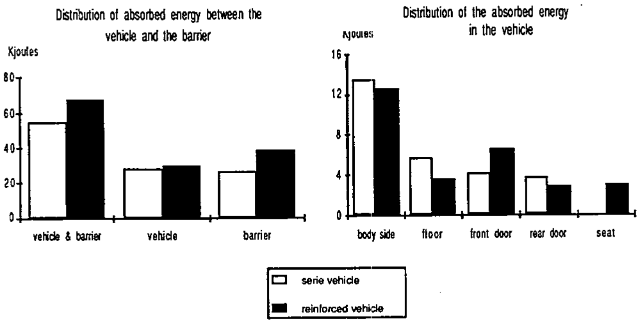


Figure 5. Distribution of Absorbed Energy

Optimizing of Structural Reinforcements

In an experimental project, the optimization phase for the structure, should the problem arise, is severely limited by economic considerations, especially where prototype vehicles are concerned. If use of modelling of side impacts still requires a lot of time, mainly required for discretization of the structure, once this is done, the model can be used immediately for a whole series of investigations.

In this paragraph, we describe optimization of the reinforced vehicle structure in two parts; the role of the seat and the role of the structure. This optimization is based on a criterion of speed of intrusion of cabin areas facing a dummy. This criterion is one of the elements in the strategy for reducing injuries to the sections of the dummy body (3).

The first line of research was to the determine the contribution of the seat at the given angle. Another way of formulating the problem is to look for the thickness of central pillar required to make up for removal of the seat from the reinforced vehicle while maintaining identical levels of intrusion and speeds of car side intrusion facing a dummy. The result of calculations lead to unrealistic thickness from the practical point of view. Therefore, in the specifications for the type of structure required, the importance or even indispensable nature of the seat is made abundantly clear.

After validation of the model for both versions of the vehicle, it was tempting to determine the contribution of each of the reinforcements, with the exception of the seat, to produce an optimum version of the structure from the point of view of side speeds facing the dummy.

Four versions of the structure definition were considered: Version 1, door sill reinforcements removed; Version 2, door sill and lower part of central pillar reinforcements removed; Version 3, roof reinforcements removed; and Version 4, internal reinforcements of central pillar removed.

The curves show the intrusion and the speed of two side points opposite the pelvis and thorax of the fictitious dummy (annex 3). They warrant several comments. The reinforcements for the roof seem to be of little use. All of the other reinforcers make a positive contribution to reducing the kinematic parameters. The role of internal reinforcers of the central pillar is particularly evident as, in their absence, the speed of the side opposite the thorax increases from 11 to 14 m/s. Finally, the reinforced version, in terms of its structure and performance, is very close to the optimum version.

Conclusions, Perspectives

The satisfactory validation of the numerical model of side impacts illustrates a certain degree of know-how. However, this cannot exclude the fact that for certain vehicle configurations which are notably different from those studied, new validations will be necessary. This results mainly from the barrier model which, although its area of application has been extended, cannot yet respond correctly for extreme load conditions.

The approach to impacts by study of sub-structures may turn out to be one of the most interesting areas for future investigation and may complete overall studies of side impacts. Firstly, this type of study makes it possible to respond with computation times much shorter than for global models. They will therefore allow for optimization of local part design. In addition, these local studies can be incorporated into partial specifications which could be established for each area of the structure to give better planning and control over global behaviour. It is therefore possible to envisage extending the type of study carried out on the central pillar to other parts of the structure (roof, seat, sub-frame, etc.).

The applications which resulted from the validation phase well illustrate the present state of development of this type of calculation and its possible role in the methods used to study side impacts. The criteria for final results nevertheless have a bearing on experimental measurements on dummies during impact. The introduction of a model of this dummy into the global numerical simulation of impact can be envisaged, but there must first be a rigorous validation phase for this model and its coupling with the seat and structure.

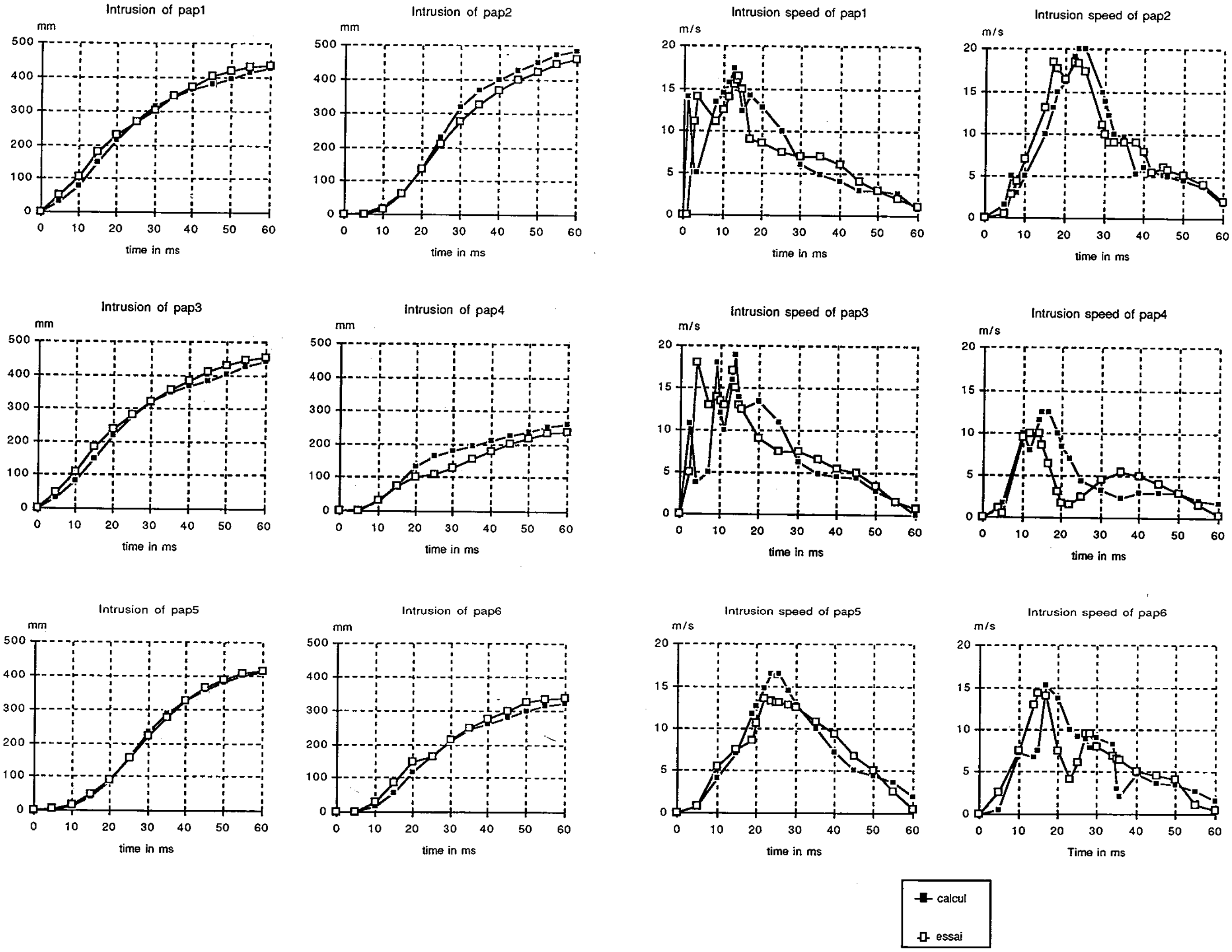
References

(1) Mathematical Modelisation of Side Collisions. C. Steyer, P. Mack, P. Dubois, Régie Renault. E.S.V conference 1989.

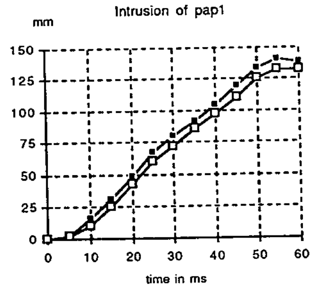
(2) Radioss User Manual Version 1.8 MECALOG.

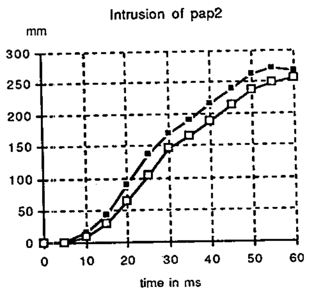
(3) "Renault VSS" Safety Vehicle: Occupant Safety in Side Impact. J. Rio Régie Renault. E.S.V conference 1991.

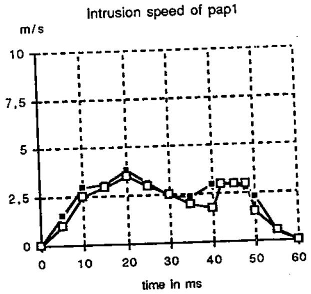
Annex 1

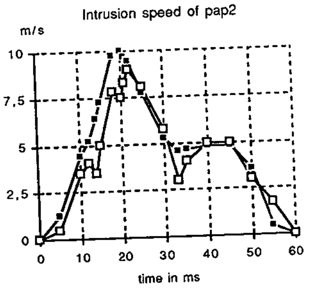


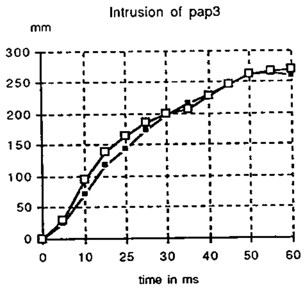
Annex 2

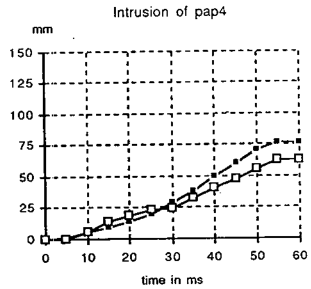

Intrusion of pap1

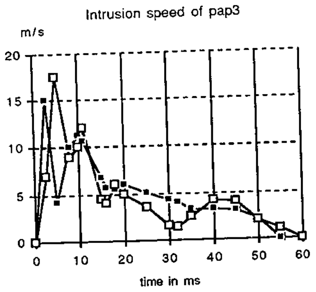

Intrusion of pap2

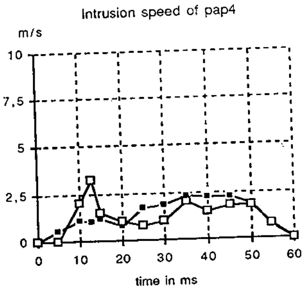

Intrusion speed of pap1

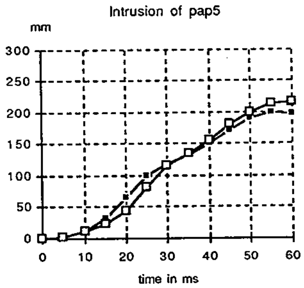

Intrusion speed of pap2

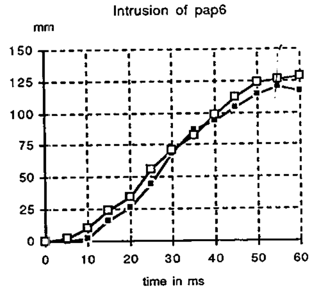

Intrusion of pap3

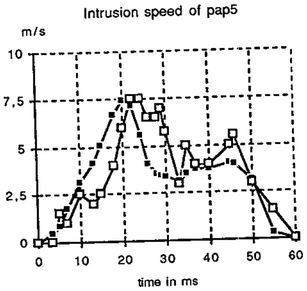

Intrusion of pap4

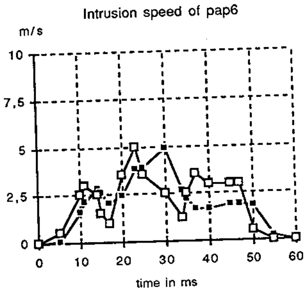

Intrusion speed of pap3


Intrusion speed of pap4


Intrusion of pap5

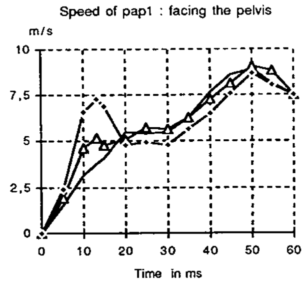

Intrusion of pap6

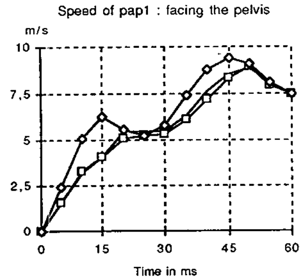

Intrusion speed of pap5

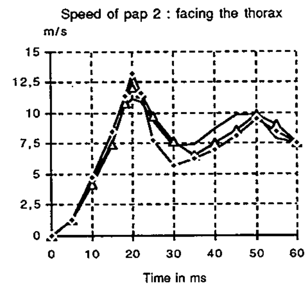

Intrusion speed of pap6

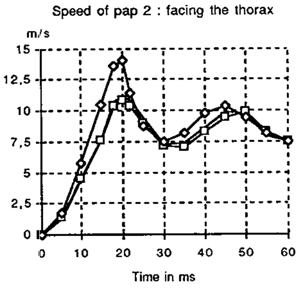
-■- calcul
-□- essai

Annex 3


Speed of pap1 : facing the pelvis


Speed of pap1 : facing the pelvis


Speed of pap 2 : facing the thorax


Speed of pap 2 : facing the thorax

— reinforced version
△ version 1
◆ version 2

— reinforced version
□ version 3
◇ version 4

S5-O-13

A Simulation Method of Vehicle Model Coupling with Dummy in Side Impact

Yutaka Tsukiji, Koji Taga
Mazda Motor Corporation

Abstract

The authors demonstrate a simulation method for the proposed NHTSA side impact test using a large vehicle FEM model which includes two occupants models. The calculation of the model is performed base on the results of several dynamic tests of various components and full scale vehicles. This paper presents modeling results which satisfactorily correlate to actual tests.

Introduction

Side impact does have some features that compare with frontal and rear impact. In side impact tests, a Moving Deformable Barrier (MDB) hits the vehicle with a "crab" angle of 27 degree, resulting in deformation. While in a frontal or rear impact, the crash is an impact between both rigid and deformation structures. In these, the direction of force is perpendicular to the vehicle. In a side impact collision, the occupant that hits the door or the B-pillar has a direct influence on the body structure of the vehicle while this is generally not the case in a front or rear crashes.

Numerical simulation is very useful to optimize the body structure by utilizing Finite Element Methods (FEM) software such as PAM-CRASH, DYNA3D, and RADIOS, and is useful in the study of occupant restraint systems by utilizing Lumped mass spring software such as MADYMO and MVMA. In this paper, validation of coupling with body structure represented by finite elements in PAM-CRASH and occupant models represented by Lumped mass spring model in MADYMO by using coupling simulation code PAM-CVS, in order to evaluate both body structure and front seated dummy response is described.

First, MDB and body structural models have to be developed adequately to accurately simulate the crashworthiness of full vehicle. Component tests of MDB and full scale side impact test without dummy were performed for the validation of these models.

Second, based on the result of sled tests, the dummy model developed at Ford Motor Company by Dr. P. Prasad and T.C. Low was calibrated for coupling simulation. By utilization of these models, full vehicle side impact simulation was performed. As a result, good correlation between simulation and test data was obtained.

Lastly, the validity of coupling simulation including padding model is described based on the comparison with sled test.

MDB Model

The Moving Deformable barrier (MDB) proposed by NHTSA consists of an aluminum honey comb and a "crabbed" mode carrier. Forty eight-beam elements are utilized in order to coincide with the geometry of the carrier, total weight, center of gravity and moment of inertia. For the honey comb, 1600 solid elements with crushable foam material are used and 1530 shell elements are used for its surface. MDB model is shown in Figure 1. To smooth the contact between MDB and body structure, corner of honey comb is modeled accurately. Crushable foam material of solid elements in PAM-CRASH is quite complicated and it is impossible to obtain all of the material parameters directly from experiments. Therefore volumetric strain-pressure curve is obtained by static component tests and by tuning other parameters, correlation is taken with dynamic component tests against flat barrier at 10 m/s. Deformation and force deflection curve for honey comb comparisons between dynamic component test and simulation as well as crushable foam material validation are shown in Figures 2 and 3.

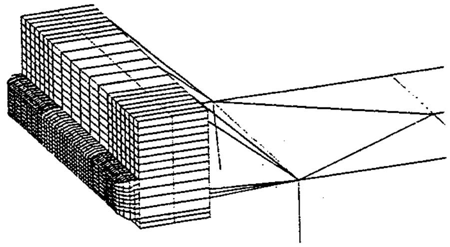


Figure 1. MDB Model

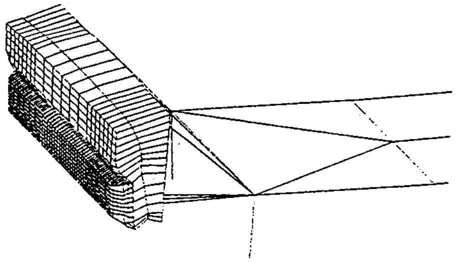


Figure 2. Barrier Deformation

Body Structural Model

The structural modeling is very classic. Fine meshes of approximately 15x15 mm are used around the hit area near MDB such as the door, hinge pillar, center pillar, side sill, etc. Coarse meshes are utilized in areas far from MDB such as the opposite side of the vehicle. Seat structure which is important for side impact, is included.

This model which utilizes about 20,000 shell elements and 500 bar/beam elements is illustrated in Figure 4.

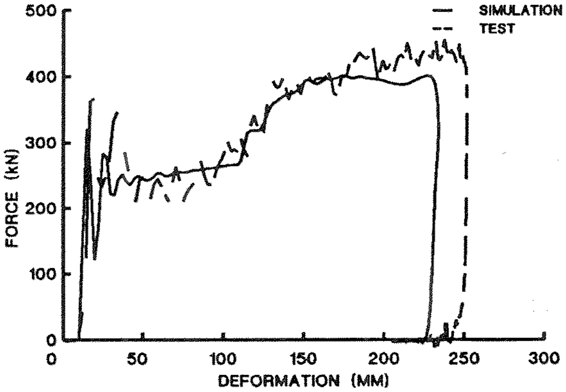


Figure 3. Comparison of Deformation Characteristics

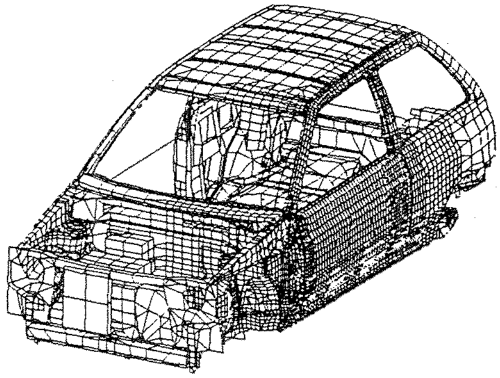


Figure 4. Full Scale Structural Model

There is no boundary condition imposed on the structure because the friction force is negligible compared to the interaction force between MDB and body structure in the lateral direction. Many contact areas are defined precisely, for example MDB to side door outer panel, side door outer panel to impact bar inside the door, impact bar to door inner etc.

Full Scale Simulation Without Dummy

In order to validate these model, full scale side impact simulation and test without dummy were performed. In the first simulation, many penetration occurred and the simulation results were very unstable. This was due to using automatic self-contact algorithm, weakness of the calculated contact force and incomplete contact definition where it was difficult to foresee considering the initial configuration. Changes of the automatic self-contact algorithm to master/slave contact algorithm, of a larger scale factor value for the contact force and the addition of contact definition were made. As a result, good agreement between simulation and test is obtainable. Comparison of acceleration time histories of MDB is shown Figure 5 and velocity-time histories of door and MDB are shown in Figure 6. Deformation is shown in Figure 7. It is felt that the body structural model was validated through this simulation.

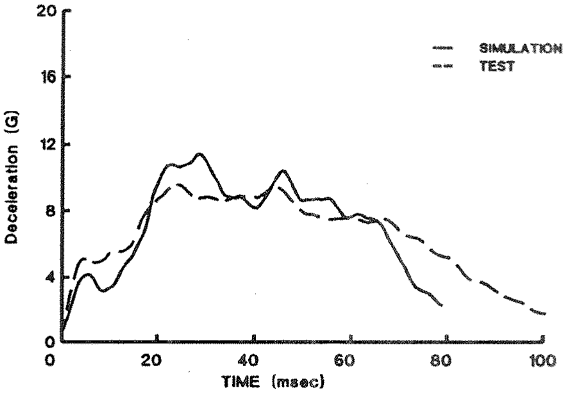


Figure 5. MDB Deceleration Comparison

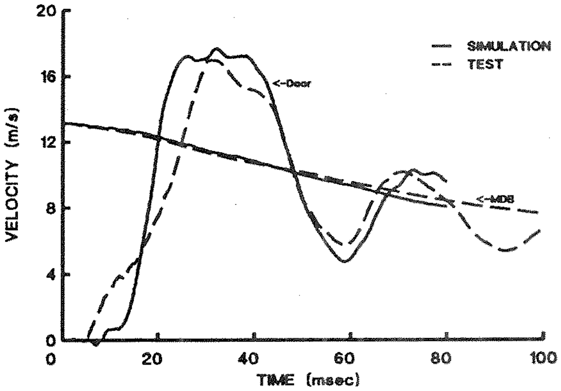


Figure 6. Comparison of Velocity at MDB and Door

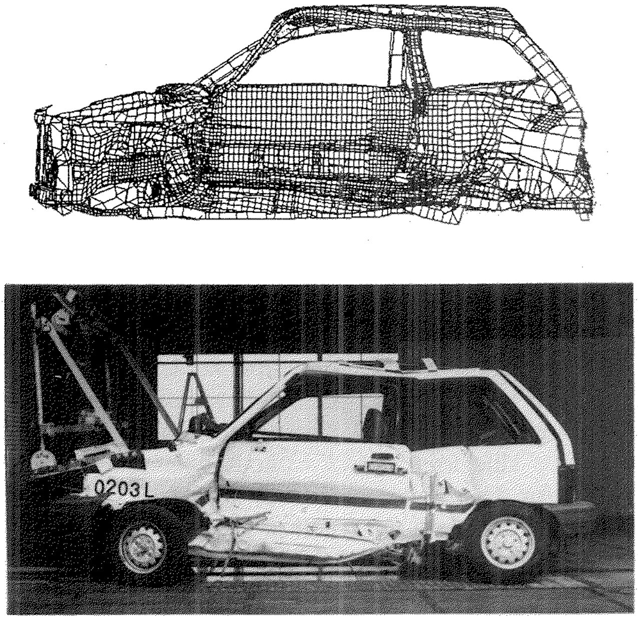


Figure 7. Final Deformation Except Barrier

Calibration of Dummy Model for Coupling Simulation

The DOT Side Impact Dummy (DOT-SID) model for MADYMO has been developed and reported in detail by Low and Dr. Prasad (3). In this model the occupant interaction with side structure are exemplified by ellipsoids representing the chest, abdomen, pelvis and legs. By the difference of algorithm between lumped mass, MADYMO and finite element method, PAM-CRASH small modification in this model is needed. New springs and ellipsoids for contact with FEM structure were added.

Dummy response is determined by contact conditions between body structure and dummy. Because of its simplicity it is difficult to simulate dummy response in all contact condition. Contact condition means location of hit points, area of contact and force direction upon the dummy. It is thought that according to contact condition configuration of contact ellipsoid, several new spring characteristics must be changed. Hence, for calibration of the dummy model and, in addition, to clarify the problem of coupling simulation validation was performed by comparison with sled test. In this sled test contact condition between body structure and the dummy is the same as that in a full scale side impact test (explained below). The sled test model is illustrated in Figure 8.

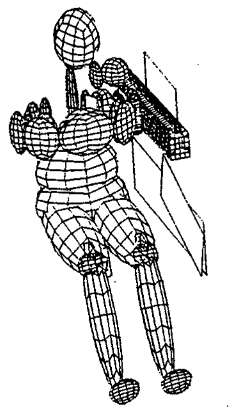


Figure 8. Model Configuration for Sled

The belt-line at upper part of the door, where it is in contact with the chest, is designed to collapse and to absorb the energy when the chest hits this line. Cross section of this belt-line is shown in Figure 9. The structure in contact with the pelvis is a rigid wall. At first running penetration with belt-line and chest was found because of severe contact with rigid ellipsoids and deformable structure. By tuning contact force scale factor, and the additional spring characteristics, good correlation between test data and simulation is obtained, as can be seen in Figures 10 through 13.

Full Scale Side Impact Simulation

In this full scale side impact test, vehicle structure is the same as that used without dummy explained above. The structure at belt-line in contact with chest is the same as in the sled test. The structure in contact with the pelvis is assumed rigid impact bar inside the door. As for a rear seated dummy no validation is attempted because contact condition is complicated in the force direction acting on the dummy. In order to minimize the influence

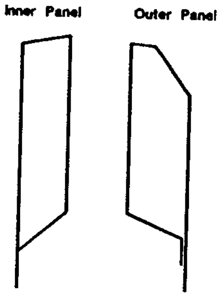


Figure 9. Cross Section at Belt-line

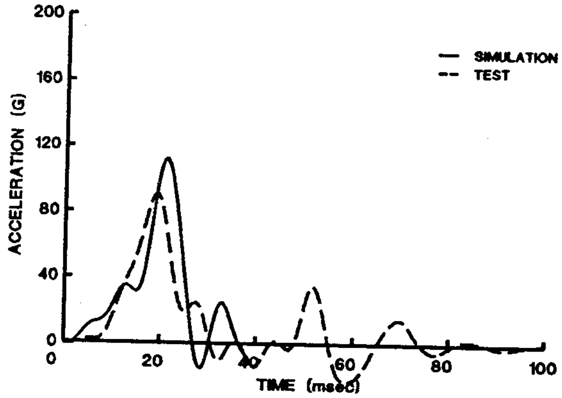


Figure 10. Comparison of Upper Rib Acceleration (Sled with Steel Structure)

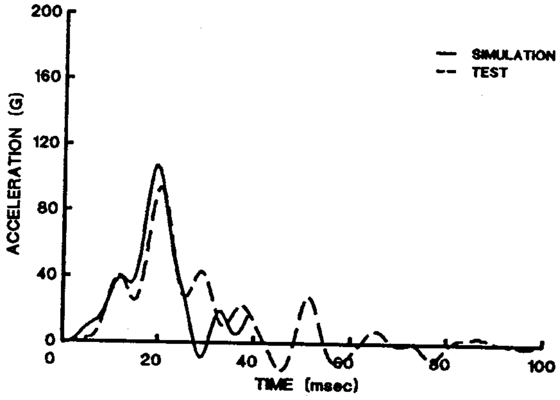


Figure 11. Comparison of Lower Rib Acceleration (Sled with Steel Structure)

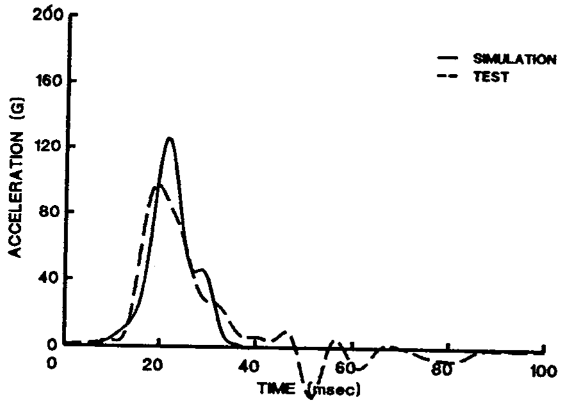


Figure 12. Comparison of Lower Spine Acceleration (Sled with Steel Structure)

of the rear seated dummy, the same dummy as in the front was set and several contacts were defined. Full scale side impact simulation results are shown in Figures 14 through 18 and deformations are shown in Figure 19. Good agreement of MDB and dummy response is obtained. It is thought that this model is validated and it is possible to predict both deformation of body structure and dummy response.

However, in case of large change of contact condition, for example large change of impact bar location, large changes in initial seated dummy location, it is necessary

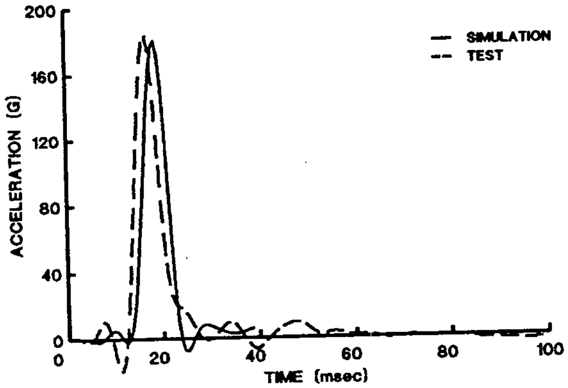


Figure 13. Comparison of Pelvis Acceleration (Sled with Steel Structure)

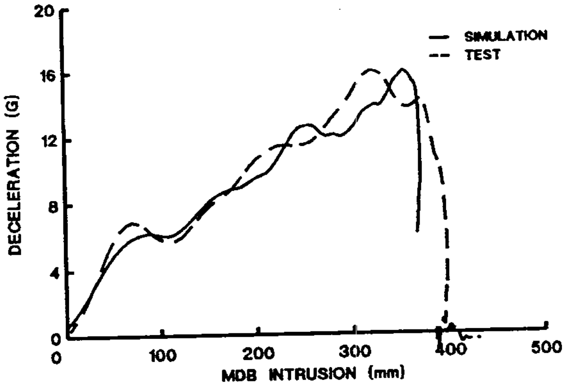


Figure 14. Comparison of Deceleration-Intrusion Curve at MDB (Full Scale Vehicle)

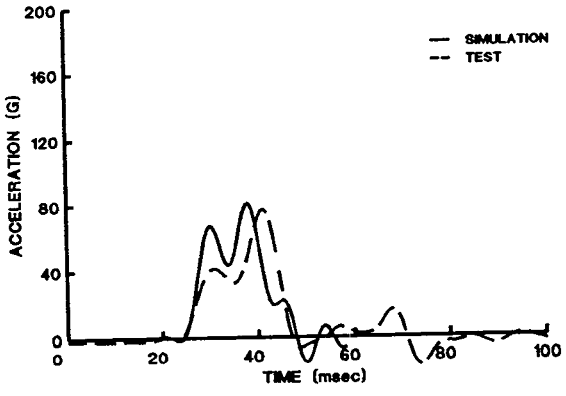


Figure 15. Comparison of Upper Rib Acceleration (Full Scale Vehicle)

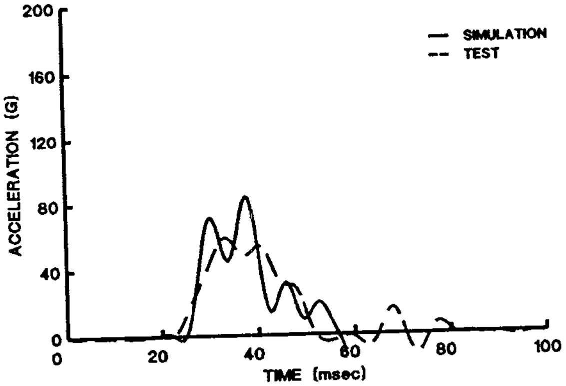


Figure 16. Comparison of Lower Rib Acceleration (Full Scale Vehicle)

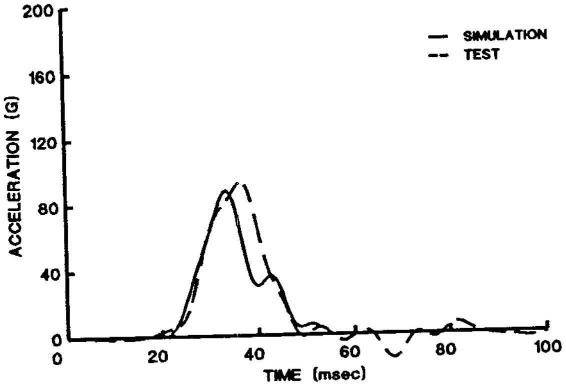


Figure 17. Comparison of Lower Spine Acceleration (Full Scale Vehicle)

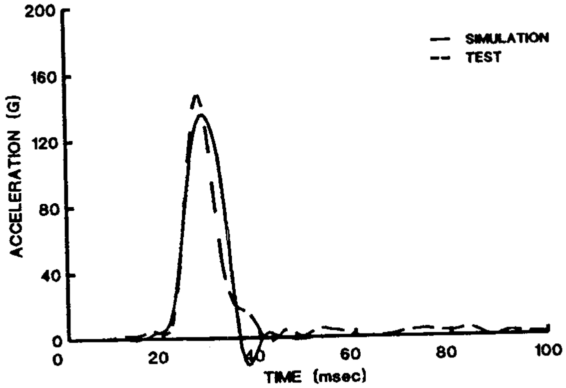


Figure 18. Comparison of Pelvis Acceleration (Full Scale Vehicle)

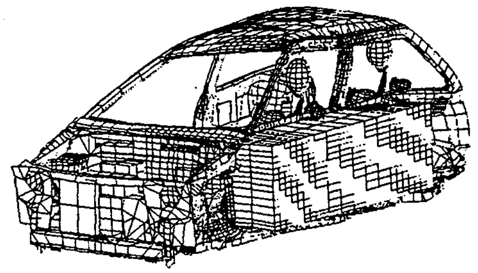


Figure 19. Deformation at 60 msec (Full Scale Vehicle)

to calibrate the dummy characteristics based on sled test in the same contact condition as full scale side impact test.

Coupling Simulation Including Pad Model

As in side impact, padding is very effective to reduce the dummy injury, it is important to include this in simulation technology. It was attempted to include padding when attempting to compare coupling simulation with sled test data.

In order to achieve the force-deflection curve, isotropic crushable foam material was used. The validation process of the padding material is the same as for MDB honey comb material. Typical dynamic test was performed (Figure 20). The radius of impactor is same as that of the DOT-SID ribcage. Parameters are decided to coincide with force-deformation curve and deformation mode of the padding. Characteristic comparisons are shown in figure 21. The unloading curve is not valid, however in side impact this difference is acceptable due to the fact that the dummy injury criteria is thought to depend primarily on the loading curve.

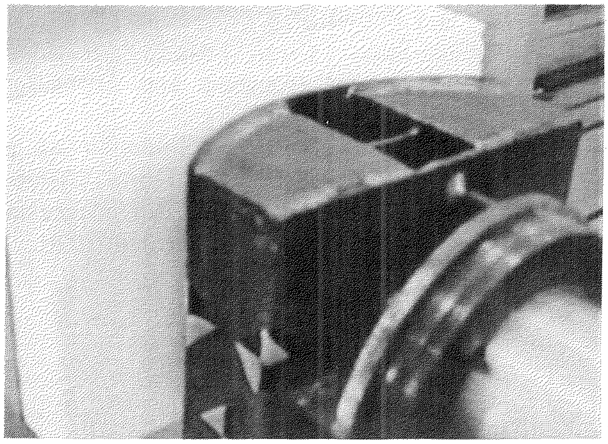


Figure 20. Component Test of Padding

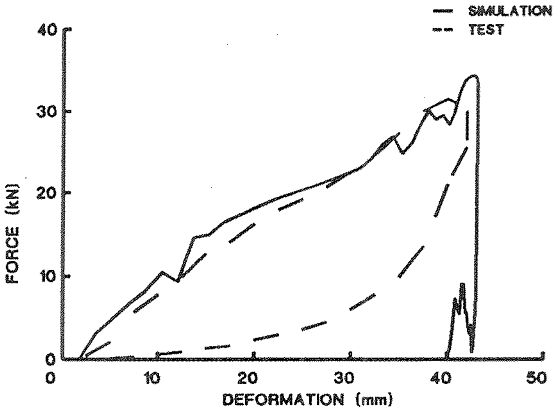


Figure 21. Comparison of Pad Characteristics

In the early simulations for sled there were some problems in PAM-CRASH in using this material. First was penetration problem between dummy and padding. Second was hourglass mode of solid elements. This problem is solved by tuning contact force scale factor and hourglass viscosity coefficient.

Most difficult problem of coupling including padding is the configuration of the dummy, especially around thorax. Crushable foam material is mainly governed by pressure-volumetric strain curve. By using rigid contact ellipsoids it is impossible to achieve the complicated deformation caused by combination with jacket and rib cage. In spite of tuning the configuration of contact ellipsoids, first peak value of acceleration at upper and lower rib is different from those of test results as shown in Figures 22 and 23. At pelvis acceleration, small deformation of pelvis and leg in actual sled test results in good agreement with the simulation (see Figure 25). It is indicated that more precise model of the dummy such as FEM is needed to simulate dummy response.

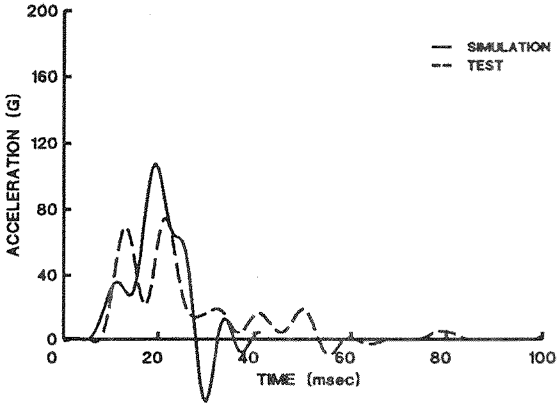


Figure 22. Comparison of Upper Rib Acceleration (Sled with Padding)

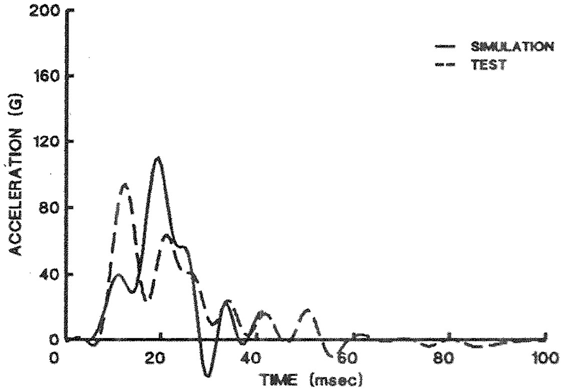


Figure 23. Comparison of Lower Rib Acceleration (Sled with Padding)

Conclusion

- Validation of MDB and structural model for side impact is presented.
- It has been shown that without padding it is feasible to simulate both body structure and front seated dummy response in a given condition. it is believed that it is possible to know the influence of body stiffness to dummy response by this coupling simu-

lation. Moreover, dummy model developed by FORD performs well in this coupling simulation.

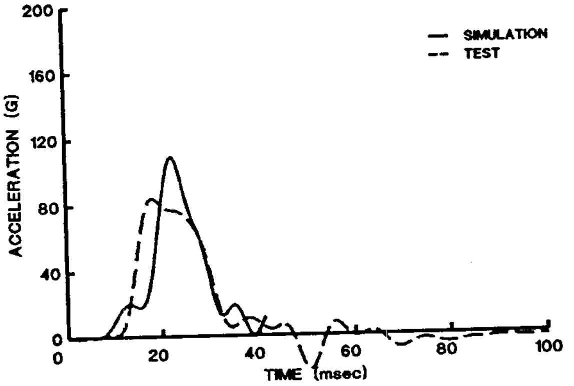


Figure 24. Comparison of Lower Spine Acceleration (Sled with Padding)

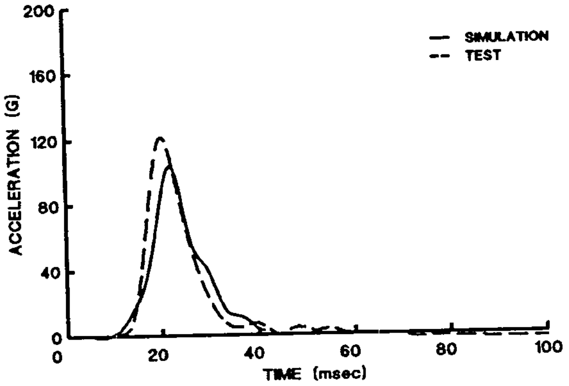


Figure 25. Comparison of Pelvis Acceleration (Sled with Padding)

- Including padding a precise model of the dummy such as FEM model is necessary to develop for coupling with FEM structure.

Acknowledgements

The authors would like to thank Dr. Priya Prasad and T.C. Low, FORD Advanced Vehicle Engineering Technology, Dearborn, Detroit for providing a mathematical model of the SID dummy and many advise. The authors would like to thank Mr. Atalolo DAGBA for many advise to develop this structural model.

References

(1) Steyer, C., Mack, P., DuBois, P., "Mathematical Modelisation of Side Collisions," Proc. of 12th ESV conf., 1989.
(2) Kurimoto, K., et al., "Simulation of Vehicle Crashworthiness and Its Application," Proc. of 12th ESV conf., 1989.
(3) Low, T.C. and Prasad, P., "Dynamic Response and Mathematical Model of Side Impact Dummy," SAE90231, Proc. of the 34th Stapp Car Crash Conference, SAE Inc., 1990.
(4) Low, T.C. and Prasad, P., "Side Impact Modeling Using Quansi-Statics Crush Data," SAE910601, Proc. of International Congress and Exposition, Detroit, 1991.
(5) Tilakasiri, A., Bois, P., "A Simulation of an Automotive Side Impact with Finite Element Dummies Included in the Analysis," 5th Science and Engineering on Supercomputers, London, 1990.

S5-O-14

A Resolution of Side Impact Phenomena by Means of Dynamic Nonlinear FEM Simulation and a Study of Vehicle Body Construction

Akihiko Inagaki, Nobuhiko Takahashi
Akira Tohyama, Akihiro Ohtomo
Nissan Motor Co., Ltd.

Abstract

There are two fundamental techniques that can be employed to improve side impact protection. One approach involves increasing the reaction force of the vehicle body in the interval between the onset of the crash (primary impact) and the moment the door strikes the occupant (secondary impact). The second approach involves improving the energy absorption capacity of the door inner assembly at the time of the secondary impact. This work focused on the first technique of improving the body reaction force. Using a dynamic nonlinear FEM simulation program (PAM CRASH), an analysis was made of the body deformation behavior of a four-door sedan in a side impact. In conducting this analysis, a method was developed for preparing an analytical model having sufficient size to provide good correlation with the deformation behavior of an actual vehicle in the interval between the primary and secondary impacts. The results obtained with the model were then analyzed by examining time histories of the displacement of body structural elements and strain distributions during the side impact phenomenon. The purpose of the analysis was to find ways of reducing the impact velocity between the door and the occupant, which would be most effective in mitigating the thoracic trauma index (TTI) of the occupant. The results of the analysis clarified the deformation mechanism of the body structures and indicated the respective contribution that various body reinforcements would make toward increasing the reaction force of the vehicle body.

Introduction

The mechanism producing the thoracic trauma index (TTI) in a side impact test,which is conducted with the procedure specified in FMVSS 214 (3)-(8), is explained here in reference to Fig. 1. This figure shows velocity time histories of the moving deformable barrier (MDB), dummy, struck vehicle and impacted door following the impact. The phenomena that occur at each point of elapsed time are explained below (1).

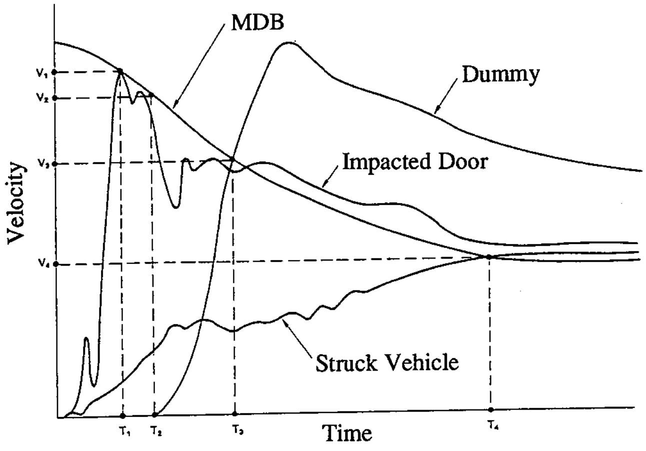


Figure 1. Velocity-Time Data for the MDB, Struck Vehicle, Impacted Door and Dummy in Side Impact Test

T0 to T1: The MDB strikes the vehicle and the impacted door is rapidly accelerated to the same velocity as the barrier.

T2: The door impacts the dummy. During the interval of T0 to T2, the vehicle moves in the direction of the MDB's forward motion, but the dummy remains in a stationary position relative to the ground.

T3: The dummy reaches the same velocity as the door and begins to separates from it.

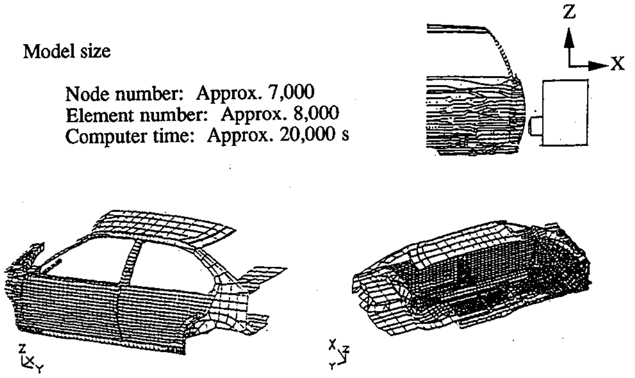
T4: The vehicle and the MDB reach the same velocity and body deformation stops.

There are two basic approaches that can be taken to reduce TTI. One approach is to increase the reaction force of the vehicle body in the interval from the onset of the crash (primary impact) to the moment when the door strikes the dummy (secondary impact). The second approach is to increase the crash energy absorption capacity of the door inner assembly in the passenger compartment. This work focused on the first approach of increasing the reaction force of the vehicle body and an investigation was made of ways of reducing the velocity of the MDB, V2, at the time of the secondary impact (T2 = 20 msec) (1).

Modeling Method

Analytical Model

The side impact test procedure specified by the U.S. National Highway Traffic Safety Administration (NHTSA) requires approximately 60 msec for the completion of impact phenomena. However, since this investigation focused on the body deformation mechanism up to the moment of the secondary impact (T2 = 20 msec), the analytical model was designed as indicated in Fig. 2. This model was based on the results of analyzing video tape recordings of actual body deformation behavior that occurred during the first 20 msec interval. The analytical model did not include the portion of the body forward of the front pillar or the portion after the rear pillar, as these areas have relatively little effect on the side impact phenomena of interest. In addition, only the left half of a four-door sedan passenger car was modeled.


Model size

Node number: Approx. 7,000
Element number: Approx. 8,000
Computer time: Approx. 20,000 s

Figure 2. Analytical Model

Analytical Conditions

The analytical conditions were set as follows in order to correspond to the NHTSA side impact test.

Initial velocity. The vehicle was stationary at the time of impact; the MDB was moving at a combined velocity of 30 mph in the X-direction and 15 mph in the Y-direction.

Restraint conditions. The following conditions were assumed with respect to the boldfaced nodes in Fig. 3. Movement in the X- and Y-directions was unrestrained, while movement in the Z-direction was restrained.

Additional weight. Since weight is an important factor in impact tests, it was necessary to add the weight of the portions of the vehicle body which were not modeled. Weight was added at the boldfaced nodes of the body model in Fig. 3, excluding the dead weight of the model.

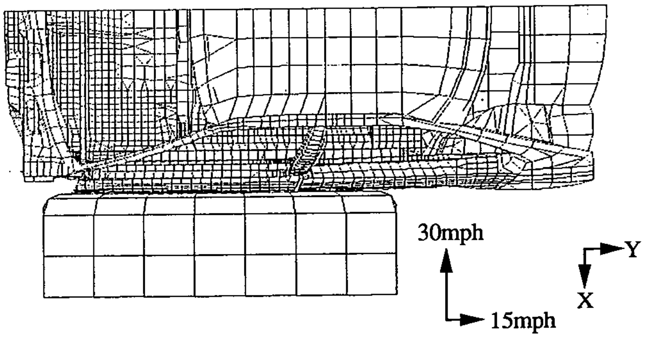


Figure 3. Model of Analytical Conditions

Analytical Results

The calculated results obtained with the analytical model were compared with experimental data to validate the correlation between the two sets of data. Calculated and measured results for the MDB-generated deceleration are shown in Fig. 4 and time histories of the MDB velocity are given in Fig. 5.

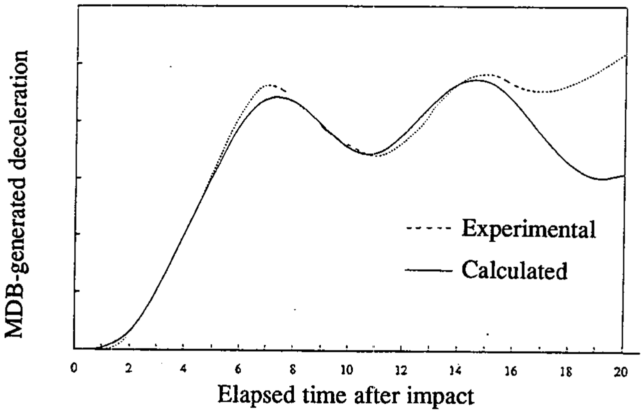


Figure 4. Calculated and Measured Time Histories of MDB-Generated Deceleration

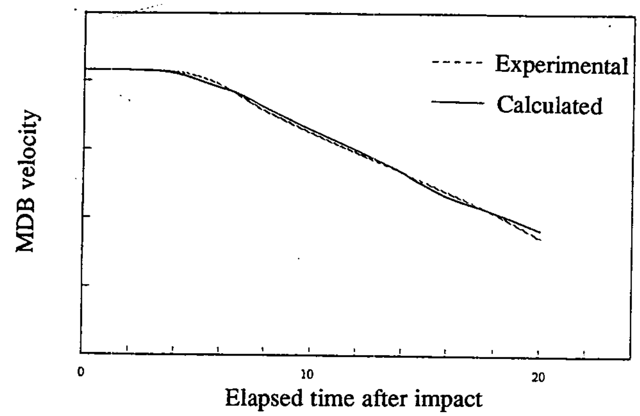


Figure 5. Calculated and Measured Time Histories of MDB Velocity

Although the calculated and measured waveforms showed good agreement until around 16 msec, they differed considerably at about 20 msec. To clarify the cause of this difference, an examination was made of a high-speed film of the experimental impact. It was found that the experimental waveform included deceleration components attributable to the deformation of the seat and instrument panel. The deceleration generated by the body alone would show a waveform like the calculated result. Therefore, it was concluded that the calculated and measured values showed sufficient correlation.

Body Deformation Mechanism

Figure 6 presents a deceleration time history diagram in which the MDB velocity is represented along the vertical axis and the elapsed time from the moment of impact is given along the horizontal axis. The body deformation mechanism is outlined in reference to the elapsed time.

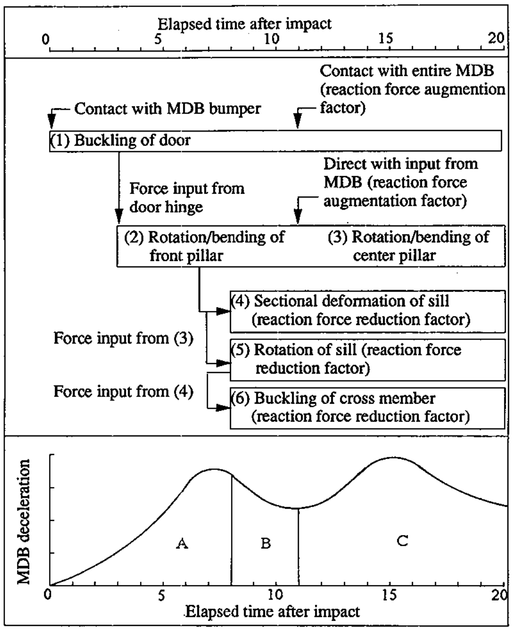


Figure 6. Body Deformation Mechanism

The deceleration time history diagram was divided into three zones (A, B and C) and an investigation was made of the body deformation mechanism in each zone. Zone A was the interval from the moment of impact until the first MDB deceleration peak occurred 8 msec later. Zone B was the interval from 8-11 msec during which MDB deceleration decreased. Zone C was the interval from 11-20 msec during which time the second deceleration peak occurred.

Deformation Mechanism in Zone A (0 to 8 msec)

The force input from the bumper of the MDB is transmitted via the door hinges to the front pillar and the center pillar. Since both pillars have an inherent reaction force, MDB deceleration increases during this time frame. These phenomena continue until completion of impact.

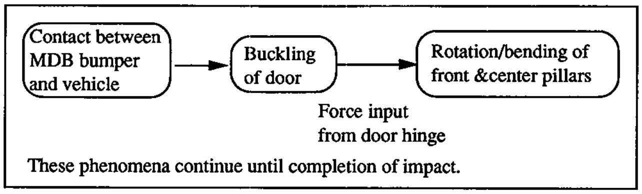


Figure 7. Deformation Mechanism in Zone A (0 to 8 msec)

The deformation modes of the body at 8 msec are shown in Figs. 8 to 11 and the strain distributions at that moment are given in Figs. 12 and 13. The strain distributions indicate that strain was concentrated at the joints between the two pillars and the side sill.

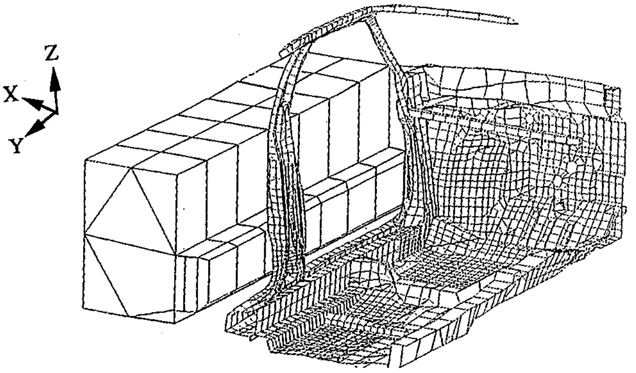


Figure 8. Body Deformation Modes at 8 msec

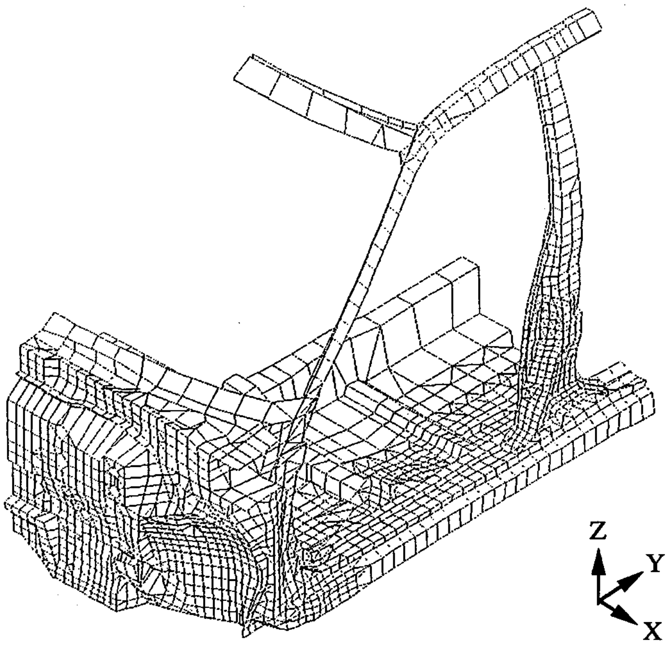


Figure 9. Body Deformation Modes at 8 msec

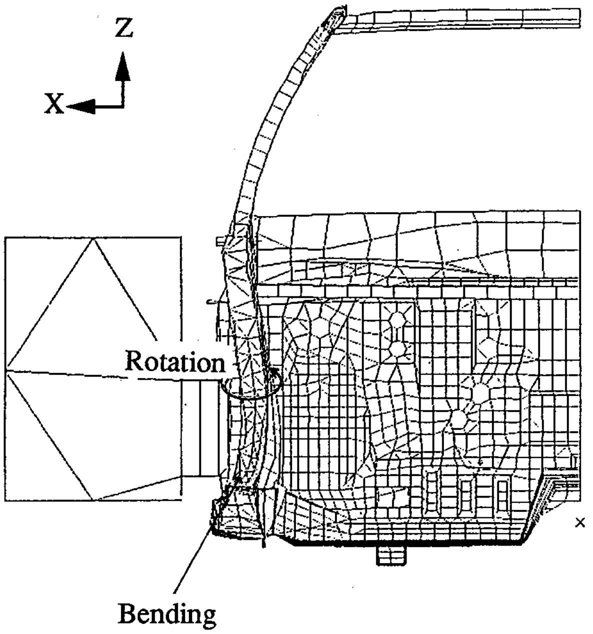


Figure 10. Front Pillar Deformation Modes at 8 msec

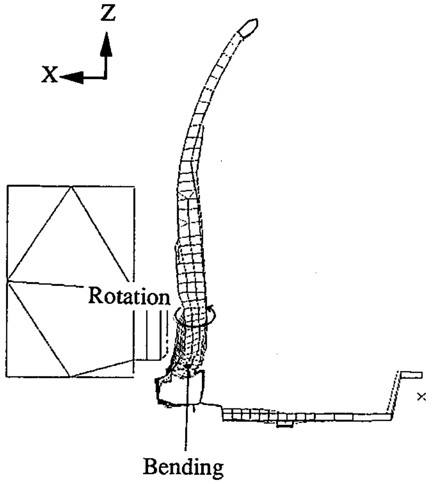


Figure 11. Center Pillar Deformation Modes at 8 msec

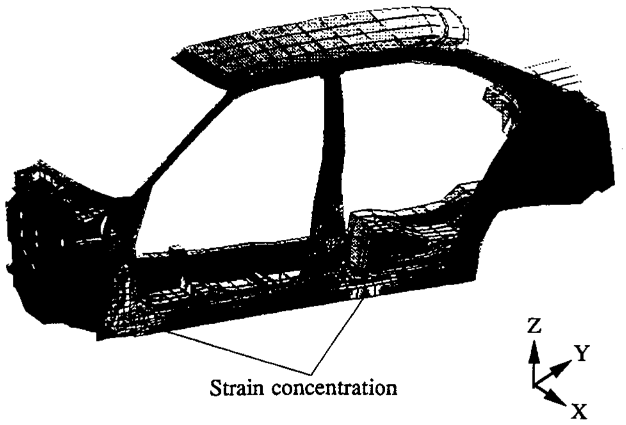


Figure 12. Strain Distribution

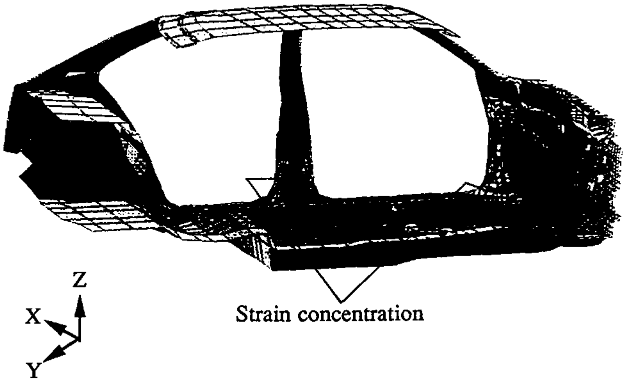


Figure 13. Strain Distribution

Deformation Mechanism in Zone B (8 to 11 msec)

The force input occurs in the same manner as in zone A. However, the transmission of force from each of the pillars to the side sill causes the rotation of the sill. Since the pillars can no longer absorb the crash energy efficiently, MDB deceleration decreases during this time frame.

The body deformation modes at 11 msec are shown in Figs. 15 to 18 and the strain distributions of the body at that moment are given in Figs. 19 and 20. The body deformation modes indicate the sectional deformation and

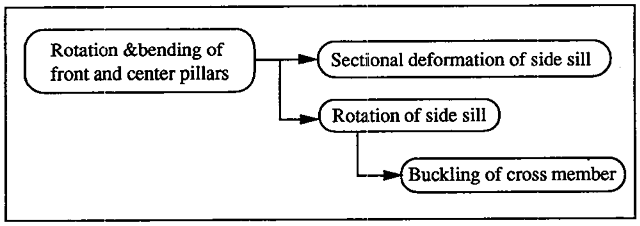


Figure 14. Deformation Mechanism in Zone B (8 to 11 msec)

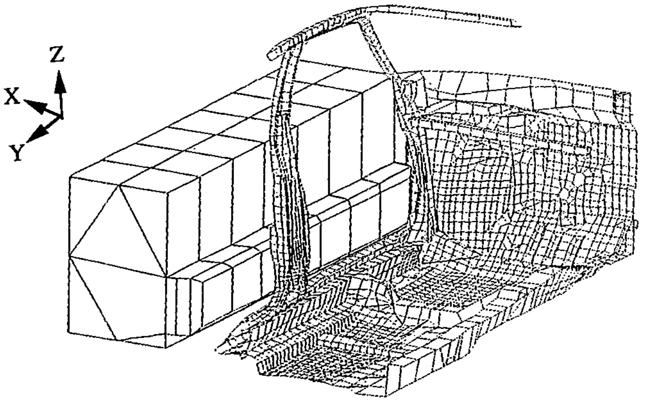


Figure 15. Body Deformation Modes at 11 msec

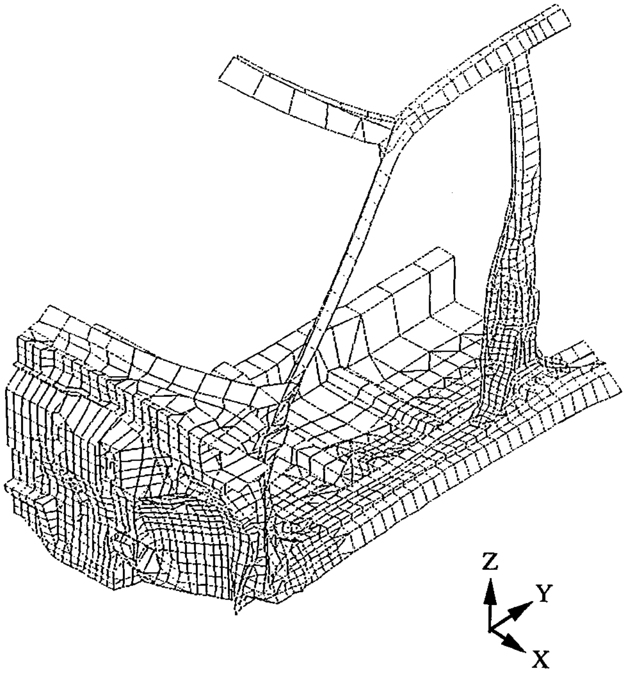


Figure 16. Body Deformation Modes at 11 msec

rotation of the side sill and also the buckling of the cross member.

Deformation Mechanism in Zone C (11 to 20 msec)

The entire MDB impacts the vehicle and the structural members over a large area of the body absorb crash energy. As a result, the deceleration of the MDB increases again in this time frame.

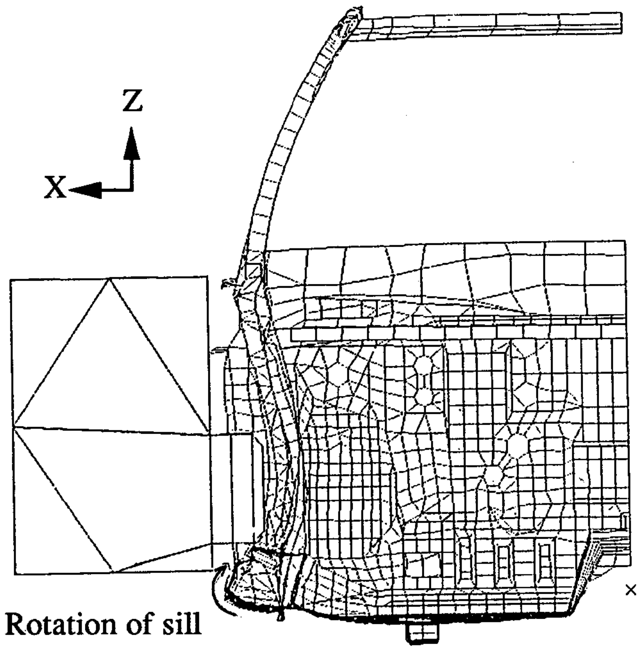


Figure 17. Front Pillar Deformation Modes at 11 msec

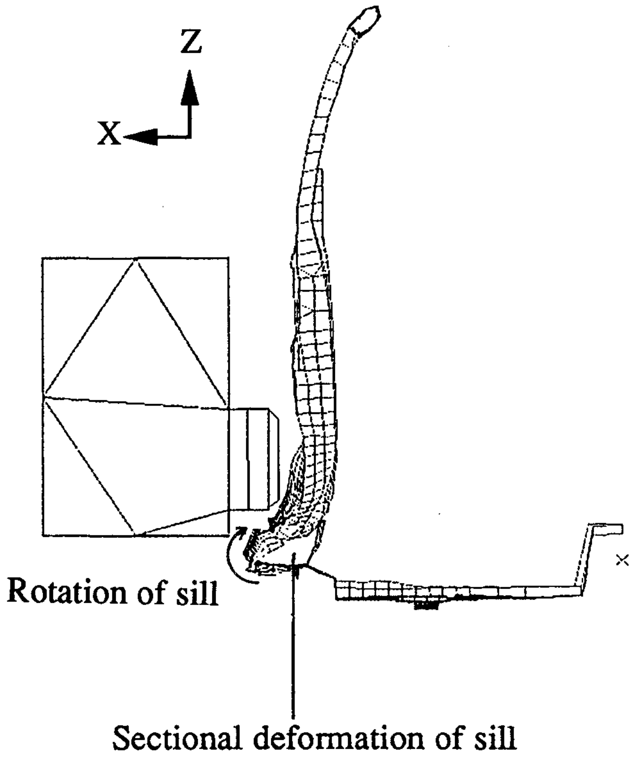


Figure 18. Center Pillar Deformation Modes at 11 msec

The body deformation modes at 20 msec are shown in Figs. 22 to 25 and the strain distribution in the vehicle body at that moment are shown in Figs. 26 and 27. The body deformation figures indicate that the entire MDB has impacted the vehicle. As a result, it can be presumed that the reason for the increase in MDB deceleration in zone C was that crash energy was absorbed by a large area of the body side. This is confirmed by the fact that

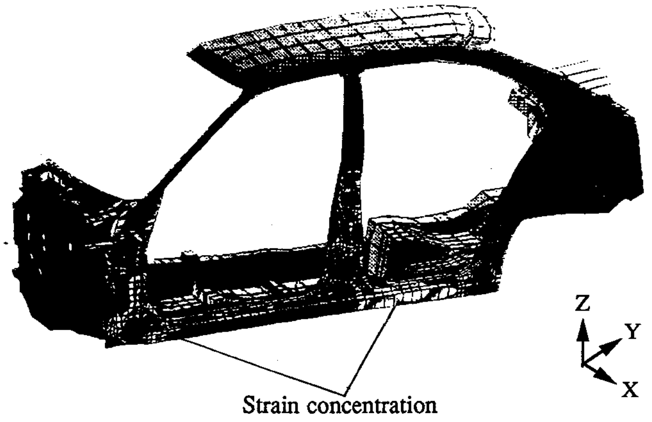


Figure 19. Strain Distribution

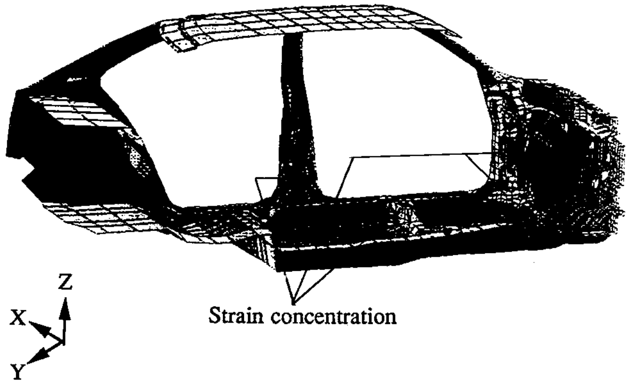


Figure 20. Strain Distribution

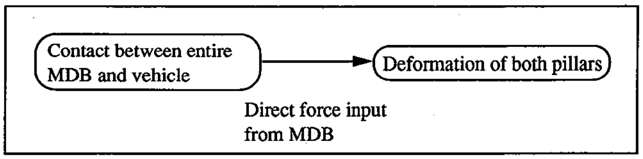


Figure 21. Deformation Mechanism in Zone C (11 to 20 msec)

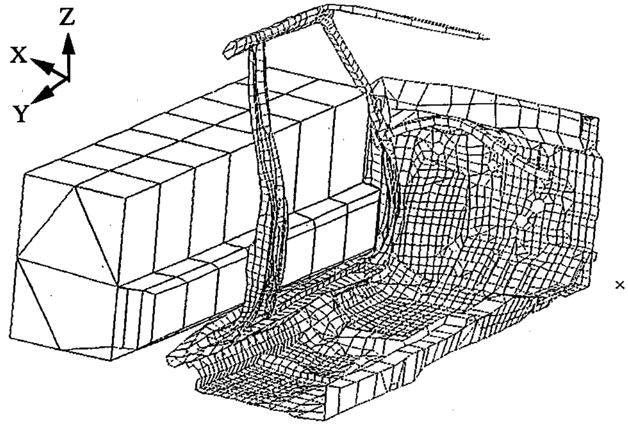


Figure 22. Body Deformation Modes at 20 msec

the strain distributions indicate that strain was distributed over large areas of both pillars.

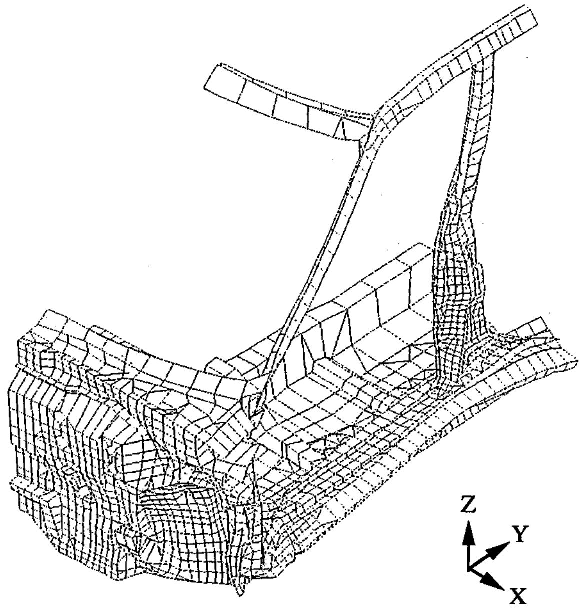


Figure 23. Body Deformation Modes at 20 msec

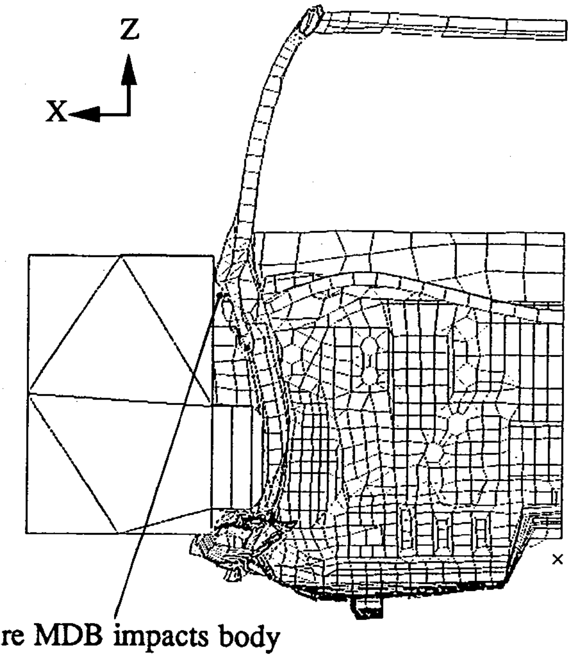


Figure 24. Front Pillar Deformation Modes at 20 msec

Analysis of Reaction Force Contribution by Various Body Parts

Based on the results of the foregoing investigation, various locations on the body were selected as indicated below, which were thought to be effective in augmenting body reaction force. Assuming that those locations were reinforced, a quantitative analysis was made of their respective contribution to increasing the reaction force of the body.

The individual effect of the four reinforcements is shown in the deceleration diagram in Fig. 28.

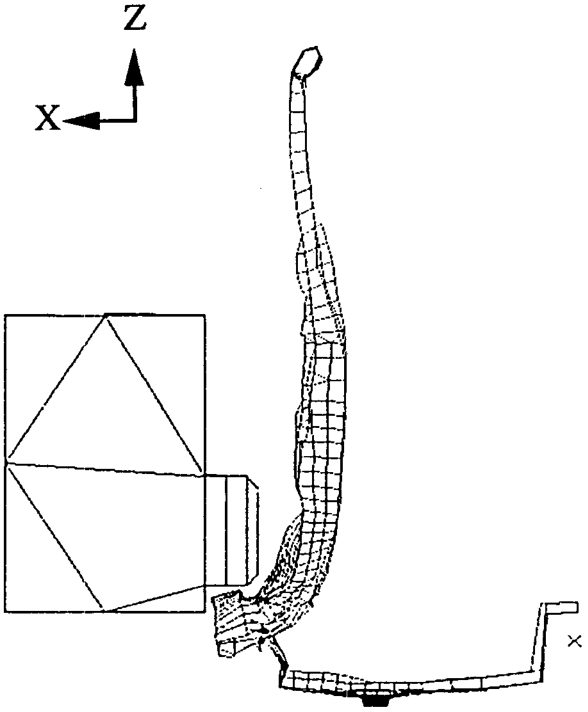


Figure 25. Center Pillar Deformation Modes at 20 msec

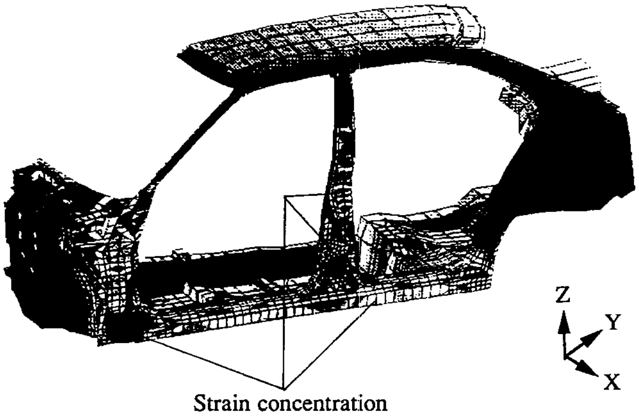


Figure 26. Strain Distribution

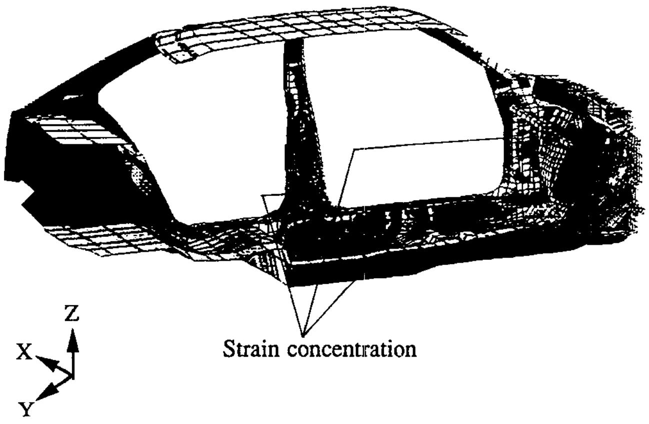


Figure 27. Strain Distribution

Table 1. Analysis of Reaction Force Contribution by Various Body Parts

	Reinforced locations	Contribution to ΔV2	Considerations
①	Lower part of center pillar	2.5%	Reinforcing the piller has little effect because it deforms into the passenger compartment away from the MDB.
②	Lower part of front pillar	48.7%	Pillar intrusion into the passenger compartment is restrained by the dashboard panels
③	Side sill	21.6%	
④	Cross member	27.2%	

Note: Contribution to△V2 indicates the individual effect of each reinforcement as a percentage of the total reduction (= 100%) in V2.

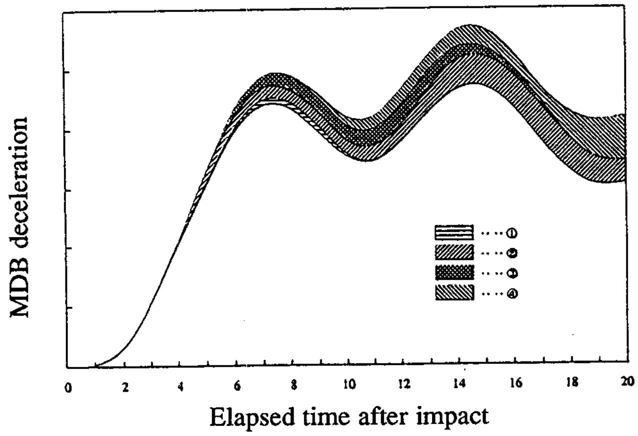


Figure 28. The Time Histories of MDB-Generated Deceleration Showing Effects of Various Reinforcements

Conclusion

An investigation was made of the crush characteristics of a four-door sedan in a side impact and the results clarified the deformation mechanism from the onset of the crash to the moment the door impacts the dummy. This mechanism had not been clearly understood before from the results of test crashes using actual vehicles. In addition, a method was also established for preparing an analytical model having sufficient capacity for studying the deformation behavior of body structures in side impacts.

In addition to clarifying the deformation mechanism, an analysis was also made of the contribution of various structural elements to the overall reaction force of the body. Effective locations for reinforcement were estimated and a quantitative analysis was made of the effect obtained with each reinforcement.

Note: All of the side impact phenomena mentioned in this paper are those by the test that are conducted with procedure specified in FMVSS 214. (3)-(8).

References

(1) Kuniyuki Watanabe and Tsuyoshi Yamaguchi, "Analysis of Factors Affecting Dummy Readings in Side Impact Tests," ESV 89-5A-0-019, 1989.

(2) Hiroyuki Okuyama, Nobuhiko Takahashi and Tatuya Futamata, "Crash Simulation Methods for Vehicle Development at Nissan," ESV 89-2a-0-011, 1989.

(3) "Federal Motor Vehicle Safety Standards; Side Impact Protection," NHTSA 49 CFR Part 571, Docket No. 88-06; Notice 8, 1990.

(4) "Side Impact Protection Anthropomorphic Test Dummy," NHTSA 49, CFR Part 572, Docket No. 88-07; Notice 3, 1990.

(5) "Side Impact Protection Moving Deformable Barrier," NHTSA 49, CFR Part 587, Docket No. 88-06; Notice 9, 1990.

(6) "Federal Motor Vehicle Safety Standards; Side Impact Protection," NHTSA 49 CFR Part 571, Docket No. 88-06; Notice 1, 1988.

(7) "Side Impact Anthropomorphic Test Dummy," NHTSA 49 CFR Part 572, Docket No. 88-07; Notice 1, 1988.

(8) "Set of Drawings for the NHTSA Side Impactor Prepared by Dynamic Science, Inc.," NHTSA, Docket No. 79-04 GR.

S5-O-15

Results of MVMA Full Vehicle Side Impact Tests on 1990 Model Year Pontiac 6000 Vehicles Using BioSID and SID

Ronald J. Wasko
Motor Vehicle Manufacturers Association
Kenneth L. Campbell
University of Michigan
Transportation Research Institute
Sherman E. Henson
Ford Motor Company

The purpose of the test series was to evaluate the responses of the BioSID and the SID dummies due to changes in vehicle interiors and also to evaluate the dummy responses for identical test conditions. A series of 12 full-scale side impact tests were conducted under highly controlled conditions using the proposed National Highway Traffic Safety Administration (NHTSA) side impact test procedure (1). The test procedure is schematically displayed in Figure 1.

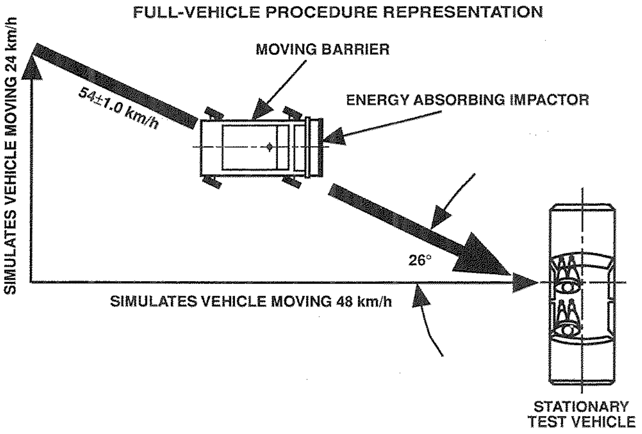


Figure 1. NHTSA Full Scale Side Impact Test Representation

The proposed NHTSA side impact test represents a 90 degree intersection crash with the struck vehicle travelling at 24.15 km/h (15 mph) and the striking vehicle travelling at 48.3 km/h (30 mph). The proposed NHTSA side impact procedure specifies the NHTSA SID and two injury criteria, the Thoracic Trauma Index (TTI(d)), and pelvic acceleration (2,3). Also included in this test series was the proposed deformation-based injury criterion, Viscous Criterion (V*C) (4). Figure 2 is a pre-test side view that shows the dummies positioned in the front and rear seats.

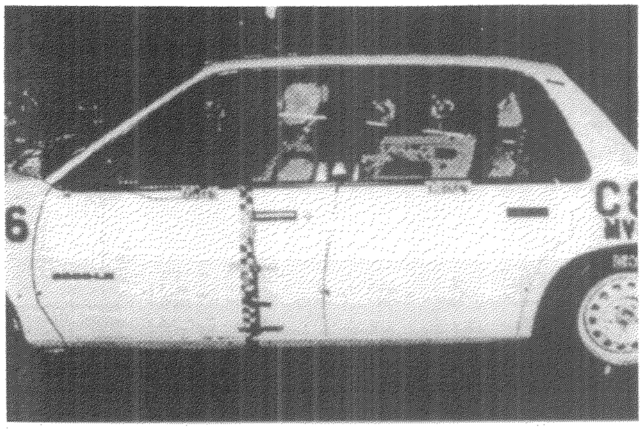


Figure 2. Pre-Test with SID and BioSID Dummy

The test vehicles were sequentially produced 1990 Model Year Pontiac 6000s, identically equipped to reduce vehicle variability. The tests were conducted using the SAE BioSID and the NHTSA SID, and the dummies were not belted. Figure 3 is a typical post-test view of one of the test vehicles.

Figures 4 and 5 show the positioning of the SID and BioSID in the test vehicles. The experimental design was a full factorial in two variables, dummy type and door padding, each having two levels.

The door padding levels correspond to the standard door interior and a modified door interior obtained by

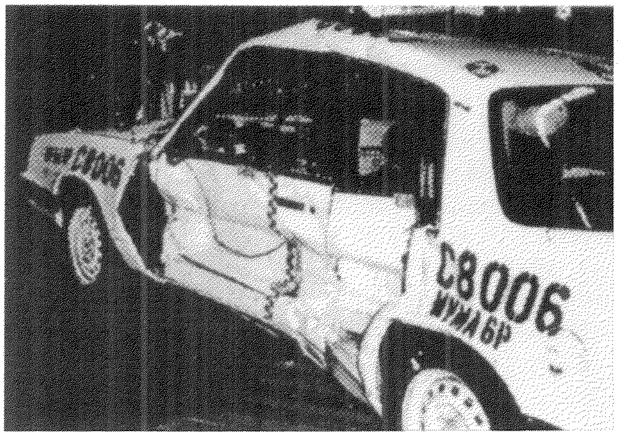


Figure 3. Post-Test Vehicle

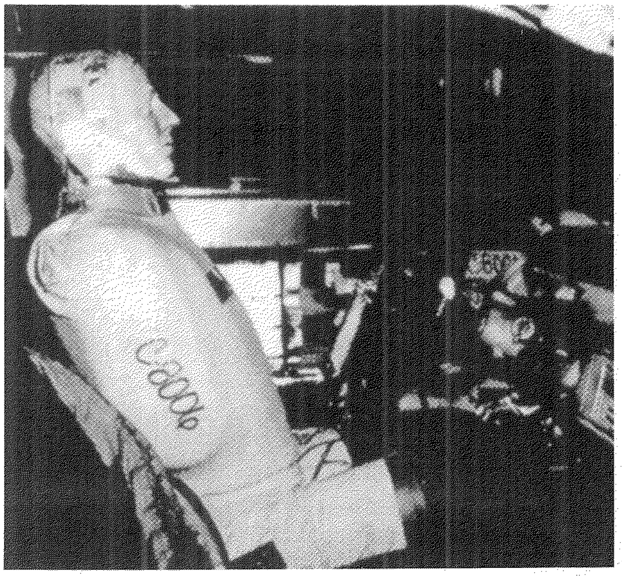


Figure 4. SID Dummy Positioned in Test Vehicle

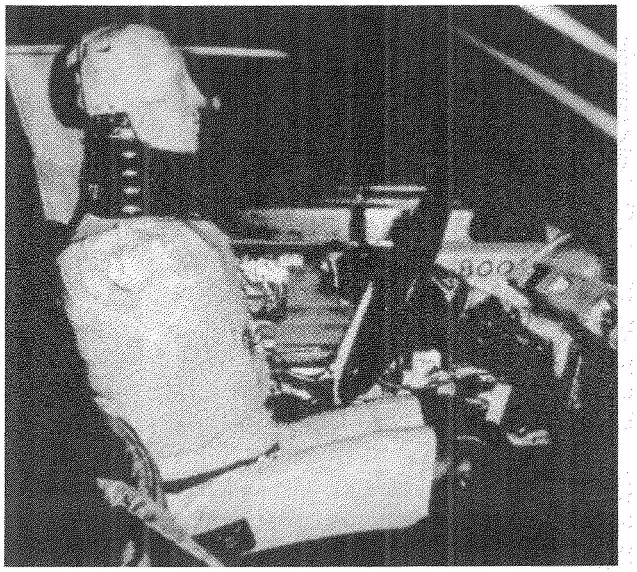


Figure 5. BioSID Dummy Position in Test Vehicle

adding 3-inch-thick (76.2 mm) Arcel 512^{tm} foam pads opposite the thorax and pelvis. The foam was selected as it had been previously used in the MVMA side impact test series using 1985 Ford LTD vehicles. The arm rest was left exposed and was approximately flush with the surface of the pads. Figure 6 shows the padding installed in the vehicle and Figure 7 shows the spacing of the dummy to the padding in the vehicle.

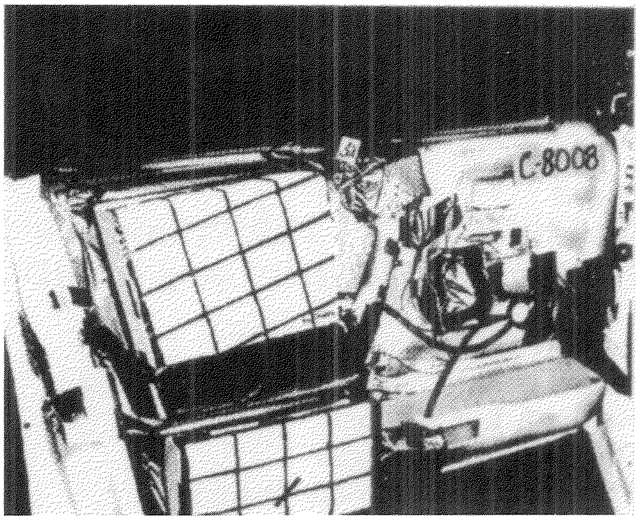


Figure 6. Test Vehicle with Padding at the Thorax and Pelvis Positions

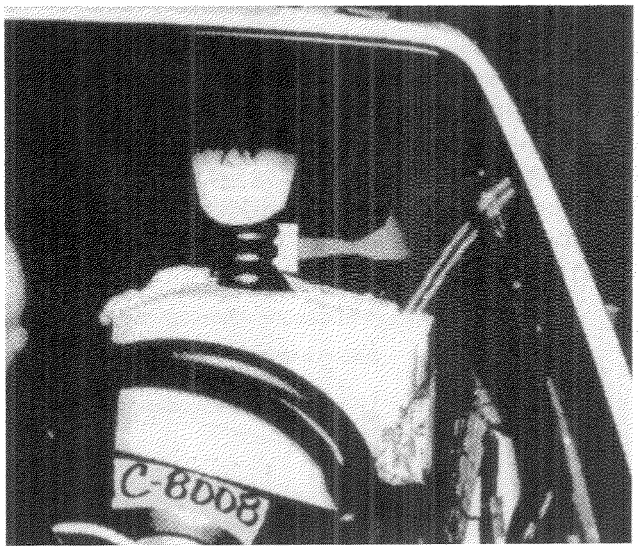


Figure 7. BioSID Showing Spacing to Installed Padding

The dummy type in the rear seat is always opposite the dummy in the front seat, so that no tests had two dummies of the same type in both the front and rear seat.

The basic test design was a 2x2 full factorial (5). There were four runs corresponding to the four possible combinations of the two levels on each of two variables. These four runs are replicated three times in order to increase sample sizes for tests of significance. Based on three replications, the expected precision is such that if the effect of the dummy or the padding is approximately equal to the coefficient of variation when expressed as a percent of the average response, the result will be statistically significant at the 95% level. The 12 tests are listed below in standard order. The order of the runs was randomized within each of the three blocks.

STANDING ORDER	FRONT DUMMY	REAR DUMMY	DOOR PAD	BLOCK NUMBER	TEST SEQUENCE	SID PELVIS PIN
1	SID	BIO	BASE	1	4	Pin
2	BIO	SID	BASE	1	1	No Pin
3	SID	BIO	MOD	1	2	No Pin
4	BIO	SID	MOD	1	3	No Pin
5	SID	BIO	BASE	2	7	No Pin
6	BIO	SID	BASE	2	5	No Pin
7	SID	BIO	MOD	2	6	Pin
8	BIO	SID	MOD	2	8	Pin
9	SID	BIO	BASE	3	10	Pin
10	BIO	SID	BASE	3	9	No Pin
11	SID	BIO	MOD	3	11	No Pin
12	BIO	SID	MOD	3	12	Pin

The sequential order in which the tests were actually conducted is shown in the next to the last column of the table above. Each block contains one replication of the basic four-run design.

The blocking was incorporated to check for systematic error over the course of the experiment. Drift in the calibration of a transducer or damage to a dummy might go unnoticed. Errors such as this could introduce a constant shift in the remaining tests. Blocking is a way to identify such changes by comparing the average value of the responses in each block. These block differences can be incorporated in the analysis if necessary.

Five acceleration-based measures were common to the two dummies, plus an additional 11 measures available only from the BioSID that were used in the analysis. These measures were the dependent variables, and are:

SID and BioSID
- Thoracic Trauma Index
- Rib 1 Peak Lateral Acceleration (g)
- Rib 3 Peak Lateral Acceleration (g)
- Peak Lower-Spine Lateral Acceleration (g)
- Peak Lateral Pelvic Acceleration (g)

BioSID ONLY
- Rib 2 Peak Lateral Acceleration (g)
- Rib 1 Maximum Compression (mm)
- Rib 2 Maximum Compression (mm)
- Rib 3 Maximum Compression (mm)
- Rib 4 Maximum Compression (mm)
- Rib 5 Maximum Compression (mm)
- Rib 1 V*C Maximum (m/s)
- Rib 2 V*C Maximum (m/s)
- Rib 3 V*C Maximum (m/s)
- Rib 4 V*C Maximum (m/s)
- Rib 5 V*C Maximum (m/s)

Data and Analysis

A summary of the test data is provided in Table 1. Figures 8 through 16 are bar charts of the thoracic trauma index (TTI(d)), lower spine acceleration, pelvic lateral acceleration, rib compression and viscous criteria (V*C). Each figure shows all 12 tests, with the three replications grouped together for each of the four test conditions. The first two groups of three correspond to

Table 1. MVMA BioSID Full Scale Side Impact Test Series

					ACCELERATION-BASED MEASURES														
										COMPRESSION					VISCOUS CRITERION, V*C				
STAND ORDER	TEST SEQ	DUMMY	PAD	BLOCK	TTI(D)	LAT PELVIS	RIB1	RIB3	LOWER SPINE	RIB1	RIB2	RIB3	RIB4	RIB5	RIB1	RIB2	RIB3	RIB4	RIB5
FRONT SEAT																			
1	4	SID	BASE	1	75.2	96.6	76.8	75.1	73.5										
2	1	BIOSID	BASE	1	103.8	92.4	110.0	154.0	53.6	31.3	36.2	41.4	35.9	64.2	0.38	0.46	0.56	0.37	1.27
3	2	SID	PAD	1	67.1	64.4	69.2	56.3	66.2										
4	3	BIOSID	PAD	1	68.7	65.4	72.6	79.0	54.2	34.2	45.9	56.9	51.5	65.9	0.28	0.4	0.66	0.63	0.99
5	7	SID	BASE	2	81.5	113.0	78.9	71.2	84.1										
6	5	BIOSID	BASE	2	77.5	91.6	77.5	103.0	52.0	31.7	36.7	41.6	36.0	63.5	0.32	0.37	0.44	0.38	1.18
7	6	SID	PAD	2	58.3	72.4	52.2	49.7	64.4										
8	8	BIOSID	PAD	2	59.8	70.8	61.0	63.9	55.6	30.7	44.6	58.1	55.6	64.6	0.23	0.51	0.89	0.89	1.26
9	10	SID	BASE	3	67.8	100.0	58.5	59.2	76.3										
10	9	BIOSID	BASE	3	71.6	94.4	87.0	81.4	56.1	29.8	37.3	42.3	45.2	58.7	0.29	0.39	0.44	0.75	0.93
11	11	SID	PAD	3	60.9	68.8	49.3	44.1	72.4										
12	12	BIOSID	PAD	3	58.1	68.8	60.5	48.2	55.6	31.2	45.3	56.6	60.3	63.4	0.24	0.41	0.59	0.87	0.94
REAR SEAT																			
1	1	SID	BASE	1	103.7	143.0	109.0	121.0	86.3										
2	4	BIOSID	BASE	1	78.5	105.0	94.5	90.2	62.5	12.8	18.9	22.9	59.1	-	0.09	0.13	0.16	1.29	-
3	3	SID	PAD	1	73.7	108.0	59.9	65.6	81.9										
4	2	BIOSID	PAD	1	61.3	102.0	48.8	58.8	63.8	10.7	21.0	26.9	49.6	55.6	0.06	0.15	0.28	0.75	0.9
5	5	SID	BASE	2	111.2	142.0	113.0	123.0	99.4										
6	7	BIOSID	BASE	2	74.9	126.0	77.2	91.5	58.2	8.5	22.4	31.9	58.4	53.2	0.03	0.19	0.34	1.47	0.99
7	8	SID	PAD	2	86.0	148.0	46.5	66.9	105.0										
8	6	BIOSID	PAD	2	63.8	100.0	60.4	53.5	67.2	14.1	23.5	32.0	53.1	64.0	0.06	0.02	0.29	0.75	1.05
9	9	SID	BASE	3	122.0	154.0	129.0	142.0	102.0										
10	10	BIOSID	BASE	3	87.9	122.0	106.0	97.9	69.7	16.9	23.2	26.7	54.6	65.8	0.13	0.21	0.26	1.36	1.46
11	12	SID	PAD	3	81.8	144.0	49.5	71.3	92.3										
12	11	BIOSID	PAD	3	63.9	101.0	50.6	60.3	67.5	13.0	25.6	36.9	51.1	66.2	0.05	0.13	0.27	0.64	1.12

the baseline door interior, and the last two groups show the responses with the modified padding. The type of dummy, SID or BioSID, is indicated under each group of three replications. Selected data from the front seat position are shown in Figures 8-10, and from the rear seat position in Figures 11-13. Compression measures from the BioSID are shown in Figures 14 and 15, and the V*C results for rib 3 of the BioSID are shown in Figure 16. Results for both the front and rear seat are shown in this figure.

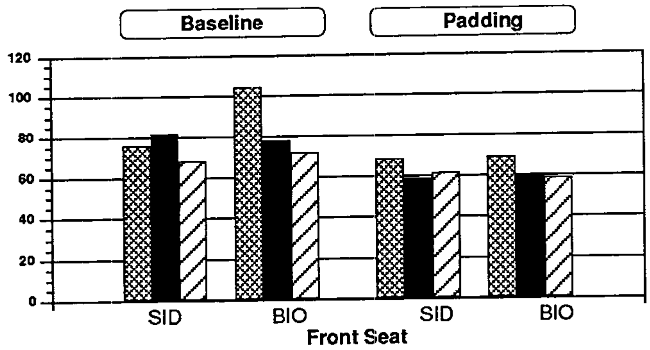


Figure 8. Thoracic Trauma Index (TTI): Three Replications by Dummy Type and Interior Padding

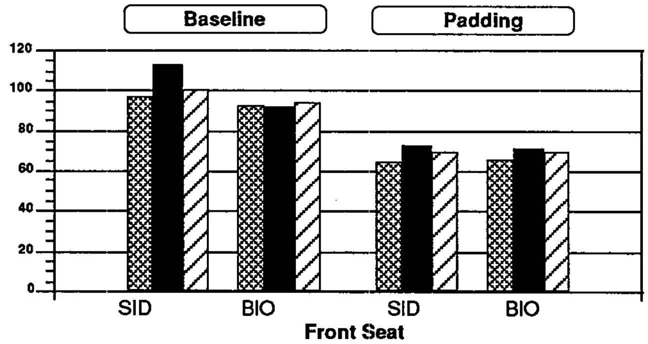


Figure 9. Pelvic Lateral Acceleration: Three Replications by Dummy Type and Interior Padding

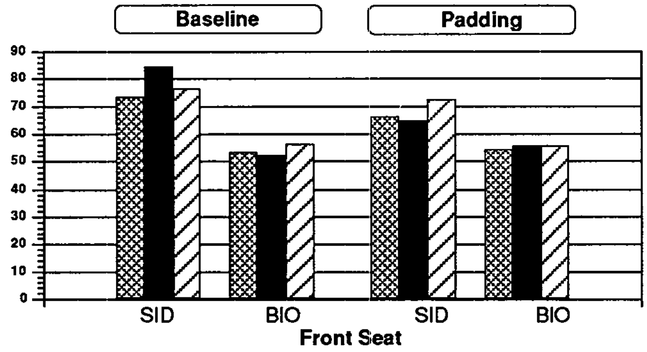


Figure 10. Lower Spine Acceleration: Three Replications by Dummy Type and Interior Padding

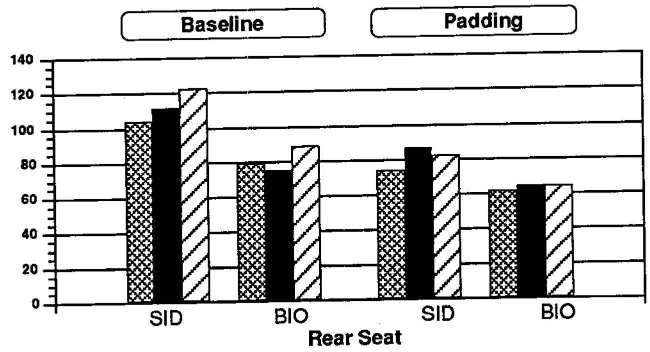


Figure 11. Thoracic Trauma Index (TTI): Three Replications by Dummy Type and Interior Padding

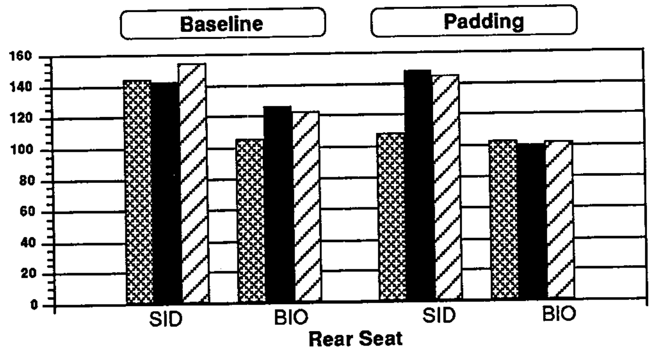


Figure 12. Pelvic Lateral Acceleration: Three Replications by Dummy Type and Interior Padding

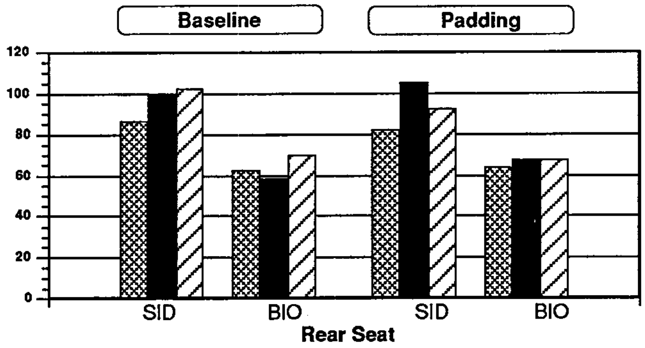


Figure 13. Lower Spine Acceleration: Three Replications by Dummy Type and Interior Padding

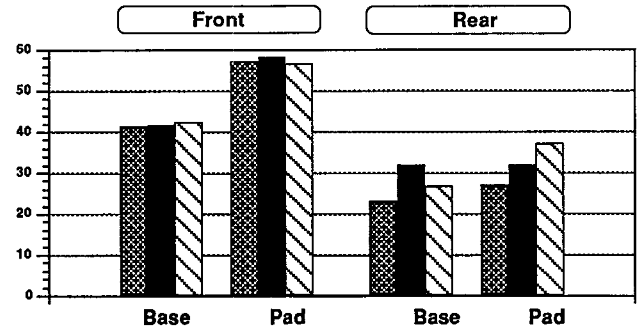


Figure 14. Thoracic Rib 3 Compression: Three Replications by Interior Padding and Seat Position

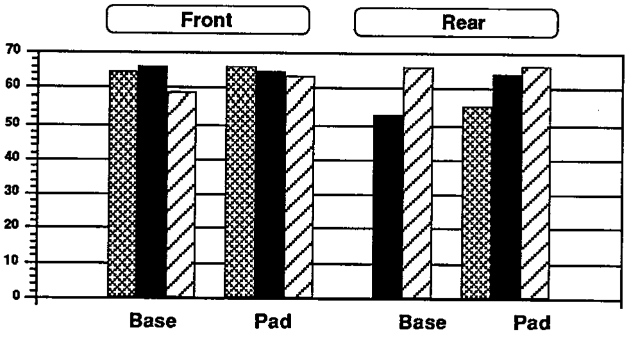


Figure 15. Abdominal Rib 5 Compression: Three Replications by Interior Padding and Seat Position

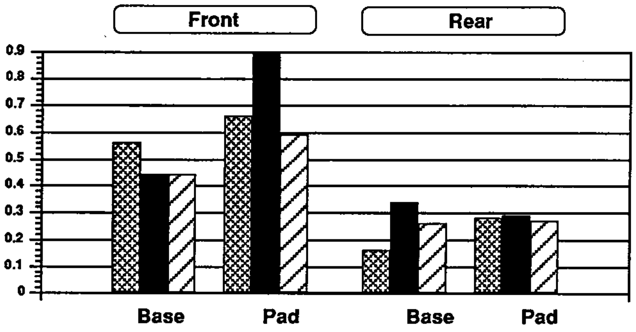


Figure 16. Thoracic Rib 3 Viscous Criterion, V*C: Three Replications by Interior Padding and Seat Position

Summary Front Seat Acceleration Results

As shown in Figure 8 for the front seated dummies, both the BioSID and SID showed a decrease in the TTI(d) measure when padding was introduced into the vehicles.

Figure 9 shows the results for the front seated dummies for pelvic lateral acceleration. Again both dummies experience a decrease in pelvic lateral acceleration levels and for this test condition a greater reduction was exhibited by the SID when padding introduced.

An issue that might have confounded the pelvis lateral acceleration data is after the tests were completed, it was discovered the pelvis assemblies for the two SID dummies were not identical. One dummy pelvis had a limiting pin in the femur ball socket that allowed up and down motion of the femur but constrained femur rotation. The other SID did not have the limiting pin. The test table defines tests with or without the pelvis limiting pin.

Front seat lower spine acceleration data are summarized in Figure 10. These measures show a slight reduction for the lower spine accelerations when the SID dummy results for padding/no padding are compared. Contrasting the SID results, the BioSID levels essentially remained the same when padding was introduced to the test matrix.

Summary Rear Seat Acceleration Results

Results for identical measures made on the dummies in the rear seat the rear seat dummies as provided in SID Figure 11 shows a decrease when padding was introduced into the test matrix.

Similar to the front seat condition where only the SID showed a drop in TTI(d) for the padded condition, both the BioSID and SID exhibited significantly reduced TTI(d) values for the rear seat position.

Figure 12 provides the rear seat pelvic lateral acceleration results for the 12 tests. BioSID shows some reduction in magnitude for the padded versus unpadded test conditions. The SID did not exhibit a consistent change when tested with or without padding. These results are in contrast to the same test conditions with the dummies placed in the front seat where they both exhibited significant reductions in pelvic lateral accelerations with the introduction of padding. It is interesting to note that the absolute values are greater in the rear seat than the front seat.

Figure 13 provides the lower spine acceleration data for the 12 tests with the dummy in the rear seat. The SID average values were approximately the same with or without padding. The BioSID also exhibited approximately the same values with or without padding. Once again, the absolute values of the rear seat dummy lower spine accelerations were slightly higher than the front seat dummy when tested with or without padding.

Compression Measure

Thoracic rib 3 compression is shown in Figure 14. This chart shows that the addition of this padding in either the front or rear seated condition, had essentially no effect on reducing rib compression.

The position of the dummy relative to the exterior of the vehicle was not changed when the padding was added. The 3-inch (76.2mm) pad had the result of effectively moving the interior surface closer to the dummy by 3 inches. For ribs 2 through 4, rib compression was not reduced by the addition of padding. However, examination of the data in Table 1 shows that rib compression increases for padded tests as one observes from rib 1 to rib 5.

Abdominal rib 5 compression data are provided in Figure 15. Again, the addition of padding did not reduce the compression of the abdominal rib during the tests.

Figure 16 is the thoracic rib 3 viscous criterion (V*C). The V*C is based on the instantaneous value of rib velocity times the instantaneous value of rib compression (V*C max) as proposed by Viano and Lau (1985) (4). The results of the test show that the V*C was increased by the addition of padding for the front seat tests. There was no discernible difference for the rear dummy with the introduction of padding.

The compression measurements and Viscous Criteria results contradict the TTI(d) results. TTI(d) was reduced by the addition of the padding, whereas peak rib compression and V*C were increased. These results are similar to those of other studies that have found that certain types of padding decrease acceleration levels but increase the chest deformation (6,7). Because the dummy position was not changed when padding was added, the pad effectively moved the interior surface 3 inches closer to the dummy. A study by Deng (8) showed that when padding is positioned to produce an earlier contact with the thorax, the duration an earlier contact with the thorax, the duration of impact is longer.

Coefficients of Variation

The coefficients of variation, shown in Table 2, are a measure of the repeatability of the dependent variables and injury measures. It is calculated form the variation in the replicate runs and expressed as the standard deviation of the replicate observations as a percentage of the average value for the measure. Block effects were not adjusted for in the calculation of the coefficient of variation.

Table 2. Coefficients of Variation

COEFFICENTS OF VARIATION

MEASURE	FRONT SEAT		REAR SEAT	
	SID	BIOSID	SID	BIOSID
ACCELERATION				
TTI	8.7%	17.4%	8.2%	6.8%
RIB1	17.1	16.4	10.6	15.3
RIB2	-	29.6	-	9.2
RIB3	12.3	32.3	8.6	5.1
LOWER SPINE	6.7	2.9	10.7	6.7
PELVIS	7.9	2.7	11.6	7.2
COMPRESSION				
RIB1	-	4.8	-	25.3
RIB2	-	1.5	-	10.2
RIB3	-	1.5	-	16.1
RIB4	-	10.3	-	3.9
RIB 5	-	3.6	-	11.3
(V*C) max				
RIB 1	-	12.9	-	51.2
RIB 2	-	12.9	-	42.8
RIB 3	-	20.3	-	24.1
RIB 4	-	28.4	-	7.5
RIB 5	-	15.9	-	19.3

Coefficients of variation on acceleration-based measures from past tests are on the order of 10% (6,9). Many of the acceleration-based measures shown in the top group of Table 2 have comparable coefficients of variation. The rib accelerations from the BioSID in the front seat are appreciably higher at 16-32%, as is the upper thoracic rib (Rib 1) acceleration for the SID in the front seat. This is a reflection of block differences that have been discussed previously (5).

The compression measurements in the front seat generally have very good coefficients of variation, well below 10% for the most part. The V*C measure shows higher coefficients of variation in the front seat, ranging from 13-28%. This result is consistent with EuroSID results (10). Overall, the compression and viscous measures have much higher coefficients of variation in the rear seat position as compared to the front seat. This variation may be due to vehicle, dummy, or test. The variability may be "real" values if differences exist in the vehicle, dummy or test.

Summary

The responses of the two dummies are clearly different in many respects. Only the pelvis acceleration in the front seat and the upper thoracic rib (Rib 1) in the rear seat were not significantly different. Higher rib accelerations are consistent with the reduced inertia of the BioSID chest. Differences in the TTI(d) were not significant in the front seat position because this measure averages the rib accelerations (that were higher in the BioSID) with the spine acceleration (that was lower in the BioSID).

In the rear seat, all of the acceleration-based measurements common to both dummies were lower for the BioSID. This result may be due to differences in the direction of impact and/or dummy spacing in the rear seat as compared to the front. Despite these differences, when acceleration-based measures are used, both the SID and the BioSID show significant reductions when 76.2mm (3 inches) of Arcel 512^{tm} was added in both the front and rear seat positions.

However, the compression and viscous measures show the opposite result in the front seat. Both the compression measurement and the Viscous Criterion increased with the modified door interior in the front seat. The results were mixed in the rear seat, with most of the compression and viscous measures showing no significant difference, except for the fourth rib, that showed a reduced compression and Viscous Criterion with the padding. Coefficients of variation were generally low for the compression measurements, but were appreciably higher for the viscous measurement. The Viscous Criterion is the product of two quantities each having variation, therefore the total variability is expected to be higher than other descriptors that are non-multiplicative.

These results have important implications for the side impact test procedure. With the acceleration-based TTI(d) as the measure of injury, the modified door interior produces substantial reductions using either SID or BioSID. The modified chest structure of the BioSID shows even greater reductions in the TTI(d) due to the padding than the SID. In the front seat however, the compression-based measures predict the opposite result. These results illustrate the critical impact the choice of injury measure may have on vehicle design changes that are to be developed on the basis of the side impact test procedure.

References

1. U.S. Department of Transportation, National Highway Traffic Safety Administration, Laboratory Test Procedure for FMVSS NO. 214 "Side Impact Protection-Passenger Cars," August 9, 1991.

2. Morgan, R.M.; Marcus, J.H. and Eppinger, R.H. (1986) Side impact—the biofidelity of NHTSA's proposed ATD and efficacy of TTI(d). In Proceedings of the 30th Stapp Car Crash Conference, pp. 27-40. Paper no. 861877. Society of Automotive Engineers, Warrendale, Pennsylvania.
3. Eppinger, R.H.; Marcus, J.H. and Morgan, R.M. (1984) Development of dummy and injury index for NHTSA's thoracic side impact protection research program. Paper no. 840885. Society of Automotive Engineers, Warrendale, Pennsylvania.
4. Lau, I.V. and Viano, D.C. (1986) The viscous criterion: Bases and applications of an injury index for soft tissues. In Proceedings of the 30th Stapp Car Crash Conference, pp. 123-142. Paper no. 861882. Society of Automotive Engineers, Warrendale, Pennsylvania.
5. Campbell, K.L.; Wasko, R.J. and Henson, S.E. (1990) Analysis of Side Impact Test Data Comparing SID and BIOSID. In Proceedings of the 34th Stapp Car Crash Conference, pp. 185-201. Paper No. 902319. Society of Automotive Engineers, Warrendale, Pennsylvania.
6. Campbell, K.L. and Smith, E.J. (1988) Statistical analysis of the MVMA side impact test data. Report no. UMTRI-88-44. The University of Michigan Transportation Research Institute, Ann Arbor, Michigan
7. Ohmae, H.; Sakurai, M.; Harigae, T.; Watanabe, K. and Nakamura, Y. (1989) Analysis of the influence of various side impact test procedures. Paper No. 890378. Society of Automotive Engineers, Warrendale, Pennsylvania.
8. Deng, Y.C. (1988) Design considerations for occupant protection in side impact/a modeling approach. In Proceedings of the 32th Stapp Car Crash Conference, pp. 71-79. Paper no. 881713. Society of Automotive Engineers, Warrendale, Pennsylvania.
9. Campbell, K.L.; Smith, E.J.; Wasko, R.J. and Henson, S.E. (1989) Analysis of the JAMA side impact test data. In Proceedings of the 33th Stapp Car Crash Conference, pp. 87-100. Paper no. 892430. Society of Automotive Engineers, Warrendale, Pennsylvania.
10. Henson, S.E. and Wasko, R.J. (1988) An Evaluation and Comparison of U. S. and European Side Impact Tests, International Research Conference on Biomechanics of Injury (IRCOBI), September 13, 1988, Cologne, Germany.

S5-O-16

Comparative Performance of SID, BIOSID, and EUROSID in Lateral, Pendulum, Sled, and Car Impacts

Joseph N. Kanianthra, Donald T. Willke, Hampton C. Gabler
National Highway Traffic Safety Administration
David S. Zuby
TRC Inc.

Abstract

Prior to the issuance of the final rule for side impact protection, the National Highway Traffic Safety Administration initiated a research program for evaluation of three side impact dummies for potential use in side impact testing per the regulation. The test devices evaluated included the NHTSA developed SID, the EUROSID-1 developed under the sponsorship of the European Experimental Vehicle Committee and the BIOSID which was designed and developed under the auspices of the Society of Automotive Engineers', Biomechanics and Simulations Subcommittee. The test program included dummy performance verification testing, sled tests to evaluate the capability of the dummies to discriminate impact surfaces of various crush strength characteristics and a limited number of production passenger car tests. Assessment of the comparative performance of the dummies was made on the basis of the injury criteria specified in the final side impact rule, namely, the Thoracic Trauma Index and pelvic accelerations. Repeatability performance and biofidelity of the dummies were also evaluated. This paper describes the tests conducted and the results in detail, comparing the performance of the three dummies.

Introduction

The National Highway Traffic Safety Administration (NHTSA) amended the U.S. Federal Motor Vehicle Safety Standard (FMVSS) No. 214 in October 1990 to include a dynamic test requirement for side impact protection in passenger cars [1]. Per this requirement, each passenger car must protect its occupants in a full-scale dynamic crash test where the car is impacted on either side by a Moving Deformable Barrier (MDB) in a crabbed test configuration, simulating a two-car intersection type collision. Instrumented Side Impact Dummies (SID) are positioned in the target car to measure the potential for thoracic and pelvic injuries to its front and rear occupants.

The Anthropomorphic Test Device (ATD) specified in the final rule is the SID developed by NHTSA prior to the issuance of the final rule. The design and development of this dummy spans several years' research effort undertaken by NHTSA. The agency conducted a substantial number of tests of the dummy using the pendulum, in sled tests with padded and rigid walls, and in passenger car impact environments. The SID adopted in the rule is based on the Part 572, Sub-part B ATD that is used in the existing occupant protection safety standards. The SID has a thorax and pelvis re-designed to produce human-like acceleration responses when impacted in the lateral direction. This device has no articulating arms or shoulders. The mass of the arms and shoulder have been incorporated into the thoracic mass. Arm and shoulder foam have also been added for the proper thoracic response.

Under the auspices of the European Experimental Vehicle Committee (EEVC), a group of European research laboratories designed and built a European Side Impact Dummy (EUROSID) during mid 1980's [2, 3, 4]. After a preliminary evaluation of the earlier design by organizations in Europe, the U.S.A., Canada, and Japan, the dummy design was revised to develop a production prototype. Further refinements led to a production version of the dummy, known as EUROSID-1, in 1989 [5].

Since the appearance of the SID and EUROSID-1 as potential side impact test dummies, the Society of Automotive Engineers' (SAE) Biomechanics and Simulations Subcommittee formed a task force to design and develop an alternate side impact dummy called BIOSID, based on the Hybrid III structure and conforming to certain characteristics defined by the task force [6]. The first production prototype of this dummy became available in December 1989.

Both the EUROSID-1 and BIOSID are distinctly different from the SID in their design features. The SID is primarily intended to measure thoracic and pelvic accelerations. The Thoracic Trauma Index [TTI(d)], based on thoracic accelerations, and pelvic acceleration are the two injury criteria used in the final rule for side impact protection in the U.S.A. [1]. The TTI(d) is determined from the peak lower spine and maximum rib accelerations. The EUROSID-1 and the BIOSID, on the other hand, have additional measurement capabilities beyond those measured by the SID. For example, in addition to the rib, spine, and pelvic accelerations, both the BIOSID and EUROSID-1 are capable of measuring rib deflections, abdominal penetrations or the forces associated with prescribed penetration levels, and forces at the pubic symphysis and the iliac crest.

As part of its side impact research associated with the rulemaking, NHTSA evaluated the performance of all available side impact dummies prior to the issuance of the final rule. This evaluation was limited to biofidelity assessment of the EUROSID and BIOSID in comparison to the SID based on NHTSA established criteria, their repeatability and reproducibility in sled tests, their durability, and their side impact safety performance, as indicated by TTI(d) and peak pelvic acceleration, in a limited number of crash tests using production passenger cars. The test matrix developed by NHTSA included pendulum impact tests, sled tests in rigid wall and padded wall impact environments and a few passenger car crash tests. The SID and the BIOSID were tested in five pairs of crash tests of identical production passenger cars. However, the production EUROSID-1 was not included in NHTSA's vehicle crash test program since such tests were being undertaken under the auspices of EEVC in Europe.

This paper describes the test program undertaken by NHTSA in their comparative evaluation of the SID, EUROSID-1, and the BIOSID. The biofidelity, repeatability, and reproducibility of the dummies based on available test data from NHTSA's testing will be compared. Their performance in discriminating between padded surfaces of varying crush strengths in sled tests will also be evaluated. Additionally, comparisons of the SID and BIOSID performance in side crashes, per FMVSS No. 214, of identical passenger cars will be made on the basis of the acceleration based injury criteria currently specified in the side impact rule.

Physical Characteristics of the Dummies

The NHTSA SID

The SID was developed in 1979 by the University of Michigan Transportation Research Institute (known then as the Highway Safety Research Institute) under the sponsorship of NHTSA. The SID is identical to the part 572 (B) dummy used in FMVSS No. 208, except that the thorax was re-designed for lateral impacts. The head, neck, and neck bracket of the SID are adopted from the standard part 572 (B) dummy. The thorax is of unique design from the bottom of the neck to the top of lumbar spine. The pelvis is slightly modified from the standard part 572 (B) dummy so as to make the flesh more uniform on the left and right sides. With the exception of the link rods which have been modified so that femur posts will allow lateral motion of the knee casting with respect to the upper leg, the legs are also from the standard part 572 (B) dummy. The SID has no articulating shoulder - clavicle or arm. The shoulder assembly consists of the shoulder plate, and shoulder foam. The upper arms are simulated by soft urethane foam provided as inserts in the chest jacket. In the SID, the arm-shoulder mass is incorporated into the mass of the thorax. The SID thorax is composed of five ribs and is symmetric to allow left or right side impacts. However, the shock absorber assembly being asymmetric, needs to be reversed from the left side configuration to the right side.

For the purposes of the U.S. side impact rule, the SID is used to measure acceleration responses in the lateral direction of the upper and lower rib, lower spine and the pelvis. The injury criteria, namely, the TTI(d) used in the rule, is the average of the peak maximum lateral rib and lower spine accelerations. The peak pelvic acceleration provides a second injury measure prescribed under the rule, to indicate susceptibility to pelvic injuries when the prescribed threshold level is exceeded.

A schematic of the SID is shown in Figure 1A.

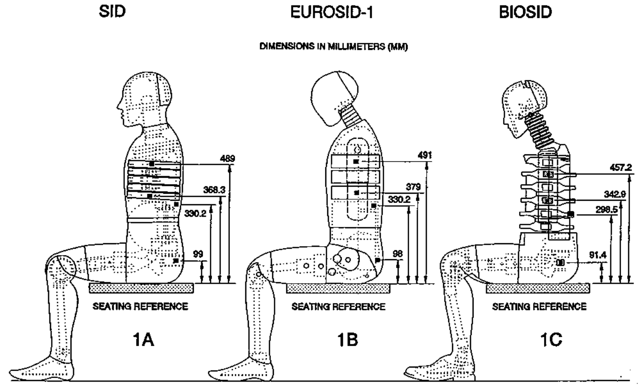


Figure 1. Schematic Diagrams of SID, EUROSID-1, and BIOSID Dummies

EUROSID-1 Dummy

The EUROSID-1 dummy developed under the auspices of the EEVC is designed for injury assessment in lateral impacts. Measurements are made in the head, thorax, abdomen, and pelvis, to evaluate the risk of occupant injury in side collisions. The dummy head is a standard Hybrid III head. It has a unique neck design capable of translation and rotation, extension and simple lateral flexion. The shoulder - clavicle assembly allows the arm to rotate forward when struck at the top, so as to expose the thorax during lateral impacts. The current EUROSID-1 design has stub arms and the shoulder-arm pivot will allow two different arm positions with respect to the thorax. As seen in Figure 1B, the thorax has three identical rib modules, consisting of steel hoops attached to a guided spring-damper system, along with a damper running parallel to the piston-cylinder. The module is mounted to the spine box by attaching the cylinder to it. Rib accelerations are measured through uniaxial accelerometers mounted on the inner surface of the ribs. The rib modules were designed to measure lateral displacements through optical displacement transducers in the earlier version. Linear potentiometers are currently used to measure the displacements. The abdomen section is a sheet metal cylinder covered with flexible material having a vinyl skin. It has leaf - spring switches to indicate when externally applied force levels are exceeded at abdominal penetrations beyond prescribed levels. In its latest design, the dummy also has an optional force measuring transducer as a replacement for the contact switches, which can measure the force levels continuously. The pelvis is composed of two iliac wings linked together at the pubic symphysis by a force transducer. To minimize the effect of leg position on pelvis loading, the impact forces are transferred to the pelvis through the hip ball joint. The pelvis is designed to measure compressive forces in the pubic symphysis, and allows installation of an accelerometer. The legs are part 572 (B) design. A schematic of EUROSID-1 is given in Figure 1B.

BIOSID Dummy

The BIOSID also represents the fiftieth percentile adult male in size and weight. It is based on the Hybrid III dummy structure but is specifically designed for use in occupant safety assessment in side impacts. It utilizes the existing Hybrid III head and neck designs. However, the thorax, shoulder, pelvis, and lumbar - abdominal region have been redesigned for the purpose of side impact injury assessment. The upper torso of the dummy uses six ribs in all. The top rib represents the shoulder while the three ribs in the middle simulate the human rib cage. The two bottom ribs are intended to represent the abdomen. The hoop like ribs are attached to a spine box opposite to the impacted side. The shoulder rib is wider than the other five ribs, which are identical. Damping material is bonded to the inside surface of the rib to provide viscous damping and dissipation of energy. Ribs are supported vertically to prevent sagging. Stub arms are attached to the shoulder rib through a clevis joint to permit arm rotation. The arm has a flat steel core which is covered by foam. The pelvic bone is made up of a series of blocks to which iliac wing structures are attached. Load transducers are used to measure compressive loads transmitted through the pubic symphysis and the sacrum, as well as loads in the iliac area. Legs are attached through ball and socket joints to side plates of the pelvic bone. The upper legs of the BIOSID are modified Hybrid III legs designed to pivot laterally when impacted, thereby isolating the effect of the lower legs and knees on pelvic responses. The impact area in the hip joint has a non-reusable foam cylindrical insert to control the pelvic response characteristics. A schematic of the BIOSID is shown in Figure 1C.

The BIOSID has many measurement capabilities including the acceleration measurement of all the ribs and the pelvis. All the six ribs have provision for measuring their relative displacement with respect to the spine box. The upper and lower spine accelerations, as well as the lateral loads in the iliac area and pubic symphysis and sacrum, can be routinely measured. Assessment of the TTI(d) is based on the average of the maximum peak lateral acceleration of the thoracic ribs and the peak lower spine accelerations.

The mass distributions of the three dummies are given in Table 1 below.

The relevant accelerometer locations and their heights from a seating reference plane for each of the dummies are also given in Figures 1A, B, and C.

Test and Evaluation of the Dummies

With the assistance of Transport and Road Research Laboratory, U.K., the production prototype originally procured by NHTSA was refurbished according to the latest specifications of EUROSID-1. Two prototype

Table 1. Nominal Mass Distribution of Body Segments of SID, EUROSID-1, and BIOSID

Body Segment	SID	EUROSID-1	BIOSID*
Head/Neck Assembly	5.72kg (12.7 lb)	5.6kg (12.4 lb)	6.03kg (13.4 lb)
Thorax Assembly	31.59kg (70.2 lb)	24.5kg (54.4 lb)	28.0kg (62.2 lb)
Abdomen	1.35kg (3.0 lb)	2.2kg (4.9 lb)	Included in the thorax assembly
Pelvis	12.29kg (27.3 lb)	14.7kg (32.7 lb)	16.43kg (36.5 lb)
Legs	24.66kg (54.8 lb)	25.0kg (55.6 lb)	23.13kg (51.4 lb)
Total	75.61kg (168.0 lb)	72.0kg (160.0 lb)	73.00kg (163.5 lb)

Table 1: Nominal Mass Distribution of Body Segments of SID, EUROSID-1, AND BIOSID

*Mass distributions based on Production Prototype dummy

BIOSID's were also procured by NHTSA in late 1989 for evaluation. A comparative evaluation of the three side impact dummies, was conducted by NHTSA at the Vehicle Research and Test Center (VRTC) in East Liberty, Ohio. The objectives of the research program were:

- To compare the ability of the dummies to discriminate various impact environments, as measured in sled tests into rigid and padded wall surfaces. A range of padding stiffnesses were used in these tests.
- To determine the repeatability and reproducibility characteristics of the dummies.
- To determine the influence of the arm position on dummy responses in a padded environment.
- To compare the capabilities of the dummies with respect to biofidelity.
- To compare the performance of the different side impact dummies in five production passenger cars in side crush tests.

The program was undertaken in two phases. Under the first phase, a series of pendulum impacts were conducted to establish the calibration and biofidelity performance of the dummies. This phase also included a series of sled tests, which were conducted to determine the capability of the dummies to discriminate between padded and unpadded impact environments, and to evaluate the repeatability characteristics of the dummy under rigid wall and padded wall impact conditions. Repeatability testing was limited to the BIOSID, since the SID's repeatability had previously been established in earlier phases of NHTSA's research program. The EUROSID-1 was not evaluated for repeatability since such tests were planned to be done in Europe. Also, no reproducibility evaluation of this dummy was done under this program. Reproducibility of the SID was already established in NHTSA's earlier research. For reproducibility, only the BIOSID was tested in this series of tests. The investigation of arm positions was conducted only on the BIOSID and EUROSID-1 since the SID does not have arms in its design.

The second phase of the test program evaluated the performance of the SID and BIOSID in five production passenger cars in side crashes per FMVSS No. 214, dynamic side impact test and performance assessment procedures. Evaluation of EUROSID-1 in the same five production passenger cars in side crashes as those tested by NHTSA was being conducted in Europe under the sponsorship of the EEVC.

Performance Verification Testing

SID

Performance verification testing of the SID was comprised of pendulum impacts to the thorax and pelvis. For the thorax tests, three accelerometers are mounted in the thorax for measurement of lateral accelerations with each accelerometer's relevant axis aligned to be perpendicular to the thorax's midsagittal plane. Two accelerometers are mounted, one on the top and the other at the bottom of the rib bar on the struck side, for the upper and lower rib acceleration measurements. Another accelerometer is mounted at the lower spine for its acceleration measurements. One accelerometer is mounted on the rear wall of the instrument cavity of the pelvis for measurement of its lateral acceleration. All of the instrumentation and sensors conform to the SAE J-211 (1980) recommended practice requirements.

The test probe used for lateral thoracic and pelvic impact tests is a 152.4mm (6 in) diameter cylinder weighing 23.4kg (51.5 lb) including instrumentation. The dummy is placed on a flat and smooth steel surface so that the dummy's midsagittal plane is vertical. The dummy legs are positioned such that their centerlines are in planes that are parallel to the midsagittal plane. For thoracic impacts, the longitudinal centerline of the test probe is positioned on the lateral surface of the thorax at the intersection of the centerline of the third rib and the rib bar on the impacted side. For pelvic impacts, the longitudinal centerline of the test probe is positioned on the lateral side of the pelvis at a point 99mm (3.9 in) from the seating surface vertically (H-Point) and 122mm (4.8 in) forward of the near side edge of the vertical back of the test surface. The test speeds for both the thoracic and pelvic impacts are 4.3m/sec (14fps). The analog data was recorded in accordance with SAE J-211 (1980) recommended channel class 1000 specification, and processed with FIR 100 filtering routine [1 and 7].

EUROSID and BIOSID

In addition to the performance verification testing normally performed with the complete dummy, certification procedures for individual body parts are also specified in the test procedure for EUROSID-1 and the BIOSID. However, for the purposes of verification testing and comparison of the three dummies, only tests performed on the complete dummies and common to all of them per FMVSS No. 214 are discussed in this paper. The test set-up procedures used in testing the SID, EUROSID-1, and BIOSID dummies were identical. The thorax and pelvis tests were done using the 23.4kg (51.5 lb) linear impact pendulum device having a cylindrical impactor of diameter 152.4mm (6 in). However, the impact velocities for the thorax and pelvis specified for the BIOSID was higher at 6.7 m/sec (22 fps) instead of that used for the SID and EUROSID-1 which was 4.3 m/sec (14 fps). Just as in the SID, the impact device was aligned with the center of the thorax and the pelvis. The acceleration response signals were processed using the same procedures as that for the SID.

Crash Environment Discrimination Tests

In order to compare the capability of the SID, EUROSID-1, and the BIOSID to discriminate various impact environments, NHTSA undertook a series of HYGE sled simulations in its research program. The dummy responses were recorded in 32km/hr (20mph) sled tests using the seat and wall configurations used by University of Heidelberg in its cadaver test program [8]. The impacted surface stiffness ranged from that of a very soft synthetic foam rubber, 75mm (3 in) thick, backed by a rigid steel plate, to the stiffness of a stiff foam such as Dytherm (64kg/meter^3 or 4 lbs/ft^3) and the rigid wall itself. The selected padding stiffnesses included a range that would be normally encountered in a dynamic side impact test of a passenger car.

Padding Selection

Because of the non-linear characteristics of the foam paddings, crush strength obtained at 35% compression was chosen as the measure used to describe each of the pads selected. Several padding materials were surveyed as candidates and uniform samples measuring 178mm x 165mm x 152mm (7 x 6.5 x 6 in) were tested for their force-deflection characteristics. As many of the materials were only available in thicknesses of 25mm (1 in), several layers were glued together using an aerosol adhesive to obtain the desired thickness. Test samples were mounted to a rigid load plate with its center aligned with a 27.2kg (60 lb) impactor. The rigid face of the impactor contacted the entire surface of the sample at a velocity of approximately 32km/hr (20mph). Two load cells located behind the load plate measured the crush force, while the deflection of the sample was measured using a linear potentiometer attached to the ram. The total crush force and the deflection of the pad as a percent of its initial thickness were determined. Except for the synthetic foam rubber, all the other materials showed an initial steep rise in the crush force with the "knee" of the force-deflection trace occurring at approximately 8% of its compression in "low stiffness" padding and at about 5% of the compression in "stiff" padding. Very stiff padding showed a tendency to build up its crush forces with a steep rise in the force below 5% of compression, with the initial force levels reaching approximately twice that in moderately stiff padding. After the initial rise, with the stiffer paddings gave nearly linear force-deflection behavior as opposed to the other types, where the force-deflection pattern continued to be non-linear. Maximum compression obtained in all categories of padding reached about 60%-80% of the sample's thickness. Typical crush strength versus pad compression curves for three different pads are plotted in Figure 2. Note that the three pads shown in Figure 2 do not have exactly the same density and thus the same crush strength as the pads utilized in the sled tests even though the same commercial name is used to designate the pad. The crush strength at 35% compression was determined to define the characteristics of the padding, and the selected padding crush strength ranged from 17.5 k.pa (2.5 psi) to 848 k.pa (123 psi). Nine pads used in the sled tests included four types of Arcel pads, two types of Ethafoam LC200, one synthetic foam rubber, one Arsan 601 and one Dytherm pad.

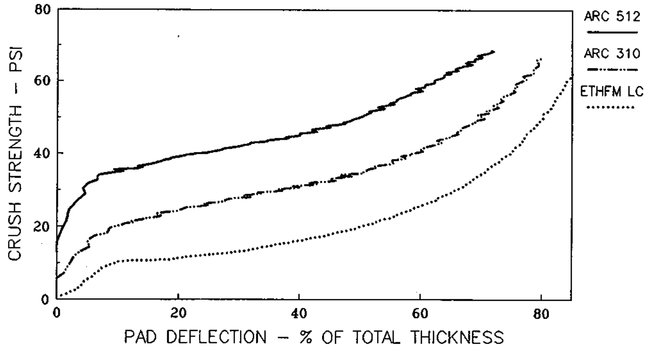


Figure 2. Comparison of Three Selected Padding Materials

Test Procedure

The sled buck had a bench seat with a low friction surface. The impact surface equipped with a load measuring plate was covered with one type of 76mm (3in) thick pad for each of the padded tests. The dummies were seated approximately 38cm (15in) away from the load plates. The sled was accelerated to produce a Δv of approximately 8.9m/sec. (20mph). The sled acceleration, pad deflection, and plate loads were measured in each test. Instrumentation and measurements common to all the dummies were rib, spine, and pelvis accelerations. For the EUROSID-1 and BIOSID, deflections of the thoracic ribs were also measured. For each dummy, one rigid wall and nine padded wall tests were conducted. Since EUROSID-1 and BIOSID had two possible arm configurations, tests with these two dummies were repeated with the arm up using five of the pads and the rigid wall configuration. In the arm up condition, the longitudinal axis of the arm was approximately 40 degrees from the vertical.

Side Impact Crash Tests

Prior to the issuance of the final rule for side impact protection, the NHTSA conducted nine side impact crash tests using the SID in the driver and left rear passenger positions. Eight of these were conducted at the Calspan Corporation, while one (Nissan Sentra) was conducted at the Transportation Research Center of Ohio (TRC). These tests were conducted following the procedures subsequently adopted for the upgraded FMVSS No. 214. Briefly, the moving deformable barrier (MDB), with wheels crabbed to 27°, was towed into a stationary subject car at 54km/hr (33.5mph). This simulated a perpendicular collision where the striking car was moving at a nominal speed of 48km/hr (30mph), and the struck car at 24km/hr (15mph). At first contact between the vehicles, the leading edge of the MDB was 940 mm (37") forward of the wheelbase center of the struck car.

In May-June 1990, the NHTSA conducted five side impact crash tests of production vehicles per the Side Impact Test Procedure later adopted for the final side impact rule, using the BIOSID. The vehicles selected included a 1987 2-door Nissan Sentra, a 1988 4-door Ford Taurus, a 1988 4-door Hyundai Excel, a 1987 4-door Chevrolet Cavalier, and a 1988 4-door Toyota Tercel. Identical vehicles were tested earlier by the agency in its production vehicle test program prior to the issuance of the side impact rule with the SID. EUROSID-1 was not included in this test series since these vehicles were going to be tested in Europe with the EUROSID-1 in a separate test series under the auspices of the EEVC. Therefore, the discussion of the crash test results will be limited to comparison of the SID and BIOSID only in this paper.

Two dummies, one in the driver seating position and the other in the left rear passenger seating position were used in these tests. The purpose of these tests was to allow a comparison between the responses of the SID and BIOSID in the FMVSS No. 214 crash test environment. These responses include TTI(d)'s, peak accelerations, acceleration waveform shapes, and component velocity profiles. The results and subsequent analysis are presented later in this paper. A complete list of all the response measurements obtained in these crash tests are given in volume II of reference 9.

Analysis of Results and Discussion

Performance Verification Test Results

The data pertaining to SID and BIOSID are based on tests conducted on several SID's and four BIOSID's. Since only one EUROSID-1 was available, the calibration data reported here are based on that dummy only. It must be noted that the SID thorax calibration tests were conducted on as many as seven dummies and tested in three different laboratories with multiple tests on all the dummies ranging from as few as two on one, to over twenty-five tests on others. On the other hand, BIOSID data are based on tests conducted at two laboratories and EUROSID-1 data presented pertain to only one dummy tested at a single laboratory.

The SID pelvic design originally included a retention pin in the femur ball and flange assembly. The data in Table 2 pertain to the tests using this configuration of the dummy. This pin was eliminated before the design specification for the dummy was finalized, due to gouging on the femur ball and due to metal-to-metal contact during the tests. Bending and breakage of the pelvic pin was also a problem. However, the elimination of the pin allowed the femur posts to rotate within the flesh during tests without any indication from the outside that such rotations occurred during tests. It was therefore necessary to examine carefully and check the alignment of the femur post with respect to the pelvis after each test of the SID. It was also necessary to ensure that the femur assembly was tightened properly prior to each test. NHTSA used an alignment procedure to check the relative orientation of the femur with respect to the pelvis prior to testing. This alignment procedure was incorporated into the test set up procedures.

The calibration data obtained from testing the SID, EUROSID-1, and the BIOSID are tabulated below in Table 2. The data given are in terms of the mean, the standard deviation and the coefficient of variation for each component measurement for the three dummies.

Table 2. Thoracic and Pelvic Accelerations in Pendulum Impact Tests

	SID			EUROSID-1 Arm down			BIOSID* Arm down		
Component	Mean g	Std. Dev. g	Coeff. of Var. %	Mean g	Std. Dev. g	Coeff. of Var. %	Mean g	Std. Dev. g	Coeff. of Var. %
Upper Rib	42.8	5.3	12.4	51.4	1.3	2.5	67.4	7.4	11.0
Lower Rib	42.7	4.9	11.4	63.0	11.3	18.0	105.4	15.6	14.8
Lower Spine	20.5	2.2	10.7	15.5	0.4	2.9	17.4	1.8	10.1
Pelvis	52.6	5.4	10.2	20.8	0.5	2.6	54	4.1	7.5

Table 2: Thoracic & Pelvic Accelerations in Pendulum Impact Tests

* Tests at Impact Velocity of 6.7m/sec.

Since the pelvic pin in the SID was eliminated, a new set of pendulum test data for pendulum impacts was generated using two SID dummies. The mean, standard deviation and the coefficient of variation in pelvic responses for 37 pendulum impact tests were 47.0 g, 4 g, and 9%, respectively, compared to that given in Table 2 above for the SID before the pelvic pin was eliminated. The calibration corridors have been defined in the final side impact rule, FMVSS No. 214, for the rib, spine, and the pelvis as 37-46 g's, 15-22 g's, and 40-60 g's, respectively. These corridors were established taking into consideration all available data on the SID, dummy response variability noted because of variations in production materials such as the pelvic foam and rib wrap foam, and variability in test results from test facility to facility. For the rib and spine responses of all the dummies tested at each test facility, the established corridor is approximately the average response ± 1 standard deviation. However, for the pelvis, this corridor is approximately the average response ± 2 standard deviations, which is somewhat wider than the ranges for the rib and spine responses. The design change made in the pelvis eliminating the pelvic pin before the final specifications of the SID were defined, did not appear to have appreciably changed the calibration corridor established earlier. Further, the inherent variability in the pelvic foam characteristics generally found in all dummies has necessitated the retention of the calibration corridor already established, to avoid too frequent failures of the dummy in passing the calibration specifications of the final rule.

One concern which is often expressed by automobile manufacturers is that the wide calibration corridor specified in the side impact rule is likely to affect the performance of the dummy in vehicle crash tests. However, analysis of available data from repeated sled tests at 20 mph into padded walls using the SID shows that, irrespective of the spread in the peak pelvic g's in calibration tests, the response of the pelvis in sled tests remained approximately the same. The peak pelvic g in sled tests using one SID is plotted against the calibration test results, in Figure 3. This figure shows that the calibration values and the sled pelvic g's in sled tests are not directly correlated.

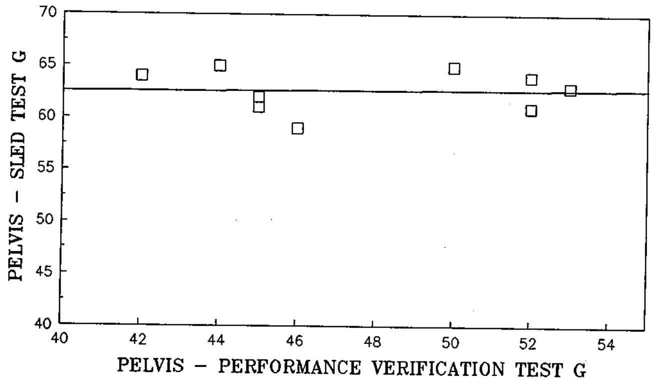


Figure 3. SID Pelvic Responses in Performance Verification Tests and Sled Tests

Pendulum impact tests for BIOSID were conducted at 6.7m/sec (22fps) per the specification for the dummy. The pendulum test data presented in Table 2 are based on only a limited number of tests of EUROSID-1. Both of the dummies produced higher rib accelerations than the SID as expected, because of the lighter rib mass as well as the higher impact speed in the BIOSID tests. However, the lower spine accelerations indicated by EUROSID-1 and the BIOSID were lower than that given by the SID. In pendulum impacts, while the SID gave approximately the same mean accelerations for the upper and lower rib, EUROSID-1 and BIOSID gave higher accelerations in the lower rib. The coefficient of variability in responses for the SID and BIOSID in performance verification tests were similar. Except for lower rib response, all of the other measures indicated less than 5% coefficient of variation in EUROSID-1. SID, EUROSID-1, and BIOSID indicated moderate variability in acceleration measurements of the lower rib. The coefficient of variation in pelvic responses in the SID and BIOSID were in the range of about 8-10% while that for the EUROSID-1 was under 3%.

Calibration corridors are generally meant to serve as indicators of proper functioning of the dummy, so that when thoracic and/pelvic responses fall outside the established corridors, the dummy can be checked for faulty components.

Sled Test Performance

As mentioned earlier, for comparison purposes, the SID, EUROSID-1, and BIOSID were tested on the sled using nine pads and rigid wall configurations. No repeat tests of these configurations were conducted. The EUROSID-1 and BIOSID were tested in the arms down and arms up positions. Since SID responses are comparable to the other dummies in the arms down configurations only, the discussion below comparing responses of the three dummies are based on the SID results to that of the arms down tests of the other two dummies.

SID

The peak rib accelerations, lower spine accelerations, and pelvis accelerations were recorded in all the tests. The TTI(d) were calculated as the average of the maximum rib acceleration and that of the lower spine.

The lower rib of the SID generally gave the higher rib reading in all cases, except for the paddings having a crush strength less than 138 k.pa (20 psi) and the rigid wall condition. The SID rib accelerations ranged from 60 to 203 g's for the upper rib, and 53 to 194 g's for the lower rib. The lower spine readings ranged between 67 and 115 g's.

Based on TTI(d) ranging from 66 to 159 g's for various paddings and the rigid wall configurations, Arsan 601, at 131 k.pa (19 psi) was judged to be the optimum padding among those tested. However, this padding gave a slightly higher pelvic acceleration for the SID than with the next best pad for the TTI(d). Arcel 310 having a crush strength of about 220 k.pa (32 psi) gave a TTI(d) of approximately 71 g's and a pelvic acceleration of 70 g's. This pelvic acceleration was 11 g's lower than that given by Arsan 601 for the SID. It must be noted that since these paddings were backed by a rigid wall, the dummy responses under such conditions are likely to be different from that obtained when backed by a yielding surface such as in car doors. From these test results it can be stated that the optimum padding crush strength that is likely to yield minimum TTI(d) under these impact conditions is somewhere in the range of 131-220 k.pa (19-32 psi).

Based on TTI(d), each of the ribs and the lower spine indicated approximately the same ranking of the impact surfaces. The best pad selected on the basis of SID TTI(d) and the next best pad showed a difference of only 3 g's. When the padding was extremely soft, the TTI(d) was only slightly less than the results in rigid wall impacts. These soft pads "bottomed" out in these tests. The load transmitted to the wall in tests using very soft pad was approximately the same as that obtained under rigid wall conditions. On the other hand, when very soft padding was used, probably very little energy absorption occurred in the pad resulting in a high TTI(d), and a high plate load.

The plate loads were measured by load cells mounted behind the load plates. The total plate force-time history generated by adding the forces recorded by each load cell was used to obtain the peak load on the upper and lower load plates. For the arms down configuration for the EUROSID-1 or BIOSID, and the SID in its normal test configuration, the total force obtained from this procedure is generally an accurate indication of the total load transmitted to the load plate by the dummy, as very little phase shifts were observed in the individual load cell traces. However, when the arms are up, since the dummies do not load the plate uniformly, likelihood of phase shifts in load cell data exist and therefore, the total peak plate load may not always indicate differences in the loading pattern, when force-time history data from load cells are added to obtain the total force-time histories.

The forces transmitted to the load plates varied depending on the impact surface. For the optimum pad, the upper plate load from thoracic loading of the SID, was approximately 20 k.newtons (4500 lbs) and in the range of 17-19 k.newtons (3850-4300 lbs), from pelvic loading on the lower plate. The results of the sled tests using the SID are tabulated in Table 3 below.

Table 3. Peak Acceleration (G's)/TTI(d)/Peak Force (lbs) for the SID

TEST CONDITION	U.RIB	L.RIB	T 1	T 12	PELVIS	TTI	UP.LOAD	LO.LOAD	TOTAL
RIGID WALL	203	194	138	115	134	159	5477	5817	11293
L.C.200 ETHAFOAM	65	53	75	72	83	69	4654	4259	8913
ARCEL 512,2.5 PCF	84	100	74	69	89	85	4386	4348	8735
ARCEL 310,1.5 PCF	62	74	73	67	70	71	4370	3855	8225
ARSAN 601,1.0 PCF	60	53	83	72	81	66	4868	4295	9163
DRILLED ETHAFOAM	74	60	82	76	83	75	5167	4246	9413
ARCEL 512,4.0 PCF	114	128	81	91	106	110	4970	5175	10166
ARCEL 310,3.0 PCF	99	115	74	79	98	97	4624	4625	9249
DYTHERM 4.0 PCF	170	173	118	107	145	140	5504	6482	11986
SOFT PADDING	177	156	118	112	125	144	5344	5883	11227

Table 3: Peak Acceleration (G's)/TTI(d)/Peak Force (lbs) for the SID

EUROSID-1 and BIOSID

A total of ten sled tests were conducted with EUROSID-1 and the BIOSID in the arms down condition. However, for these two dummies, only five padded wall and one rigid wall tests were conducted in the arms up configuration.

Since the thoracic ribs included the center rib in EUROSID-1 and the BIOSID, the highest acceleration of the three thoracic ribs were used for the TTI(d) calculation, as opposed to the higher of the upper and lower rib accelerations only for the SID.

The rib accelerations for EUROSID-1 ranged from 59 to 134 g for the upper rib, 52 to 149 g for the center rib and 50 to 151 g for the lower rib, in the ten tests conducted with the arms down. Rib accelerations were maximum for the center rib in six of the tests and maximum for the upper rib in two of the tests. In one test (Ethafoam LC200, drilled) the center and lower rib accelerations recorded had questionable spikes in the data and therefore, only the upper rib acceleration was available for the analysis. In the rigid wall test, with the arms down, the center rib and lower rib accelerations were less than 2 g's apart. Therefore, the center or lower rib could be considered to have produced the maximum reading. Similarly, the upper and center rib accelerations in the Arcel 512 padded test were only 1 g apart.

When the arm was up, the lower rib accelerations were the maximum in four of the five padded wall and the rigid wall tests. In Ethafoam LC200 drilled padding, the center rib acceleration was approximately 3 g's higher than that for the lower rib.

From the above data, it can generally be concluded that, when the arm is up, the lower rib generally produced the maximum rib acceleration. One possible explanation for this is that when the arm is up, only the lower rib is completely exposed to direct loading from the impacting surface, while in the upper two ribs, reaction to the impact forces is through the arm, which at least partially covers the two upper thoracic ribs. With the arm down, the maximum accelerations could be indicated either by the upper or center rib of the EUROSID-1 dummy. The upper plate loads in the EUROSID-1 ranged from about 11 k.newtons to 16 k.newtons (2400-3600 lbs) when the arms were down. However, for the arm up configuration, the upper plate load was slightly lower at 9.3 k.newtons (2100 lbs) for the soft foam pad and slightly higher at 17.8 k.newtons (4000 lbs) for the rigid wall, when compared to the results from the arms down position of the dummy. The lower plate loads in the arms down and arms up configurations ranged from approximately 14 k.newtons to 24 k.newtons (3100 to 5300 lbs) and 15 k.newtons to 24 k.newtons (3300 to 5300 lbs) respectively. EUROSID-1 sled test data are tabulated in Table 4.

Table 4. Peak Acceleration (G's)/TTI(d)/Peak Force (lbs) for the EUROSID-1

EUROSID-1 ARMS DOWN										
TEST CONDITION	U.RIB	C.RIB	L.RIB	T 1	T 12	PELVIS	TTI	UP.LOAD	LO.LOAD	TOTAL
ARCEL 512,2.5 PCF	96	97	72	40	58	78	77	2681	3379	6060
ARCEL 310,1.5 PCF	98	82	54	45	59	69	78	2638	3130	5758
ARSAN 601,1.0 PCF	81	53	50	39	57	75	69	2488	4023	6511
ETHAFOAM DR LC200	59	N/A	N/A	35	54	83	57	2451	4181	6632
ARCEL 512,4.0 PCF	111	134	110	47	64	107	99	3012	3930	6942
ETHAFOAM LC200	71	52	54	38	57	82	64	2572	3985	6557
ARCEL 310,3.0 PCF	117	129	109	55	68	96	99	3078	3776	6834
DYTHERM 4.0 PCF	128	138	133	44	61	115	99	2889	4487	7376
SOFT FOAM RUBBER	112	122	114	43	63	120	92	3585	5277	8862
RIGID WALL	134	149	151	44	63	118	107	3596	5102	8698
EUROSID-1 ARMS UP										
ARCEL 310,1.5 PCF	82	148	152	43	59	73	105	2602	3301	5903
ARCEL 512,2.5 PCF	88	173	185	52	67	90	126	2890	3772	6662
ARSAN 601,1.5 PCF	79	97	97	40	54	80	76	2131	4252	6383
ETHAFOAM DR LC200	55	68	65	40	55	86	62	2463	4576	7039
ARCEL 512,4.0 PCF	111	174	185	47	71	95	128	3497	4646	8143
RIGID WALL	110	200	209	57	78	120	143	3987	5238	9225

Table 4: Peak Acceleration (G's)/TTI(d)/Peak Force (lbs) for the EUROSID-1

However, in the BIOSID, lower ribs yielded the maximum acceleration in eight of the ten arms down tests. Upper rib accelerations were maximum in the other two tests. When the arms were up, half of the six tests conducted had maximum acceleration for the upper ribs, and in the other half the lower ribs had the maximum acceleration. In rigid wall tests, irrespective of whether the arms were up or down, upper rib responses were always the highest among the thoracic ribs in the BIOSID. It can be surmised that the stub arm in the BIOSID generally interacted with the lower thoracic rib more than the upper and center rib, when the impact surface was padded.

The BIOSID rib accelerations ranged from 69 to 159 g's for the upper rib, 72 to 148 g's for the center rib, and 85 to 157 g's for the lower rib when the arms were down. When the arms were up, the accelerations were 72 to 168 g's for the upper rib, 74 to 140 g's for the center rib, and 77 to 132 g's for the lower rib, respectively.

For the BIOSID, the upper and lower plate loads were slightly higher than those of EUROSID-1 in the arms down and arms up positions. Further, the arms up position always yielded higher loads on the upper plate for the BIOSID irrespective of the type of padding used. Only very slight differences were detected in the lower plate loads between the arm down and arm up positions of the BIOSID.

Thus, based on the plate loads, it can be concluded that the EUROSID-1 dummy transmitted the lowest force to both the loading plates followed by the BIOSID. The maximum total plate forces were indicated by the SID. The total load in the arm down rigid wall configuration was about 39 k.newtons (8700 lbs) given by EUROSID-1 compared to 45.5 k.newtons (10,300 lbs) by the BIOSID and 50 k.newtons (11,300 lbs) by the SID. However, BIOSID tests with very soft padding such as the synthetic foam rubber and a very stiff padding like Dytherm produced approximately the same total plate loads as that obtained under the rigid wall condition for the same dummy. The SID indicated similar results. The total force measured in EUROSID-1 tests was lower when stiff pad was used in comparison to the rigid wall or the soft synthetic foam rubber pad configuration, thus indicating that the force transmissibility under rigid wall or stiff and soft pad conditions for EUROSID-1 are not the same as in the other two dummies. BIOSID sled test data are presented in Table 5.

Table 5. Peak Acceleration (G's)/TTI(d)/Peak Force (lbs) for the BIOSID

BIOSID ARMS DOWN										
PADDING TYPE	U.RIB	C.RIB	L.RIB	T 1	T 12	PELVIS	TTI	UP.LOAD	LO.LOAD	TOTAL
ARCEL 512,2.5 PCF	107	112	128	46	54	72	91	2942	3636	6578
ARCEL 310,1.5 PCF	94	102	120	40	53	66	87	2841	3374	6215
ARSAN 601,1.0 PCF	69	72	86	51	53	76	69	2749	3988	6737
ETHAFOAM DR LC200	82	86	89	54	54	75	71	3030	4123	7153
ARCEL 512,4.0 PCF	132	131	146	50	59	99	102	3232	4484	7716
ETHAFOAM LC200	74	83	85	51	52	69	69	2896	3343	6239
ARCEL 310,3.0PCF	119	125	142	46	52	74	97	2879	3787	6666
DYTHERM 4.0 PCF	143	139	153	58	68	119	110	3746	5886	9632
RIGID WALL	159	148	157	75	65	122	112	4155	6073	10228
SOFT PADDING	120	112	108	73	68	115	94	4126	5610	9736
BIOSID ARMS UP										
ARCEL 512,2.5 PCF	131	122	97	48	56	74	93	3023	3685	6708
ARCEL 310,1.5 PCF	112	107	127	46	55	67	91	2957	3374	6331
ARSAN 601 PCF PAD	72	75	118	47	55	72	87	2835	3721	6556
ETHAFOAM DR LC200	75	74	77	54	58	73	68	3248	3711	6959
ARCEL 512,4.0 PCF	149	137	126	56	66	94	108	3809	4322	8131
RIGID WALL	168	140	132	88	76	125	122	4445	5880	10325

Table 5: Peak Acceleration (G's)/TTI(d)/Peak Force (lbs) for the BIOSID

As seen from Table 1, the mass distributions of the three dummies are comparable. However, it must be noted that the total plate load transmitted by the SID is generally higher than the other two dummies, with the plate loads in BIOSID tests being higher than in the EUROSID-1 tests. This may be due to the differences in the stiffness and damping characteristics of the thorax of the three dummies.

One of the most noticeable difference in dummy responses was observed in the lower spine readings. The SID lower spine responses for the softest and the stiffest padding were 112 and 107 g's respectively. Under rigid wall conditions, lower spine accelerations in the SID was about 115 g's. However, for EUROSID-1, its comparable response was 63 g's, 61 g's, and 63 g's for the soft foam, stiffest padding (Dytherm) and the rigid wall, respectively. Equivalent readings for the BIOSID were 68 g's, 68 g's, and 65 g's, respectively. For the remaining seven paddings of varying crush strengths, the lower spine responses in the SID ranged between 67 g's and 91 g's showing clear discrimination between them. EUROSID-1 also indicated a slightly narrower range of 54 g's to 68 g's in its lower spine accelerations in those seven paddings. However, lower spine responses for the BIOSID in the range of 52 g's to 59 g's did not discriminate the pads as well as the other two dummies. From these results, it appears that lower spine of the BIOSID responds in the same manner and with approximately the same peak value irrespective of the impact surface conditions encountered by the dummy. One difference, especially in padded tests, is in the delayed peak lower spine response of the EUROSID-1 and the BIOSID compared to the SID. This may be because of the construction difference between the SID and the other two dummies.

Typical response curves for the upper and lower ribs, lower spine and pelvis are given in Figures 4, 5, 6, and 7, for the rigid wall, arms down condition. Comparable plots of typical responses in padded tests are given in Figures 8, 9, 10, and 11. The time histories of each of the above dummy components show that in general, they respond similarly even though, their peak values indicate differences because of the mass, stiffness characteristics and design differences in the dummy. TTI(d) and Pelvic g's of the three dummies are compared in Figures 12 and 13, respectively. On the basis of TTI(d), the optimum pads from those tested, selected by the SID and the BIOSID, are the Arsan 601 and Ethafoam LC200 having approximate crush strengths of 103 k.pa (15psi) and 131 k.pa (19psi), respectively. However, EUROSID-1 produced a lower TTI(d) with a softer pad having a crush strength of only 65 k.pa (9.5psi). It must however, be noted that the differences in TTI(d) obtained by the EUROSID-1 when compared to that given by SID and BIOSID is about 12 g's. It appears that the range of crush strength for which a minimum TTI(d) level could be achieved as indicated by the SID is slightly wider than the range indicated by the other two dummies. Minimum Pelvic g's were indicated by all the three dummies for Arcel 310 pad having a crush strength of approximately 220 k.pa (32psi).

Based on the sled test results and using TTI(d) and pelvic g's as the criteria, all the three dummies selected paddings which are nearly the same in terms of its force-deflection characteristics. However, their performance in discriminating padded impacting surfaces when backed by yielding surfaces cannot be conclusively ascertained from these test results, because the combined stiffness characteristics of the backing plate, especially when they are yielding, and pad react differently to each of these dummies.

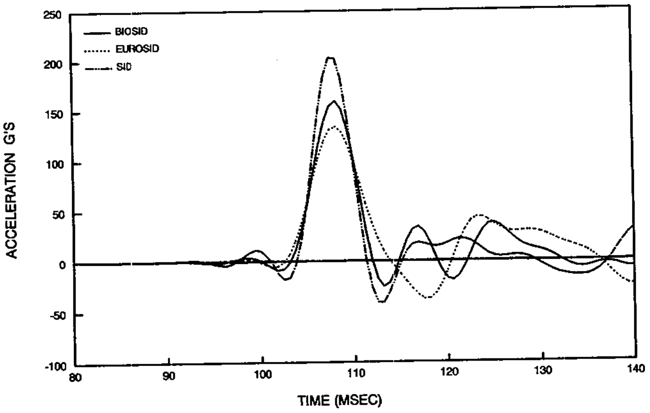


Figure 4. Comparison of Typical Responses of Side Impact Dummies Test at 32 Km/Hr (20 mph) (Rigid Wall (Arm Down) - Upper Rib)

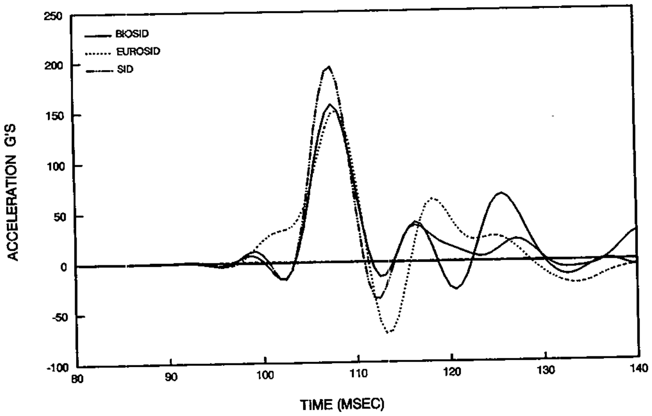


Figure 5. Comparison of Typical Responses of Side Impact Dummies Test at 32 Km/Hr (20 mph) (Rigid Wall (Arm Down) - Lower Rib)

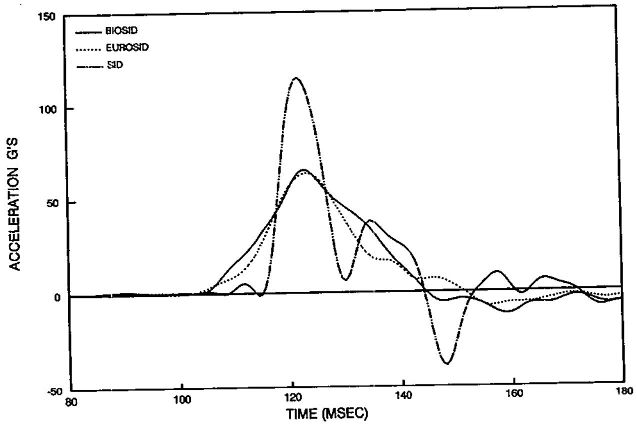


Figure 6. Comparison of Typical Responses of Side Impact Dummies Test at 32 Km/Hr (20 mph) (Rigid Wall (Arm Down) - Lower Spine)

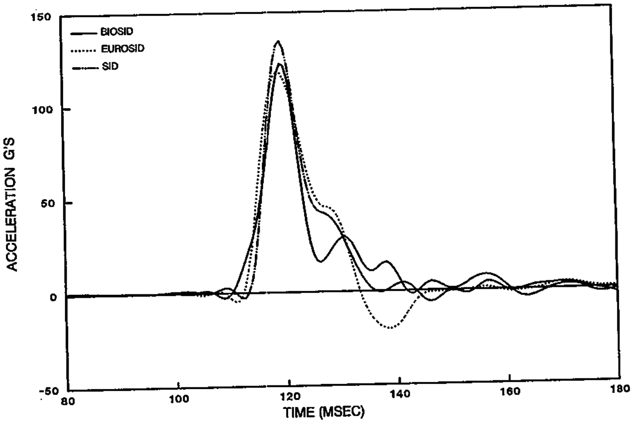


Figure 7. Comparison of Typical Responses of Side Impact Dummies Test at 32 Km/Hr (20 mph) (Rigid Wall (Arm Down) - Pelvis)

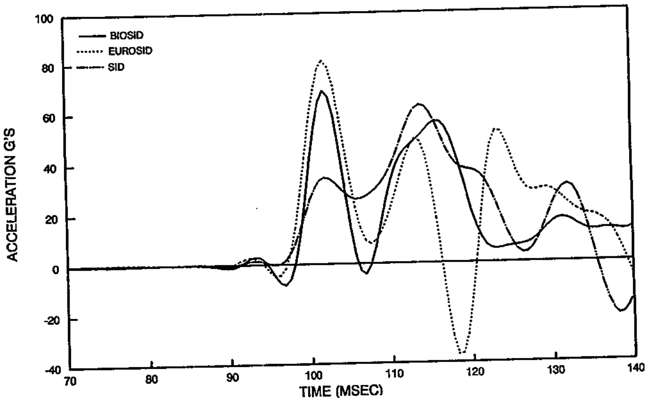


Figure 8. Comparison of Typical Responses of Side Impact Dummies Test at 32 Km/Hr (20 mph) (Padded (Arm Down) - Upper Rib)

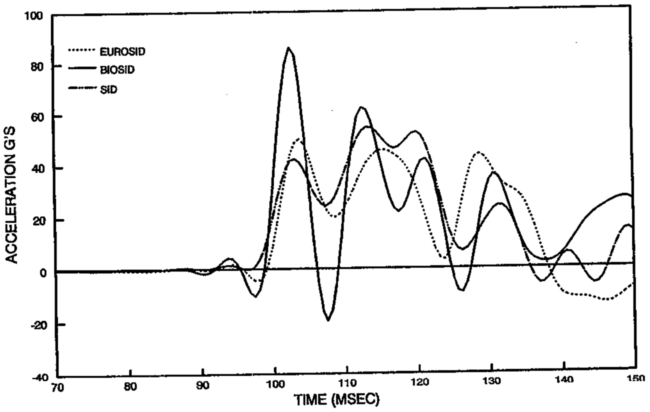


Figure 9. Comparison of Typical Responses of Side Impact Dummies Test at 32 Km/Hr (20 mph) (Padded (Arm Down) - Lower Rib)

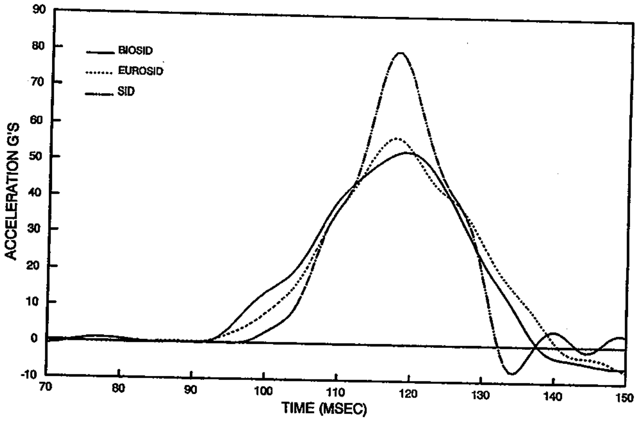


Figure 10. Comparison of Typical Responses of Side Impact Dummies Test at 32 Km/Hr (20 mph) (Padded (Arm Down) - Lower Spine)

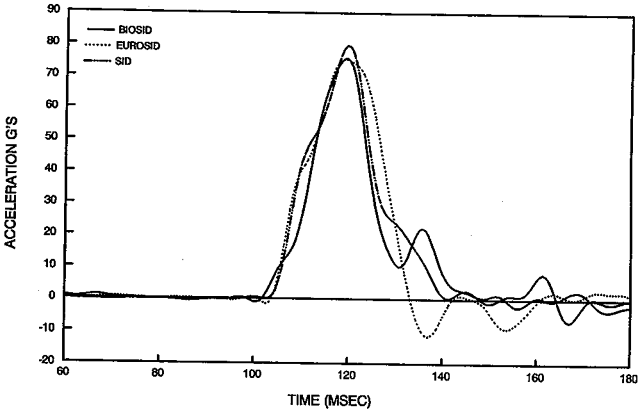


Figure 11. Comparison of Typical Responses of Side Impact Dummies Test at 32 Km/Hr (20 mph) (Padded (Arm Down) - Pelvic)

Repeatability and Reproducibility

NHTSA conducted a series of twenty tests for the assessment of repeatability and reproducibility of the BIOSID dummy. Since the agency had only one EUROSID-1 available, no reproducibility assessment was possible with this dummy. Therefore, this dummy was not tested for repeatability under this series of tests. SID was also evaluated for repeatability and reproducibility in the agency's earlier research in support of its side impact rulemaking. Therefore, the repeatability and reproducibility testing under this research program was limited to the BIOSID dummy. However, since repeatability characteristics of the SID and EUROSID were established earlier, a brief discussion of those findings will be included for comparison to the BIOSID.

Repeatability and reproducibility of the SID was established on the basis of tests conducted prior to the issuance of the side impact rule. These included 27.2km/hr (17mph) and 36.8km/hr (23mph) rigid wall and 36.8km/hr (23mph) padded wall impacts. Repeatability and reproducibility discussions relating to the SID and BIOSID from sled tests are limited to impact environments comparable to those encountered in passenger car side crashes with door contact velocities up to 40km/hr (25mph). The maximum variation observed in various acceleration response parameters in the SID were about 5% or less in rigid wall tests and 2-3% in padded wall tests. However, reproducibility which accounts for dummy to dummy variability for the ribs spine and the pelvis measured 3%, 7%, and 13%, respectively in rigid wall tests. The variability indicated in APR padded tests were only 3-4% in all of the relevant acceleration measures.

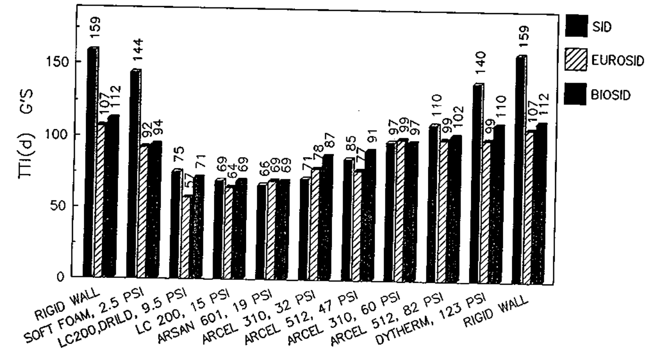


Figure 12. TTI in Sled Tests Using Various Types of Pads (SID/EUROSID/BIOSID Comparison - 20 mph Delta V) (EUROSID/BIOSID Arm Down)

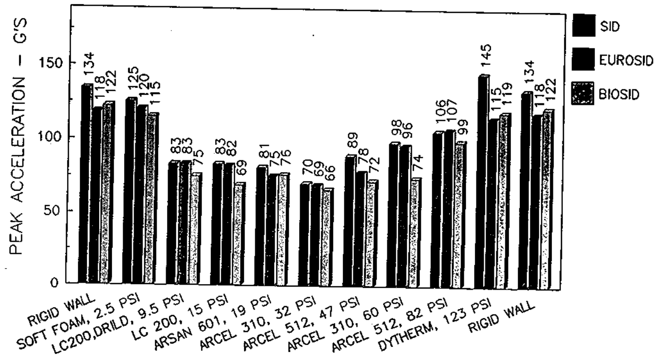


Figure 13. Pelvic G in Sled Tests Using Various Pads (SID/EUROSID/BIOSID Comparison - 20 mph Delta V)

Individually, each of the dummies also showed coefficient of variation below 5% for each of the response parameters, under all padded wall impact conditions. However, for the rigid wall, one of the BIOSID's gave a coefficient of variation of 9% and 11% in the shoulder and upper rib accelerations, respectively.

BIOSID repeatability and reproducibility tests were carried out with two BIOSID's in the arms down configuration. Three test speeds were used for this evaluation. Under the rigid wall condition, two BIOSID's were tested at 27.2km/hr (17mph), repeating the tests three times. Repeat tests were also conducted at 32km/hr (20mph) using Ethafoam LC200 and Arcel 512 paddings which had crush strengths of approximately 103 k.pa (15 psi) and 324 k.pa (47 psi) respectively. Using two dummies, these tests were repeated five times under each test condition. Finally, APR paddings were used for one BIOSID, repeating tests at 36.8 km/hr (23mph) three times. Acceleration responses were recorded for all the thoracic and shoulder ribs as well as the lower spine and the pelvis.

The data from the two BIOSID's were pooled for repeatability assessment. Under padded conditions, the accelerations of the thoracic ribs, the lower spine and the pelvis showed a coefficient of variation of less than 10% for all the measured parameters except for upper rib acceleration. When Ethafoam LC200 was used, the coefficient of variation in the upper rib acceleration was 11%. When the responses for the two dummies and the two paddings were combined and analyzed statistically to investigate whether response differences existed between the two dummies, it was observed that the dummy differences were not statistically significant for the three thoracic rib responses, lower spine responses, the TTI(d) and the pelvic g's. It was, therefore, concluded, for the limited number of dummies tested, that the repeatability and reproducibility of the BIOSID's were good. However, when final production dummies become available, more elaborate evaluation similar to the evaluation of the SID will be necessary for complete repeatability assessment.

Biofidelity Comparisons

Biofidelity of the test devices are established to ensure that the test devices measure responses that are comparable to that obtained from cadaver testing. In developing the SID for the final side impact rule, NHTSA established the biofidelity requirements for the ATD on the basis of 27.2km/hr (17mph) rigid wall sled tests and 36.8km/hr (23mph) APR padded wall tests similar to those conditions under which cadaver subjects were tested at University of Heidelberg. In addition to the quantitative comparisons of the acceleration time histories, the peak accelerations, time of its occurrence, and the wave forms between SID and cadaver subjects tested were also compared. The dummy cumulative response variance (DCV) was calculated and compared against the cadaver cumulative response variance (CCV) also for biofidelity assessments [10 and 11]. The ratio of DCV to CCV is a measure of the biofidelity of the dummy NHTSA has used to test for biofidelity of dummy response measures. When the ratios of cumulative variances are with in ± 1, the dummy responses are considered to be similar to that of cadaver responses and when they are between ± 1 to 2, they are considered good. When this ratio is greater than ± 2, it is concluded that the dummy responses are different from those from cadaver testing. This biofidelity assessment criteria is translated into a scale given below for the DCV/CCV ratios to determine biofidelity of the three dummies.

1.0 > DCV/CCV > 0.0	Dummy responses not more variable than the MCR.
2.0 > DCV/CCV > 1.0	Dummy responses sufficiently close to those of the MCR.
DCV/CCV > 2.0	Dummy responses different from the MCR.

Dummy responses in 27.2km/hr (17mph) rigid wall and 36.8km/hr (23mph) APR padded wall tests were analyzed along with human cadaveric subjects tested by University of Heidelberg in the same test conditions. The responses of each of the dummy components from the tests conducted using the SID, EUROSID, and the BIOSID are tabulated in Table 6.

Table 6. Biofidelity Comparison of SID, EUROSID, and BIOSID

Component	DCV/CCV			Peak Accel. g's			Delta % with respect to cadaver peak acceleration		
27.2km/hr, Rigid wall (17mph)	SID	EUROSID*	BIOSID	SID	EUROSID*	BIOSID	SID	EUROSID*	BIOSID
U.RIB	1.27	2.35	0.89	155	118	124	74.2	33.1	39.7
L.RIB	0.75	1.22	0.67	137	104	118	14.0	13.5	1.4
L.SPINE	1.02	2.56	1.78	81	69	46	3.8	18.2	45.5
PELVIS	2.47	1.17	0.43	118	88	89	71.0	27.3	28.8
36.8km/hr (23mph) APR Padded Wall Tests									
U.RIB	0.78	N/A	1.32	58	N/A	101	15.7	N/A	46.2
L.RIB	0.48	N/A	0.52	79	N/A	137	20.4	N/A	38.2
L.SPINE	1.13	2.13	1.06	77	78	88	0.3	1.4	13.7
PELVIS	1.03	1.19	0.36	82	85	74	7.6	11.6	3.3

Table 6: Biofidelity Comparisons of SID, EUROSID, and BIOSID
* Based on tests of a pre-production prototype

Based on the DCV/CCV ratios, the SID thoracic responses were considered to have good biofidelity both in 27.2km/hr (17mph) rigid wall and 36.8km/hr (23mph) APR padded wall impact conditions. However, the data showed that the SID pelvis over responds under rigid impact conditions. In padded wall impacts similar to that encountered in vehicle impact environments, the biofidelity of the SID was considered good.

Under rigid wall impact conditions, EUROSID lower rib and pelvic responses indicated good biofidelity. However, the upper rib and lower spine responses did not indicate good biofidelity. Since data from APR padded tests were available only for the lower spine and pelvic responses, no conclusions could be drawn on the biofidelity of the upper and lower thoracic ribs in the EUROSID. The pelvic responses in padded tests showed good biofidelity for the EUROSID, while the lower spine did not. On the other hand, the biofidelity indicated by BIOSID under rigid wall conditions were good for the upper and lower ribs, lower spine, and the pelvis. The tests at 36.8km/hr (23mph) with APR pads also indicated good biofidelity in responses of all the BIOSID components.

Vehicle Crash Test Results

The purpose of the vehicle tests was to compare the performance of the different side impact dummies in the FMVSS No. 214 crash test. An analysis was conducted to compare the responses of the SID and BIOSID in these crash tests. These responses include TTI(d)'s, peak accelerations, acceleration waveform shapes, and component velocity profiles. The TTI(d) and peak accelerations for the pelvis, lower spine, and ribs (upper and lower) are listed in Tables 7 through 11. For each SID/BIOSID test pair, the coefficient of variation (c.v.) was calculated. For this analysis, c.v. was defined as the sample standard deviation divided by the average of the responses. However, it must be noted that the standard deviation is based on two tests only, one with each dummy for all the models of cars tested.

The average c.v. for the driver TTI(d) responses was 10.8%. This is well within the variation expected from repeated crash tests of this type, as shown in the Final Regulatory Impact Analysis (FRIA) for FMVSS No. 214 [12]. Note that the c.v. from the pair of Hyundai Excel tests was very high (37.1%). Without these data, all the driver TTI(d) c.v.'s were less than 6%, averaging just 4.2%. A thorough investigation into the cause of this large discrepancy was conducted, but no concrete explanation was found [9, Vol II]. The average c.v. for the passenger TTI(d) responses was 7.2%, ranging from 3.8% to 10.6%. Once again, this range of variation was well within that established in the FRIA.

For the driver peak pelvis accelerations, the average c.v. was 13.0%, ranging from 4.5% to 18.9%. For the passenger pelvic responses, the average c.v was 15.5%. Note again that there was one very high c.v. (39.5% for the Sentra). Without these data, the average passenger pelvis c.v. was 9.5%, with the maximum at 17.1%. As for the driver TTI(d) responses in the Excel tests, a thorough investigation was conducted to determine the cause of this large discrepancy. Once again, no concrete explanation was found. For both driver and passenger peak pelvis accelerations (excluding Sentra passenger), the upper range of c.v.'s was just high enough to raise question as to whether or not the differences seen between the two dummies could be explained as normal crash test variability.

It is important to note that the observations stated above are based on a very limited number of tests. Additional testing may lead to different conclusions. In the study of Reference 9 Vol. II, these data were combined with those from a series of twelve crash tests sponsored by the Motor Vehicle Manufacturer's Association (MVMA). Those tests involved the use of SID's and BIOSID's in FMVSS No. 214 type crash tests of 1990 4-door Pontiac 6000's. Both baseline and padded door configurations were tested, three times each. As reported in Reference 9, Vol II, a more rigorous statistical analysis of the combined data was performed. The results of this analysis led to observations somewhat different from those stated above.

Although acceleration levels for the ribs and spine are not regulated in FMVSS No. 214, it is interesting to compare these individual responses in the two dummies. For the driver, the average c.v.'s are rather high, ranging from 24.2% for the lower spine to 36.7% for the left lower rib (27.8% without Excel responses). From these limited data, it appears that the two dummies do not give

Table 7. SID and BIOSID Crash Test Responses TTI(d)

	DRIVER		PASSENGER		DRIVER	PASSENGER
VEHICLE	SID	BIOSID	SID	BIOSID	c.v. (%)	c.v (%)
SENTRA	99.5	103.7	100.8	87.3	2.9	10.1
TAURUS	78.2	84.4	69.1	80.3	5.4	10.6
EXCEL	88.5	151.5	90.5	85.2	37.1	4.3
CAVALIER	84.6	79.6	87.7	83.1	4.3	3.8
TERCEL	82.4	87.5	79.5	N/A	4.2	N/A
			AVERAGE		10.8	7.2
			COMBINED AVERAGE		9.2	

Table 7: SID and BIOSID Crash Test Responses TTI(d)

Table 8. SID and BIOSID Crash Test Responses Pelvis (g)

	DRIVER		PASSENGER		DRIVER	PASSENGER
VEHICLE	SID	BIOSID	SID	BIOSID	c.v. (%)	c.v (%)
SENTRA	169.7	159.2	132.2	74.5	4.5	39.5
TAURUS	105.0	82.6	91.0	115.2	16.9	16.6
EXCEL	105.0	137.4	145.2	153.0	18.9	3.7
CAVALIER	86.3	108.8	123.5	96.9	16.3	17.1
TERCEL	101.6	90.2	93.2	94.3	8.4	0.8
			AVERAGE		13.0	15.5
			COMBINED AVERAGE		14.3	

Table 8: SID and BIOSID Crash Test Responses Pelvis (g)

Table 9. SID and BIOSID Crash Test Responses: Lower Spine (g)

	DRIVER		PASSENGER		DRIVER	PASSENGER
VEHICLE	SID	BIOSID	SID	BIOSID	c.v. (%)	c.v (%)
SENTRA	107.8	90.3	80.5	65.9	12.5	14.1
TAURUS	86.9	57.6	46.8	71.9	28.7	29.9
EXCEL	103.2	76.6	88.2	78.5	20.9	8.2
CAVALIER	84.0	60.8	75.5	69.1	22.7	6.3
TERCEL	87.9	52.2	62.1	N/A	36.0	N/A
			AVERAGE		24.2	14.6
			COMBINED AVERAGE		19.9	

Table 9: SID and BIOSID Crash Test Responses Lower Spine (g)

Table 10. SID and BIOSID Crash Test Responses: Left Upper Rib (g)

	DRIVER		PASSENGER		DRIVER	PASSENGER
VEHICLE	SID	BIOSID	SID	BIOSID	c.v. (%)	c.v (%)
SENTRA	91.2	94.9	102.9	49.4	2.8	49.7
TAURUS	69.5	105.8	91.5	72.2	29.3	16.7
EXCEL	73.8	174.0	79.4	66.0	57.2	13.0
CAVALIER	79.0	98.5	93.1	58.7	15.5	32.0
TERCEL	77.0	108.8	75.6	N/A	24.2	N/A
			AVERAGE		25.8	27.9
			COMBINED AVERAGE		26.7	

Table 10: SID and BIOSID Crash Test Responses Left Upper Rib (g)

Table 11. SID and BIOSID Crash Test Responses: Left Lower Rib (g)

	DRIVER		PASSENGER		DRIVER	PASSENGER
VEHICLE	SID	BIOSID	SID	BIOSID	c.v. (%)	c.v (%)
SENTRA	78.3	117.1	121.2	108.7	28.1	7.7
TAURUS	68.9	111.3	87.0	88.6	33.3	1.3
EXCEL	73.2	226.5	92.8	92.0	72.3	0.6
CAVALIER	85.1	93.0	99.9	97.1	6.3	2.0
TERCEL	65.0	122.9	96.9	N/A	43.6	N/A
			AVERAGE		36.7	2.9
			COMBINED AVERAGE		21.7	

Table 11: SID and BIOSID Crash Test Responses Left Lower Rib (g)

similar driver rib and spine peak accelerations. For the passenger, the average c.v.'s range from a very low 2.9% for the left lower rib, to a rather high 27.9% for the left upper rib.

The TTI(d) and peak acceleration responses were also examined to determine if any trends were present. That is, does one of the dummies give consistently higher responses than the other? For the purpose of this analysis, three terms were chosen to describe the level of variation between the SID and BIOSID. They were as follows:

same - c.v. ≤ 7%
slightly higher/different - 7% < c.v.≤ 14%
higher/different - c.v > 14%

TTI(d)

On the basis of the above definition, for the driver, 4 of the 5 TTI(d) responses can be considered to be the same between the SID and BIOSID. In the other case, the BIOSID result was higher. For the passenger, 2 of the 4 TTI(d) responses were the same, while the BIOSID response was slightly higher in 1 case and the SID TTI(d) was slightly higher in the other. Also note that the BIOSID showed less discrimination between the vehicles in the passenger position (average = 84.0 g, c.v. = 3.6%) in comparison to the SID. In summary, the TTI(d) responses of the two dummies may be considered the same or just slightly different in all but one case. In that case (Excel driver), the BIOSID TTI(d) was substantially higher than that of the SID.

Pelvis

For the driver, 1 of the 5 peak lateral pelvic accelerations was the same, 2 were higher in the BIOSID, and 2 were slightly higher or higher in the SID. For the passenger, 2 of the 5 responses were the same, 1 was higher in the BIOSID, and 2 were higher in the SID. In summary, the peak pelvic accelerations of the two dummies were different in 6 of the 10 cases, but there was no consistent trend in these differences.

Lower Spine

For the driver, all 5 of the SID peak lower spinal responses were slightly higher or higher than those in the BIOSID. For the passenger, 1 of the 4 spinal responses was the same, the BIOSID response was higher once, and the SID results were slightly higher or higher in the other 2 cases. In summary, the SID lower spine responses were the same, slightly higher, or higher than those in the BIOSID in all but one case. This indicates that higher peak lower spinal accelerations would usually be indicated in the SID than in the BIOSID. In the padded and rigid wall sled tests, the lower spine accelerations were lower in the BIOSID than in the SID.

Upper and Lower Ribs

For the driver, 2 of the 10 peak rib accelerations were the same, while those for the BIOSID were higher in the other 8 cases. For the passenger, 3 of the 8 responses were the same, with slightly higher or higher peaks for the SID in the other 5 cases. In summary, the peak rib accelerations were always either the same or higher for the BIOSID in the driver position, while these responses were always either the same, slightly higher, or higher for the SID in the passenger position.

The shapes of the rib acceleration traces for the BIOSID were compared to those of the SID. These wave shapes varied from test to test and from driver to passenger. For both dummies, driver rib acceleration curves generally had two significant peaks, although there were exceptions to this for each. For the passenger, the SID rib acceleration curves were always single peaked, while those for the BIOSID were mixed single and double peaked responses. In cases where the responses were double peaked (driver and passenger), the BIOSID traces had more pronounced oscillations, probably indicating a less damped system. Also in those cases, the maximum response was from either peak, with no clear trend as to which peak was higher.

The shapes of the spinal and pelvic accelerations in these tests were generally very similar for the SID and BIOSID. With a few exceptions, they were single peaked and of similar time duration. Some of the traces had a slight "ripple" in them, creating a small secondary peak or a flat spot, but this was the case for both dummies.

For both dummies, each of the four primary lateral acceleration responses (upper and lower ribs, lower spine, and pelvis) was integrated to obtain velocity-time profiles. Examination of these velocities did not reveal any consistent differences between the SID and BIOSID that were not expected from the acceleration response analysis. The rib velocity profiles for the BIOSID frequently displayed more oscillation than those for the SID. This was expected since the BIOSID rib accelerations had more pronounced oscillations than those for the SID. With few exceptions, SID and BIOSID spinal and pelvic velocity profiles had similar shapes, although not always similar magnitudes.

Summary and Conclusions

NHTSA undertook an evaluation of available ATD's for side impacts prior to the issuance of the final rule amending FMVSS No. 214 to include dynamic performance requirements for passenger cars.

Under the program, NHTSA tested the SID, a refurbished EUROSID per the latest specifications of EUROSID-1, and a prototype BIOSID. The test program included pendulum impact tests specified for performance verification testing and sled tests under padded and rigid wall impact environments, to assess the capabilities of these dummies to discriminate various impact surfaces of varying stiffnesses. Repeatability testing and biofidelity evaluation per NHTSA specified biofidelity requirements in FMVSS No. 214 of the SID and BIOSID were also conducted. Even though biofidelity evaluation of EUROSID was done based on test data from an earlier test program of a prototype dummy, no repeatability or reproducibility testing were done with EUROSID-1. A limited number of passenger car crash tests were also conducted with the BIOSID, to compare with the safety performance of cars using the SID.

Performance verification test results showed that the coefficient of variation in rib, lower spine, and pelvic responses of the SID and BIOSID were similar. However, EUROSID-1 indicated a higher coefficient of variation in the lower rib than the other two dummies. For the upper rib, lower spine and the pelvis in EUROSID-1, the coefficients of variation were below 3% and substantially lower than the SID and BIOSID. Even though the SID and EUROSID-1 were tested at identical pendulum impact velocities, the average rib responses were higher in EUROSID-1 than in the SID. However, the mean pelvis and lower spine accelerations were lower in EUROSID-1 than in the SID, with the pelvis giving less than ½ the reading obtained in the SID. Since the BIOSID test speed was higher, the thoracic responses were generally higher in the BIOSID than in both the other dummies. The exception to this was the lower spine responses, where despite the higher speed, they were lower in these tests than in the SID. However, pelvis response in the BIOSID was similar to that of the SID.

Padding discrimination tests showed that based on TTI(d), all the three dummies were able to select nearly the same paddings in terms of its stiffness characteristics. However, as the paddings deviated from the optimum, the SID gave generally higher TTI(d) than the other two dummies.

Repeatability of the SID and BIOSID are considered to be good on the basis of sled tests conducted under rigid and padded wall impact conditions. The SID generally indicated less than 5% coefficient of variation in relevant dummy accelerations of the rib spine and the pelvis. BIOSID repeatability results were also similar. EUROSID-1 was not tested for repeatability.

NHTSA conducted five pairs of side impact crash tests on identical passenger cars, using SID and BIOSID. Inspection of crash test data showed that, for the driver dummy, the TTI(d)'s indicated by SID and BIOSID in four of the tests were similar with a coefficient of variation of about 5% or less. For the passenger, the coefficient variability in TTI(d) for two tests were over 10%.

Individual rib and spine responses as well as pelvic responses in the two dummies indicated substantial differences in majority of the tests both in the driver and passenger seating positions. Therefore, even though the TTI(d) indicated by the SID and BIOSID are similar, differences in rib, spine and pelvic responses must be carefully considered before passing judgement on the adequacy of alternate dummies in safety performance evaluations. EUROSID-1 is being tested in Europe using the same vehicles as those tested by NHTSA. When those tests are completed , a thorough analyses of all the crash data comparing the three dummies will be necessary before firm conclusions can be reached on the use of EUROSID-1 or BIOSID in place of or in addition to the SID in FMVSS No. 214 testing.

References

1. Department of Transportation, National Highway Traffic Safety Administration "Federal Motor Vehicle Safety Standards, Side Impact Protection," Rules 49 CFR Part 571, et. al., October 1990.
2. EEVC "The EUROSID Side Impact Dummy." A Report of the EEVC Adhoc Group of Dummies to the 10th ESV Conference. Proceedings of 10th ESV Conference, July 1985.
3. Lowne, R.W and Neilson, I.D., "The Development and certification of EUROSID" Proceedings of the 11th ESV Conference, May 1987.
4. Janssen, E.G., Wismans, J., and deCoo, P.J.A., "Comparison of EUROSID and Cadaver Responses in Side Impacts." Proceedings of the 12th Conference, May 1989.
5. Roberts, A.K., "Report on EUROSID 1989." Proceedings of the 12th ESV Conference, May 1989.
6. Beebe, M.S., "What is BIOSID?" SAE Paper No. 900377, Society of Automotive Engineers, Warrendale, Pennsylvania, 1990.
7. NHTSA "Finite Impulse Filter Program FIR 100." Docket 79-04, Notice 2, Item 18.
8. Marcus, J.H., Morgan, R.M., Eppinger, R.H., "Human Injury Response to and Injury From Lateral Impact," Proceedings of the Twenty-Seventh Stapp Car Crash Conference, October 1983.
9. Zuby, D., Willke, D.T., "Evaluation of the BIOSID and EUROSID-1" Volume I-V, NHTSA Reports on tests conducted by VRTC, May 1991.
10. Morgan, R.M., Marcus, J.H., and Eppinger, R.H., "The Biofidelity of NHTSA's proposed ATD and Efficacy of TTI", Proceedings of the 30th Stapp Car Crash Conference, October 1986.
11. Marcus, J.H., "Analysis of the Biofidelity of Force Responses of Side Impact Dummies." NHTSA Analysis, August 1991 (To be docketed).
12. NHTSA, "Final Regulatory Impact Analysis: New Requirements for Passenger Cars to Meet a Dynamic Side Impact Test, FMVSS 214", August 1990.

S5-O-17

Influence of Test Procedure Characteristics on the Severity During Side Impacts

J.A. Bloch, D. Cesari, R. Zac
INRETS

Abstract

In the field of researches concerning the vehicle passengers protection during side impacts, the first studies were oriented to define a full-scale test procedure as a validation test. Such researches were conducted in parallel in Europe and in the United States. The two side impact full-scale procedures resulting to these studies are very similar, but some parameters are different like the characteristics of the mobile deformable barrier—MDB—(dimensions, weights, rigidities), the direction of its movement, the dummies installed. The aim of the study presented is to look at the influence of some parameters on the global severity of the side impact.

Five tests were carried on with the Impact and Biomechanics Laboratory facilities. In all the tests, the impacted vehicle was similar and the dummy on the driver's seat was an EUROSID. The parameters examined were the basic frame of the MDB, the front deformable face constitution and the MDB trajectory (crabbed or perpendicular). As during every test only one parameter was modified, the influence of each parameter was examined. The results are given in term of vehicle kinematics and deformation and in term of measurements on the dummies.

Introduction

When work started on protecting vehicle passengers from lateral collisions, most research teams involved with the preparation of regulations began by defining Full Scale Test procedures. More recently, work has been presented which seeks to define Sub-System Test procedures and Composite Test Procedures. However, from a regulatory standpoint, the best defined and most advanced work concerns Full Scale Test Procedures.

In this field, work has been carried out simultaneously in Europe and the USA, financed respectively by the EEC and the NHTSA. Both procedures proposed are based on the same philosophy although because some parameters are different and it is difficult to estimate the effect of these differences on the final outcome. The goal of the research described in this report is to evaluate the influence on global collision shock severity of some parameters which differ from one procedure to the other.

After a brief review of the characteristics of both test procedures, this report describes the method used to enable comparisons between the results obtained by the different approaches.

Summary of the Main Characteristics of the American and European Procedures

Both test procedures described below are shown in Figure 1.

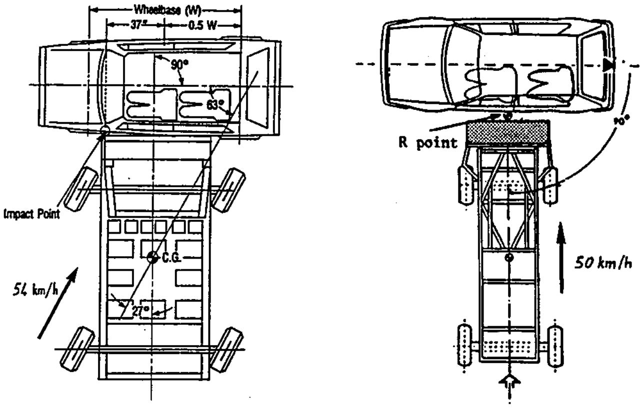


Figure 1. American and European Test Procedures

The American Test Procedure

The goal of this test procedure is to simulate a 90° lateral shock between two vehicles. The impacting vehicle is travelling at 48 km/h and the impacted vehicle at 24 km/h. To facilitate implementation of the tests the impacted vehicle is stationary and the impacting vehicle strikes it at a speed of 54 km/h in a crabwise trajectory. The impacting vehicle is in fact a mobile deformable barrier (MDB) with a mass of 1361 kg and a front face composed of an aluminum honeycomb. Two SID dummies are installed on the collision side of the test vehicle, one behind the other.

The European Test Procedure

In this procedure, the test vehicle is also stationary but the impacting vehicle has a perpendicular trajectory and is travelling at 50 km/h. Other work has shown that the speed of the impacted vehicle has little influence on shock severity. In this case too the impacting vehicle is a mobile deformable barrier but its specifications are different from those of its American counterpart—it weighs 950 kg and has a less rigid front face made of polyurethane (PU) foam. Two EUROSID dummies are installed on front and rear seats on the side of the vehicle on which the collision occurs.

Specifications of the Tests Implemented

As stated above, the test procedures developed in the USA and in Europe are relatively similar but some parameters are different (trajectory, mass, dimensions and front face of the mobile deformable barrier, dummy,...). Some laboratory work has already been carried out to compare the two test procedures but the comparisons made usually included variations in several parameters.

The INRETS Impacts and Biomechanics Laboratory initiated a series of tests to evaluate the influence of some discrete parameters on shock severity. The characteristics of these tests are described in Table 1. For each test, the impacted vehicle (Citroën BX) and the impact severity measurement instrument—a EUROSID dummy on the driver seat—were identical.

Table 1. Characteristics of the Tests Implemented

	test 1	test 2	test 3	test 4	test 5
Configuration MDB	Europe Europe	Europe USA	USA USA	USA Europe	Europe X
MDB mass (kg)	950	1360	1360	950	950
front face	Europe	USA	USA	Europe	USA
trajectory	90°	90°	crabbed	crabbed	90°
speed (km/h)	50	50.5	51.2	53.5	49.6

The analysis of the results obtained should enable us to compare the two procedures (test 1 and test 3) and to draw conclusions about the influence of specific parameters from the following comparisons:

- influence of the nature of the MDB
  - in the European configuration (test 1/test 2) 2
  - in the American configuration (test 3/test 4)
- influence of the trajectories
  - with the European MDB (test 1/test 4)
  - with the American MDB (test 2/test 3)
- influence of the front face in the European procedure (test 1/test 5)
- influence of the mass of the MDB in the European procedure with an American front face (test 2/test 5)

Marking of the Vehicles

Detailed marking is carried out on the impacted side of the bodywork of the impacted vehicle. It enables us to measure information after the shock on a 100 x 100 mm scale printout. Vertical and horizontal axes intersect at point R (Figure 2). Information can be measured in 6 horizontal lines.

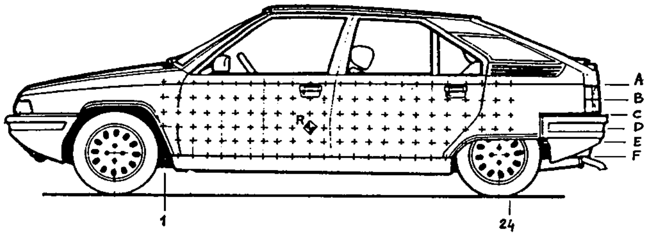


Figure 2. Positioning of Marks on Impacted Vehicles

On-Vehicle Measurements

On the mobile barrier. For each test, mobile barrier accelerations are measured in 3 directions—longitudinal (x), transversal (y) and vertical (z).

On impacted vehicles. The positions at which measurements are taken on are shown in Figure 3 below. All measurements were carried out in the transversal axis (y). 6 accelerations and the penetration are measured over time at the following points:

- Accelerations:
  - bottom left A pillar - 1
  - bottom right A pillar - 2
  - bottom left B pillar - 3
  - bottom right B pillar - 4
  - left front door, thorax level - 5
  - left front door, pelvis level - 6
- Penetration:
  - left front door, thorax level - T.

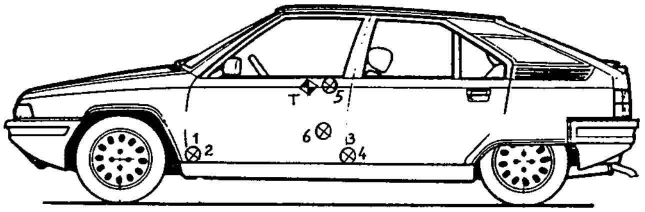


Figure 3. Positioning of Instrumentation on Impacted Vehicles

Measurements on the Dummy

In fact, two dummies are installed and strapped into place on board the impacted vehicles, a EUROSID dummy in the driving seat and a HYBRID dummy in the left rear seat. Only the EUROSID dummy is fitted with instruments in the following way:

- head:
  - 3 accelerations (x, y, z)
- thorax:
  - 3 deflection from ribs (y)
  - 2 accelerations on ribs (y)
  - 2 accelerations on spine (T1 and T12) (y)
- abdomen:
  - 3 parallel contacts
- pelvis:
  - 1 pubis force
  - 1 iliac force
  - 1 sacrum acceleration (y)

It is interesting to note that the EUROSID dummy used in these tests is a prototype. For this reason, the measurements obtained should only be compared in a relative way and the absolute value of any specific result should be used with caution.

Filmed Coverage

Two high-speed film cameras are also fitted in the vehicles, one on the mobile barrier, the other on the front end of the impacted vehicle. Both are trained on the driver.

Five other high-speed cameras are arranged on-site around the impact point and set-up for the following views:

- Overall view from above
- View of the MDB from the left (as seen from the front of the impacted vehicle), trained on the right hand side of the vehicle
- View of the MDB from the right (as seen from the rear of the impacted vehicle), trained on the impact point
- View bisecting the angle formed by the median axes of the two vehicles, from the left
- idem, from the right.

Results

The results obtained demonstrate the influence of the parameters detailed above. The various shock tests are compared for vehicle kinetics (Table 2), deformation (Figures 4 and 5) and measurements obtained from the EUROSID dummy (Table 3).

Table 2. Measurements Recorded on the Vehicles

	test 1	test 2	test 3	test 4	test 5
MDB					
X max.acc. (g)	21.8	23.5	21.7		18.5
BX					
left front door					
Y max. acc. (g)					
thorax level	181.5	210.7	137.9	169.2	162.2
pelvis level	206.8	266.2	218.6		199.5
A pillar					
Y max. acc. (g)					
left side	121.4	97	99.8	108.7	113.2
right side	46.9	44	20.1	33	34.6
B pillar					
Y max. acc. (g)					
left side	226.8	196.2	86.3	59.5	113
right side	56.3	61.1	48.2	18.1	56.1

Comparison of the Two Procedures

Test 1 and test 3 were respectively implemented using both European and American procedures. Unfortunately, in the test using the American set-up the speed of the mobile barrier was a little low (51.2 km/h instead of 54 km/h) which means that comments on the measurements obtained should be treated with caution. It can nevertheless be stated that the American procedure seems to induce more severe damage to the dummy's head.

Influence of the Nature of the MDB

It is possible to evaluate the influence of MDB type (i.e. American or European) by comparing the results obtained with test 1 and test 2—executed using the European set-up—and with test 3 and test 4—executed using the American set-up.

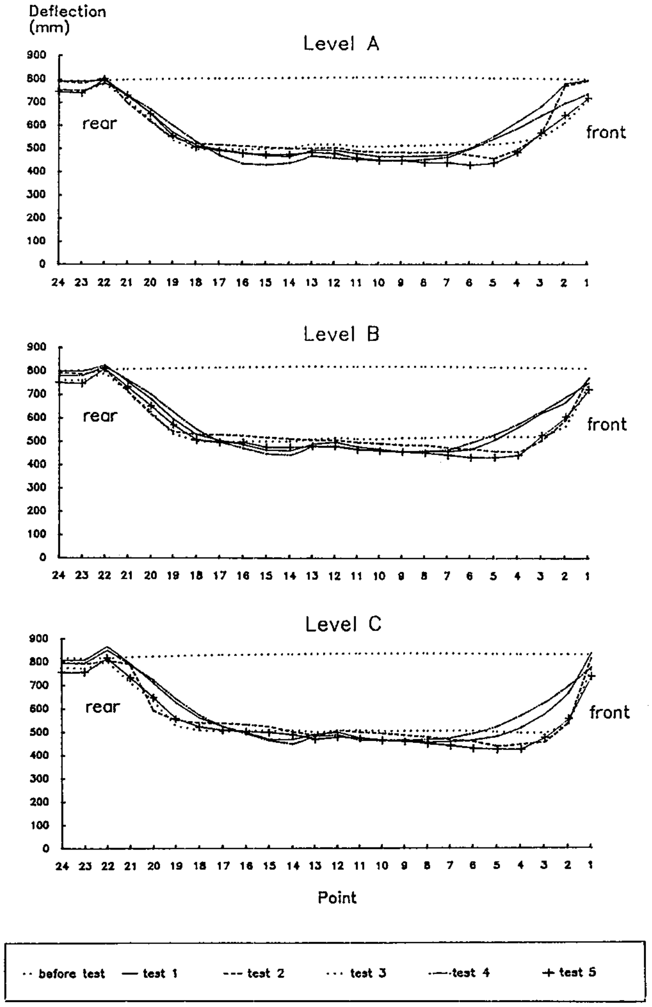


Figure 4. External Deformation of the Side Panels of the Impacted Vehicles (Upper Levels)

Table 3. Measurements Recorded on the EUROSID Dummy

	test 1	test 2	test 3	test 4	test 5
HEAD					
res.max.acc. (g)	54	80.6	57.8	66.2	103.4
res.3ms.acc. (g)	49.4	75.6	52.6	59.6	77.7
HIC	209	426	196	210	360
THORAX					
upper column					
Y max.acc. (g)	152.7	117.9	69.8	83.9	79.7
Y 3ms.acc. (g)	116.9	109.9	65.8	70.4	74.3
lower column					
Y max.acc. (g)	92.6	100.3	87.4	68.2	103.3
Y 3ms.acc. (g)	78	85.7	84.1	64.4	94.5
upper rib					
Y max.acc. (g)	250.7	289.4	104.7	249.2	180.4
Y 3ms.acc. (g)	92	88.3	80.6	104.3	63.3
lower rib					
Y max.acc. (g)	319.1	310.9	145.9	209.7	195.9
Y 3ms.acc. (g)	66.8	33.9	50.8	83.9	72.7
rib defl. (mm)					
upper	52	44	36	46	36
middle	54	48	43	41	41
lower	50	46	41	40	41
V*C					
upper	1	0.45	0.52	1.48	0.66
middle	1.03	0.55	0.75	1.27	0.78
lower	0.85	0.57	0.67	1.13	0.88
PELVIS					
Y max.acc. (g)	107.7	112.8	94.1	96.9	107.2

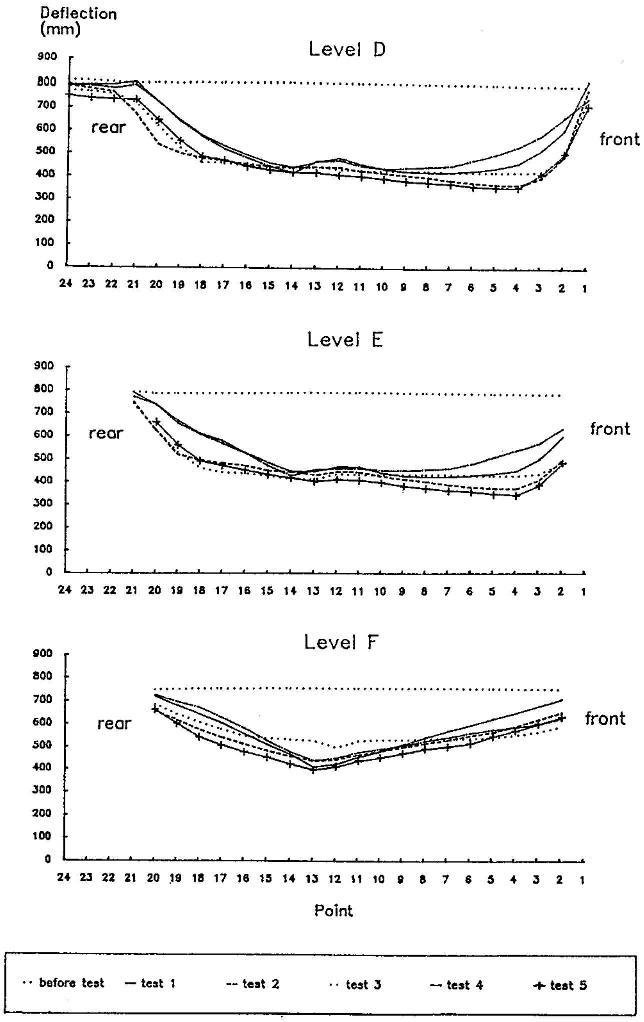


Figure 5. External Deformation of the Side Panels of the Impacted Vehicles (Lower Levels)

The initial comparison reveals higher accelerations at the door level with the American MDB and slightly lower accelerations below the A and B pillars in the impacted vehicle.

For passengers, deformation of the side panel induced by the American MDB is lower than that caused by the European MDB at the top of the door and this effect is reversed at the bottom. Both test configurations reveal the same phenomenon. As for measurements made on the dummy, the most significant difference is at the head level.

The American MDB induces higher acceleration and HIC when operated with the European configuration. This effect is, however, reversed at the thorax level although the measurements made give quite similar values.

It should also be noted that in the American set-up the severity of the American MDB is more pronounced for the upper part of the dummy.

Influence of the Trajectories

The influence of trajectories can be demonstrated by comparing tests 1 and 4 executed with a European MDB and test 2 and 3 executed with an American MDB. Overall, deformation of the side panel of the impacted vehicle is greater when the MDB trajectory is perpendicular to the impacted vehicle. This is also true for accelerations recorded by the lateral structure.

The trend is also demonstrated for severity measured on the EUROSID dummy. The perpendicular trajectory induces greater shock severity than the "crabwise" trajectory.

Influence of the Front Face

The effect of the type of front face (aluminum honeycomb or PU foam) can be demonstrated by comparing test 1 and test 5 (European set-up).

When deformations to the side panels of the impacted vehicles are examined, it is clear that the main difference is not at the passenger level, where they are very similar, but at the extremities. As the aluminum honeycomb is more rigid, it creates a more rectangular deformation than the PU foam. Furthermore, accelerations recorded on the vehicles are much higher when the PU foam front face is used.

The measurements recorded by the EUROSID dummy show that the PU foam face induces globally higher severity (except for the head).

Influence of MDB Mass

The comparison of test 2 and test 5 demonstrate the influence of the mass of the MDB used. In point of fact, in these test pair, the only parameter which was different was MDB mass.

The analysis of these test results confirms what was expected, i.e. that severity increases in proportion to MDB weight if all other factors are constant.

Conclusion

Both the European and the American test programmes designed to evaluate the performances of private cars following lateral shocks start from global reconstitution of a typical collision. The main differences between these two procedures are the dummy used, the approach set-ups of the impacting vehicles, the MDBs, and the front faces of the MDBs.

To define the influence of some parameters, we executed 5 impact tests on the same vehicle using the same EUROSID dummy. These tests enabled us to make the following comparative analyses:

- influence of the nature of the MDB in European and American configurations
- influence of the trajectories with European and American MDB configurations

- influence of the front faces in the European procedure
- influence of MDB mass on the European procedure using the American front face.

If, a priori, we thought it is possible to estimate those elements which would produce the highest severity levels for each of the values listed, our study showed that this is not as easy as it appears. We have, in fact, discovered that, in general, American and European MDB induce relatively similar shock severity, that mass increases severity and that the PU foam front face makes a greater impact than the aluminum honeycomb front face. We also noted that due to its greater mass the higher energy level of the American MDB is dissipated by the projection of the impacted vehicle to a greater distance. We have also shown that a perpendicular MDB trajectory at 50 km/h has more effect than a crabwise trajectory at 54 km/h.

To summarize, this analysis has shown that an a priori evaluation of the influence of the parameters analysed can lead to errors in judgment. We can state categorically that the European test is no less severe than the American procedure and that, in addition, the most severe evaluation procedure would be the European procedure executed using a heavier MDB.

S5-O-18

A Simple Side Impact Test Method for Evaluating Vehicle Paddings and Side Structures

Mats Lindquist
Saab Automobile AB

Abstract

A study conducted at Saab resulted in the development of a simple test method for side impacts which provides for the evaluation of injury mitigation performance of passenger cars. Also, different side impact dummies were compared (SID and BioSID) regarding injury levels and injury criteria.

Introduction

In several years the passive safety debate has been focused on side impacts. In the US must all passenger cars pass a full scale side impact test and Europe is expected to follow in a period of time. To upgrade safety for side impacts is a very complex problem and requires a great deal of testing. The side impact performance is both dependent of the cars side structure as the sill, pillars and door geometry and of the interior trim stiffness and underlying structure in the door.

The work presented in this paper has been conducted in order to simplify full scale testing to be able to evaluate door trim stiffness and underlying stiffness in the door and further to evaluate these parameters effect on a dummy in a side impact.

Sled Test Method

The figures 1 and 2 below illustrates the scenario during a full scale side impact test according to FMVSS 214 except for the dummy chosen. The curves are generated by a BIOSID in the driver seat of a Saab 9000.

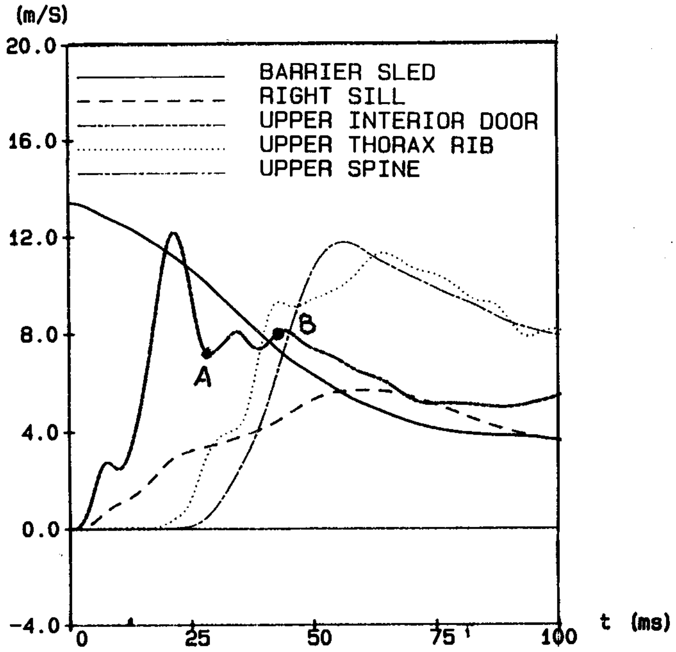


Figure 1. Velocities During a Full Scale Side Impact

Door interior velocity increases rapidly towards the velocity of the moving barrier sled during the first phase of impact. (When the driver dummy is impacted the door interior velocity decreases below the barrier sled velocity, point A in figure 1. At that moment, the dummy is deforming the door.) After the dummy is separated from the interior structure door interior velocity is again close to barrier sled velocity point B in figure 1. When the driver dummy is impacted the door interior velocity decreases below the barrier sled velocity, point C in figure 1.

Figure 3 below describes the developed sled test method used to simulate the door-dummy behavior mentioned above in a full scale test.

The dummy is seated in a front seat which is placed on a heavy sled, the seat is not fixed to the sled. On a lighter sled a door is mounted with a fixture. Below the door there is a beam intended to impact and remove the seat before the dummy contacts the door. This behavior

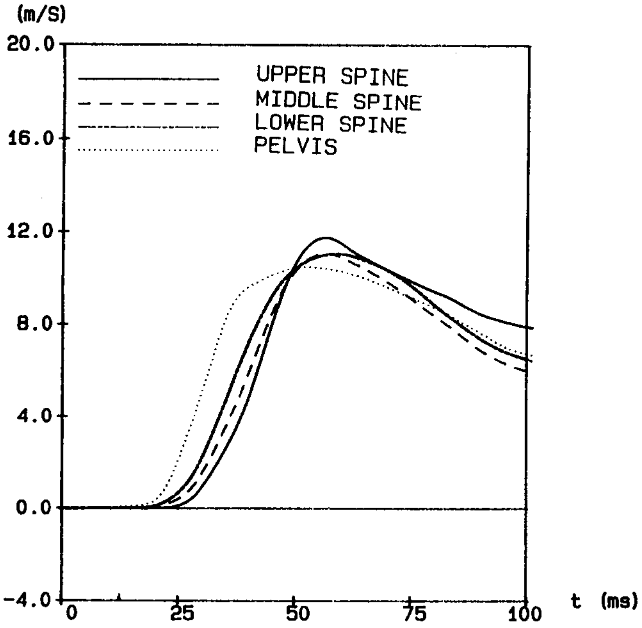


Figure 2. Dummy Velocities

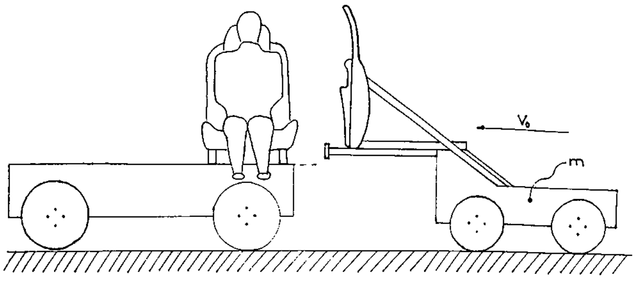


Figure 3. Sled Test Method

of the front seat occurs in a full scale test. The seat both deforms and moves with the car while the dummy is a free moveable mass.

With this method there are two parameters to adjust in order to simulate full scale behavior as close as possible. These are sled mass, m, and initial velocity, V_0, of the impacting sled. The two parameters are calculated with data from figures 1 and 2 by assuming preservation of momentum. The initial velocity chosen was 11 m/s and sled mass was determined to 420 kg which is the rate used in the tests if not otherwise written. Door with trim, from a Saab 9000, is replaced after each test.

Test Series Conducted

Four test series were conducted with the sled test method:

- Test series 1—Evaluation of wood bumper in the door.
- Test series 2—Evaluation of scattering in the test method.
- Test series 3—Evaluation of dummy responses at different test speeds.
- Test series 4—Evaluation of dummy responses to a stiff armrest.

In a full scale test the lowest part of the door is intruded by the barrier bumper in a way described in figure 4. The effect of this bumper intrusion is that the outer door structure contacts with the inside structure of the door. In other words the door trim is the only deformable section of the door between dummy pelvis and barrier bumper when the door interior impacts the dummy. Figure 5 describes the way this bumper intrusion is simulated. A wood "bumper" is placed on the inside of the door to prevent the pelvis from deforming the door interior structure.

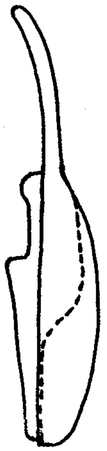


Figure 4. Door Deformation in a Full Scale Test

Figure 5. Door with a Wood "Bumper"

Test series 1—Evaluation of wood bumper in the door

Initially two sled tests were conducted in order to examine the need for a wood "bumper" in the lowest part of the door. One test with a bumper and one test without. These two tests were then compared with the results from a full scale test.

Test series 2—Evaluation of scattering in the test method

Three additional tests were conducted with the purpose to investigate the scattering of the results from this test method. These three tests were conducted in the same way as the sled test with a bumper in the door.

Test series 3—Evaluation of dummy responses at different test speeds

In order to compare the BioSID with the SID two test series were conducted. In test series no 3 the responses of the dummies for different impact velocities were investigated. Doors without the wood "bumper" were used in these tests.

Test series 4—Evaluation of dummy responses to a stiff armrest

One test with each dummy type was conducted. The door trim was equipped with additional stiff armrest compared to standard Saab 9000 door trim. The wood "bumper" in the door were used in these tests. With the BioSID reference test data was available. But for the

SID a additional reference test with standard Saab 9000 door trim was conducted.

Results

Test series 1—Evaluation of wood bumper in the door

Peak acceleration values from these two tests are presented below and are compared with the result from a full scale test. The dummy used in the tests is a BioSID, sled test 1 is without and sled test 2 is with a wood bumper in the door.

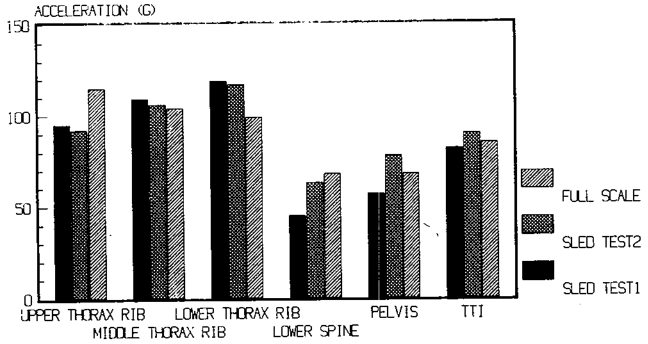


Figure 6. Comparison of Peak Accelerations from a Full Scale Test and Sled Tests With and Without a Wood "Bumper" With a BioSID (FIR-Filtrated)

Minor differences between the two sled tests regarding rib acceleration.

Lower spine and pelvis accelerations are increased with a wood bumper. As a consequence TTI-values are increased as well, with a wood bumper to simulate bumper intrusion.

The sled tests had the highest value for lower thorax rib accelerations. In the full scale test the upper thorax rib had the highest acceleration value. This must be due to the fact that the door orientation is changed during the crash in the full scale test.

The top and bottom rib acceleration were the same in the sled tests as in the full scale test.

The conclusion is that when studying top accelerations at different positions in the dummies it is difficult to see a difference between the sled tests but the test with a bumper is somewhat closer to the full scale test.

Figures 7 and 8 show the top values of chest compression and V*C (viscous criteria) from the same tests.

The difference between the two sled tests is clear. Without a wood bumper both top compression and top V*C of the thorax ribs are considerably higher. Without wood bumper top V*C and top rib compression values are considerably higher than with the wood bumper and in the full scale test.

In comparison with the full scale test it is obvious that the sled test with a wood bumper in the door is the best simulation. In appendix the curves from the sled test with a wood bumper in the door are compared to curves from the full scale test.

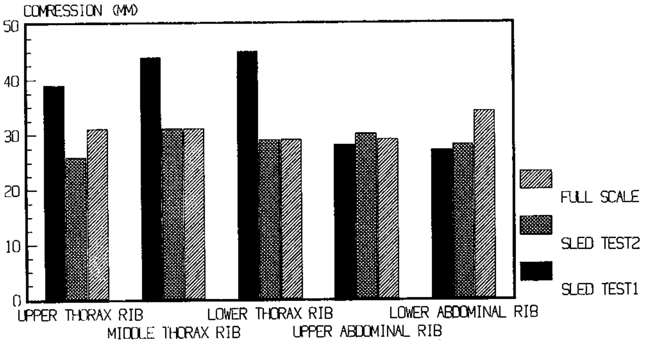


Figure 7. Comparison of Peak Chest Compression from a Full Scale Test and Sled Tests With and Without a Wood "Bumper" With a BioSID

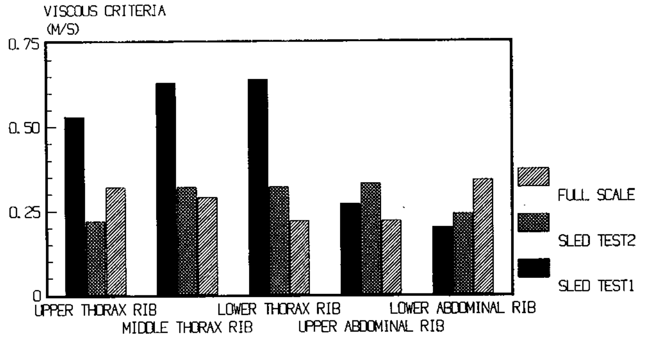


Figure 8. Comparison of Peak Viscous Criteria from a Full Scale Test and Sled Tests With and Without a Wood "Bumper" With a BioSID

Test series 2—Evaluation of scattering in the test method

In order to examine the scattering of the dummy readings with this sled test method four identical tests were conducted. The results are presented in figures 9, 10 and 11. And the results from each test are also available in appendix. The bar represents the average values and the hatched area represents the standard deviations in each direction.

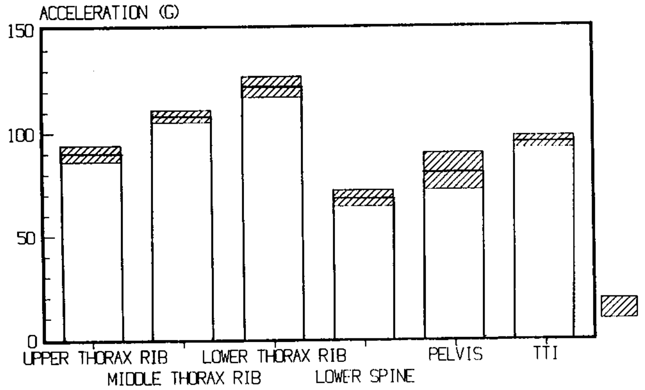


Figure 9. Average Top Acceleration Values from Four Identical Tests Conducted With a Wood Bumper in the Door

The scattering of the top acceleration values must be considered to be minor. Pelvis top acceleration has the largest scattering with a standard deviation of 11% from the average value. The scattering of rib top accelerations has a standard deviation of 4 from the average value. However the scattering in the test data of top chest compression and viscous criteria is quite high. As shown earlier the top compression and V*C values are strongly dependent on the magnitudes of loads on other parts of the body.

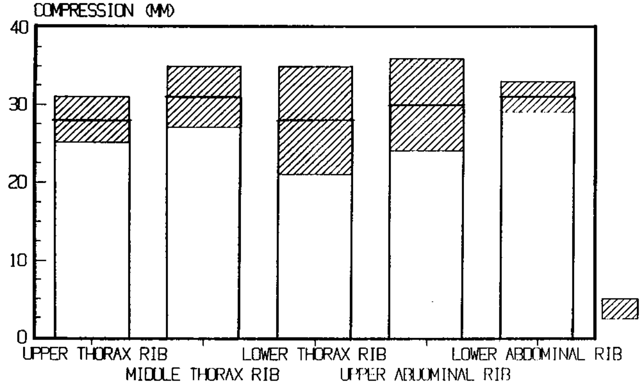


Figure 10. Average Values of Top Chest Compression from Four Identical Tests Conducted With a Wood Bumper in the Door

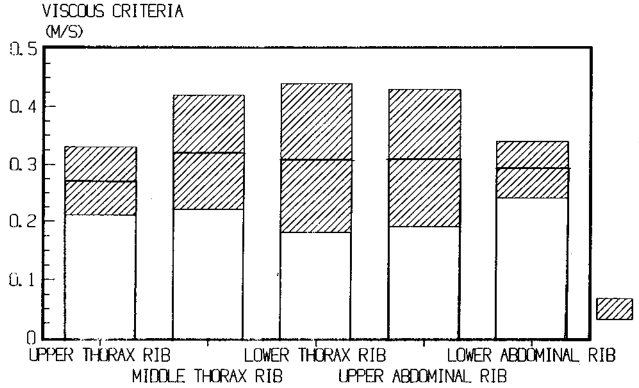


Figure 11. Average Values of Top Chest V*C from Four Identical Tests Conducted With a Wood Bumper in the Door

Test series 3—Evaluation of dummy responses at different test speeds

The two dummy types, SID and BioSID, were compared by running test series no 3. In this series was the impact velocities were changed between the tests. The test velocities were 6, 8, 10, 11 and 12 m/s. Both dummies were tested at each velocity. These tests were conducted without the wood bumper in the door. No test data is available from the 6 m/s test with BioSID.

It is obvious when comparing the TTI values for different impact velocities that there is a direct correlation of generated TTI values between the two dummy types. In each of the velocities compared the generated TTI value is 20% higher with the BioSID. This correlation is dependent on difference in ribcage mass and the vehicle tested, the stiffness of interior trim and side structure.

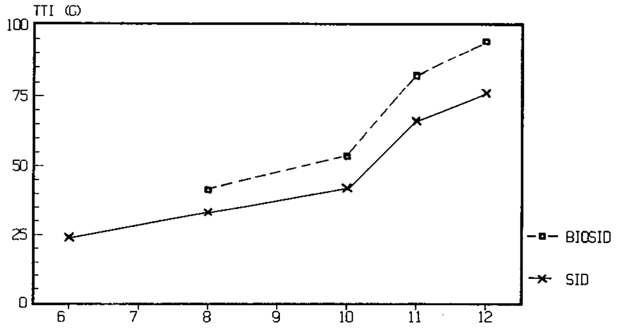


Figure 12. TTI Values from Tests With SID and BioSID With Different Impacting Sled Velocities

It is remarkable that the compression of thorax rib on the SID dummy is not influenced by the velocity tested. This is not the case with the BioSID where maximum rib compression shows a linear dependency with the velocity (Figure 13a).

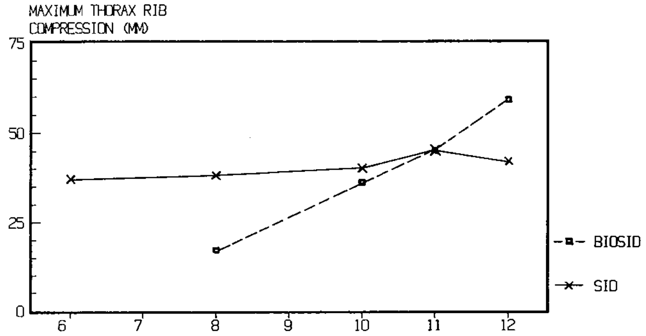


Figure 13a. Generated Maximum Thorax Rib Compression Values from Tests With SID and BioSID With Different Impacting Sled Velocities

Figure 13b below shows maximum pelvis acceleration from the tests.

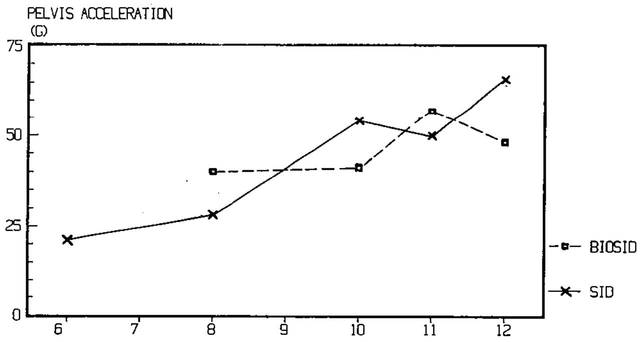


Figure 13b. Generated Maximum Pelvis Acceleration Values from Tests With SID and BioSID at Different Impacting Sled Velocities (FIR Filtrated)

The understanding of the results above must be that there is not a noticeable difference in the pelvis acceleration readings between the dummy types.

As shown earlier the pelvis acceleration has the largest scattering and it is possible to match the value from one dummy within the standard deviation of the other dummy at each velocity.

Test series 4—Evaluation of dummy responses to a stiff armrest

In test series no 4 the responses to changes in trim stiffness of the two dummy types were examined. Tests were conducted with a door trim were the armrest was stiffened and extended into the car. The intention was to evaluate the result if more load is transmitted into the abdomen. A reference test with standard Saab 9000 door trim was conducted with the SID. The results from the BioSID are presented below in Figures 14 and 15.

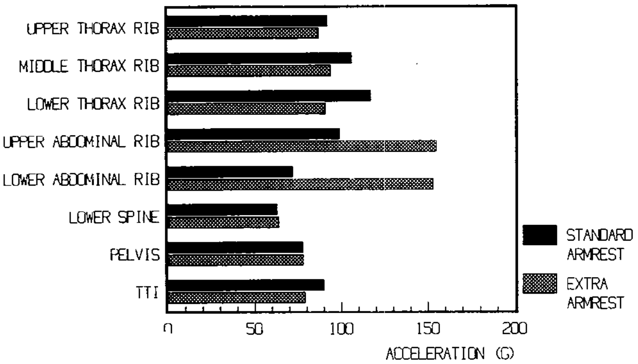


Figure 14. Maximum Acceleration Values from Tests With BioSID With Different Armrest Configurations (FIR Filtrated)

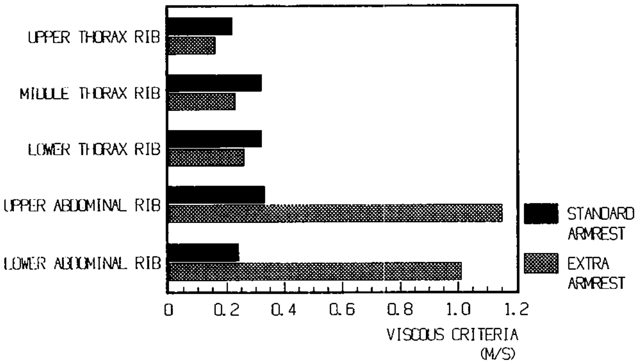


Figure 15. Maximum Rib V*C Values from Tests With BioSID With Different Armrest Configurations (FIR Filtrated)

A stiffened armrest decreases maximum acceleration and V*C in the thorax ribs. Maximum acceleration and V*C are considerably increased in the abdominal ribs as expected. The results indicates that it is possible to lower the TTI value by increasing the amount of load transmitted into the abdomen. The same tests were conducted with the SID and the results are presented in Figure 16 below. All of the peak acceleration values are lower with the stiffened armrest, the TTI value is lowered by 7%.

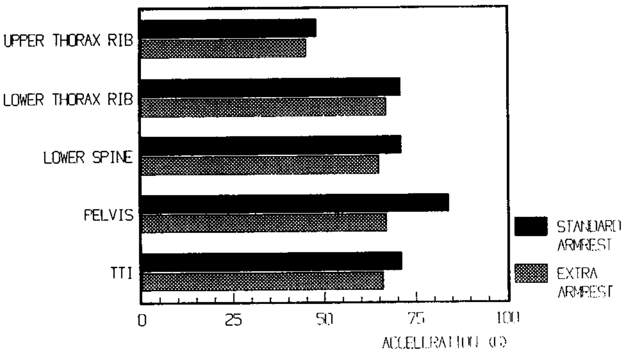


Figure 16. Maximum Acceleration Values from Tests With SID With Different Armrest Configuration (FIR Filtrated)

To summarize the results from the tests with the stiffened armrest it is possible to lower the TTI value with the SID by using a stiff armrest design. But the same armrest design increased the V*C value in the abdomen by approximately three times with the BioSID.

Discussion

The sled test method presented in this paper is useful to simulate dummy behavior in full scale testing.

The scattering of dummy results is low in the sled test method. The standard deviation is only 4% for peak rib acceleration but higher for pelvis acceleration.

The TTI value has a scattering with a standard deviation of only 3%.

Peak thorax compression and V*C have higher scattering with this test method.

Increased pelvis load increases the TTI value but decreases peak thorax compression and V*C. To increase pelvis load, but keeping it under 100 G, must be an advantage for the injury risk in the chest. Chest compression and V*C is the best measurements to predict the risk for chest injuries.

Chest compression in the SID dummy is not sensitive to different velocities. This must be considered as a not realistic behavior of the dummy. Chest compression values from this dummy does not predict risk for chest injuries.

Using the SID dummy the TTI value can be reduced by designing a stiffer armrest. This increases the load on abdomen with a dramatic increase of compression and V*C measured in abdomen in BioSID.

At SAAB we are convinced that by only using the SID in development tests in order to improve side impact test performance there is a risk to reduce field accident performance for side impacts. With this in mind we prefer to use the BioSID in our development tests for new car models.

Appendix. Peak Dummy Values from the Tests

Test serie no. Velocity (m/s) Bumper in door Trim Dummy	FULL SCALE TEST SAAB 9000 BioSID	1(1) 11 No standard BioSID	1(2) 11 Yes standard BioSID	2(1) 11 Yes standard BioSID	2(2) 11 Yes standard BioSID
THORAX					
UPPER SPINE ACC. (FIR) G	64	67	51	62	57
UPPER RIB ACC. (FIR) G	115	95	92	85	87
UPPER RIB COMP. mm	31	39	26	30	32
UPPER RIB V*C m/s	0.32	0.53	0.22	0.31	0.34
MIDDLE SPINE ACC.(FIR) G	54	55	53	59	57
MIDDLE RIB ACC. (FIR) G	104	109	106	111	110
MIDDLE RIB COMP. mm	31	44	31	32	35
MIDDLE RIB V*C m/s	0.29	0.63	0.32	0.37	0.41
LOWER SPINE ACC. (FIR) G	55	45	63	66	68
LOWER RIB ACC. (FIR) G	99	119	117	128	124
LOWER RIB COMP. mm	29	45	29	32	32
LOWER RIB V*C m/s	0.22	0.64	0.32	0.41	0.40
TTI G	85	82	90	97	96
ABDOMEN					
UPPER RIB ACC. (FIR) G	58	61	99	97	114
UPPER RIB COMP. mm	29	28	30	33	35
UPPER RIB V*C m/s	0.22	0.27	0.33	0.32	0.43
LOWER RIB ACC. (FIR) G	86	73	72	90	106
LOWER RIB COMP. mm	34	27	28	32	32
LOWER RIB V*C m/s	0.34	0.20	0.24	0.30	0.34
PELVIS ACC. (FIR) G	68	57	78	75	78

Test serie no. Velocity (m/s) Bumper in door Trim Dummy	2(3) 11 Yes standard BioSID	3(1) 6 No standard SID	3(2) 8 No standard SID	3(3) 10 No standard SID	3(4) 11 No standard SID
THORAX					
UPPER SPINE ACC. (FIR) G	66	—	—	—	—
UPPER RIB ACC. (FIR) G	94	20	35	42	47
UPPER RIB COMP. mm	26	—	—	—	—
UPPER RIB V*C m/s	0.21	—	—	—	—
MIDDLE SPINE ACC.(FIR) G	56	—	—	—	—
MIDDLE RIB ACC. (FIR) G	104	—	—	—	—
MIDDLE RIB COMP. mm	25	37	38	40	45
MIDDLE RIB V*C m/s	0.19	0.18	0.29	0.40	0.52
LOWER SPINE ACC. (FIR) G	73	25	28	41	63
LOWER RIB ACC. (FIR) G	120	22	37	44	68
LOWER RIB COMP. mm	18	—	—	—	—
LOWER RIB V*C m/s	0.12	—	—	—	—
TTI G	96	24	33	42	66
ABDOMEN					
UPPER RIB ACC. (FIR) G	105	—	—	—	—
UPPER RIB COMP. mm	21	—	—	—	—
UPPER RIB V*C m/s	0.14	—	—	—	—
LOWER RIB ACC. (FIR) G	101	—	—	—	—
LOWER RIB COMP. mm	—	—	—	—	—
LOWER RIB V*C m/s	—	—	—	—	—
PELVIS ACC. (FIR) G	94	21	28	54	50

Test serie no. Velocity Bumper in door Trim Dummy	3(5) 12 No standard SID	3(6) 8 No standard BioSID	3(7) 10 No standard BioSID	3(8) 11 No standard BioSID	3(9) 12 No standard BioSID
THORAX					
UPPER SPINE ACC. (FIR) G	—	30	54	67	66
UPPER RIB ACC. (FIR) G	67	33	60	95	131
UPPER RIB COMP. mm	—	15	30	39	54
UPPER RIB V*C m/s	—	0.06	0.25	0.53	0.99
MIDDLE SPINE ACC.(FIR) G	—	27	45	55	58
MIDDLE RIB ACC. (FIR) G	—	41	61	109	131
MIDDLE RIB COMP. mm	42	17	35	44	59
MIDDLE RIB V*C m/s	0.47	0.07	0.32	0.63	1.11
LOWER SPINE ACC. (FIR) G	63	31	38	45	54
LOWER RIB ACC. (FIR) G	88	51	68	119	135
LOWER RIB COMP. mm	—	16	36	45	59
LOWER RIB V*C m/s	—	0.06	0.32	0.64	1.07
TTI G	76	41	53	82	94
ABDOMEN					
UPPER RIB ACC. (FIR) G	—	42	68	61	112
UPPER RIB COMP. mm	—	8	23	28	40
UPPER RIB V*C m/s	—	0.03	0.14	0.27	0.55
LOWER RIB ACC. (FIR) G	—	56	57	73	126
LOWER RIB COMP. mm	—	11	23	27	40
LOWER RIB V*C m/s	—	0.06	0.12	0.20	0.53
PELVIS ACC. (FIR) G	66	40	41	57	48

Test serie no. Velocity Bumper in door Trim Dummy	4(1) 11 Yes arm rest BioSID	4(2) 11 Yes standard SID	4(3) 11 Yes arm rest SID
THORAX			
UPPER SPINE ACC. (FIR) G	53	—	—
UPPER RIB ACC. (FIR) G	87	48	45
UPPER RIB COMP. mm	22	—	—
UPPER RIB V*C m/s	0.16	—	—
MIDDLE SPINE ACC.(FIR) G	57	—	—
MIDDLE RIB ACC. (FIR) G	94	—	—
MIDDLE RIB COMP. mm	27	43	41
MIDDLE RIB V*C m/s	0.23	0.41	0.30
LOWER SPINE ACC. (FIR) G	64	71	65
LOWER RIB ACC. (FIR) G	91	71	67
LOWER RIB COMP. mm	28	—	—
LOWER RIB V*C m/s	0.26	—	—
TTI G	79	71	66
ABDOMEN			
UPPER RIB ACC. (FIR) G	155	—	—
UPPER RIB COMP. mm	65	—	—
UPPER RIB V*C m/s	1.15	—	—
LOWER RIB ACC. (FIR) G	153	—	—
LOWER RIB COMP. mm	61	—	—
LOWER RIB V*C m/s	1.01	—	—
PELVIS ACC. (FIR) G	78	84	67

S5-O-19

A Dynamic Test Method for a Car's Interior Side Impact Performance

Anders Öhlund, Venti Saslecov
Volvo Car Corporation

Abstract

This paper gives a general description of a dynamic test method for development of a car's interior towards improved side impact performance. It also describes an application and some advantages of the test method. The background and needs for this method are to:

- enable development of the interior of a car before the body is available in a new car concept.
- reduce the number of full-scale tests.
- reduce development time.
- reduce the needs of expensive test equipment.

In short, the method is based on a small moving barrier which carries the trim panels mounted on a door and side structure bullet-substitute. Any available side impact dummy can be used in the method. The dummy is placed in the seat, which is positioned on the ground, via a special frame. To run the test, the moving barrier is accelerated up to a chosen "dummy impact velocity" before it impacts on the dummy and seat.

Preliminary findings show the test method to have good conformity with a full-scale test, both in dummy response and the behaviour of the interior components. Apart from the possibility of easily evaluating the advantages of improved design of regarding the trim panels, seat and padding, the method can be used to determine the effects of different bullets and structural performance.

Introduction/Background

The increased interest in side collisions around the world has meant that the need for evaluation methods at different levels has also increased. There are a number of different ways to evaluate a car's performance in side collisions. These can be divided up into four groups:

- Full-scale tests
- Component and sub-system tests
- Computer simulation
- Analysis of accidents in the field.

The most common is the full-scale test, but this has become more and more costly, particularly when it refers to, for example, evaluation of a minor change to the interior.

This paper concerns the group, components and sub-system test methods. There are two main purposes for evaluating the side impact performance:

- Verification of legal requirements. This is relatively "simple", with only a few parameters which need to be measured.
- Development of own goals and authority's requirements. The costs and problems during this "engineering phase" are much greater since it requires the interpretation of large amounts of test data and analysis of performance, and where improvements need to be made.

The performance of a car during side collisions is often divided up into structural performance and an interior performance. The structural performance shall first and foremost make sure that the speed against the occupant is limited, by ensuring that penetration into the side of the car occurs in a peaceful manner and that the depth of penetration is kept small. The interior section shall limit the forces from the side of the car against the occupant during the course of the crash. This can occur by using a balanced impedance in the doors and seats. See figure 1.

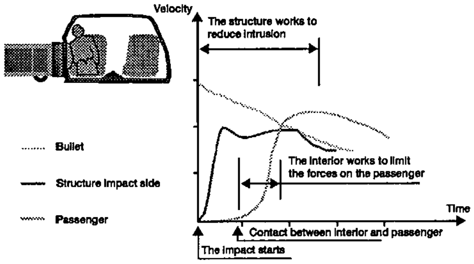


Figure 1. Basic Side Impact Dynamics in Full-scale Test

The background to the development of this test method was that Volvo needed an effective and simple method to get a better check on the stiffness of the interior. The method should primarily be used in a project where the goal of the car's structural performance was reached, but the interior still needed a certain amount of development work. The primary reasons for the choice of the method described in this paper were that the most important mechanisms of the full scale test should be retained. In addition the method should permit as quick and simple evaluations as possible.

Description of the Test Method

The test method was given the name DYNSUB test method (=DYNamic SUB-system test method), which will be used from now on in this paper. See Fig. 2.

In principle, the DYNSUB test method was developed and designed to produce the velocity to which the front seat passenger is subjected by a pre-determined combination of crash type and structural performance. In addition, the following important parameters were simulated:

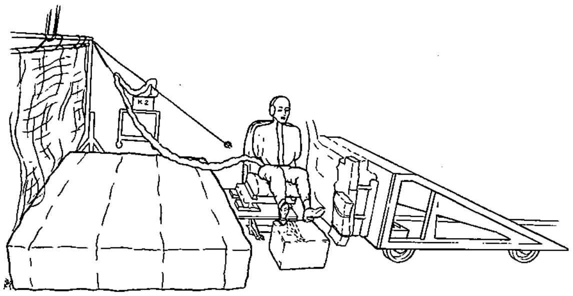


Figure 2. The DYNSUB Test Method Set-up

- Seat movement, lateral and vertical.
- Dynamic stiffness of the door which has been deformed from the outside.
- Correct movement between the seat and the door.

The test equipment was based upon three main elements:

- A small moving barrier carrying the trim panels mounted on a door and side structure bullet-substitute.
- A special frame with the seat is positioned on the ground.,
- A safety net and a large mattress which takes care of the movement of the dummy after the door impact.

The Small Moving Barrier

The barrier was equipped with a flat front plate with the measurements 1600 mm by 700 mm. The complete barrier weighed approx 650 kg. The following items were fitted to the front plate (see Fig. 3):

- The door substitute. This was made up of a plastic casting of an inner door plate filled with a very hard foam (Araldite 35 kg m3) in order to simulate the door when deformed from the outside. The door substitute was not fitted with a glass window, since experience has shown that this does not affect the dummy response, especially not that of the chest or pelvis. The door was placed vertically. Since the door's vertical profile is very important regarding how the occupant is struck, it must be adapted so that it corresponds to that which is simulated in the full-scale test (1).
- Simulation of a partly deformed CCMC barrier. This was made up of a 150 mm thick PUR foam block (40 kg m3) and was placed between the front plate and the plastic casting's flat rear side. Adjustment of the door substitute's stiffness was done using computer simulation and static pressure on the substitute.
- A car body structure section, containing A-pillar, B-pillar and bottom rail. This section was chosen from an earlier frontally crashed car, and surrounded the door in the same way as in a car. It was firmly fixed to the barrier's front plate.
- The door panel, which was the test object, was fitted on the door substitute.

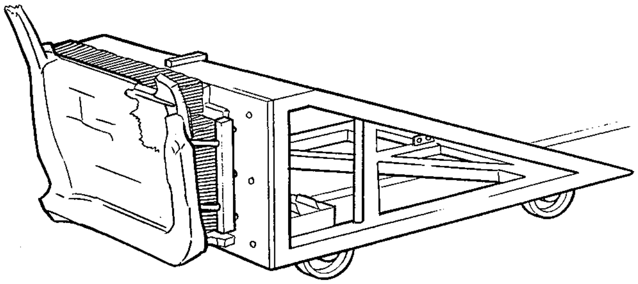


Figure 3. The DYNSUB Test Method Barrier

The Seat Frame

The seats which were used were real car seats. These were fitted on a special fixture which was placed directly on the floor of the test hall.

The fixture was made up of two sections:

- An upper section which replaced the seat's normal slide rails. This was to achieve an even surface under the seat.
- A lower section with the purpose of giving the seat a real pattern of movement during the test. This was achieved by wedges on which the upper section rested and was guided. This way the seat received a downward movement on the impact side and upward movement on the far side. In addition, the four "legs" consisting of car jacks made it easy to adjust the height and angle of the seat.

No seat belt system has been used in the DYNSUB test method, since the belt system does not allow for this to be fitted in a simple manner. Earlier investigations have shown that belts do not affect the dummy's chest and pelvis responses in side collisions (2).

Two aluminum, honeycomb blocks were fitted to the impact side seat cushion, one front and one back. Their purpose was to produce a correct relative movement between the seat and door (method parameter 4), and to give the seat the correct lateral speed. The blocks each had a thickness of 100 mm and a stiffness of 6 kN. Both the thickness and the stiffness of the blocks required adjusting during the fine tuning of the method (see Fig. 4).

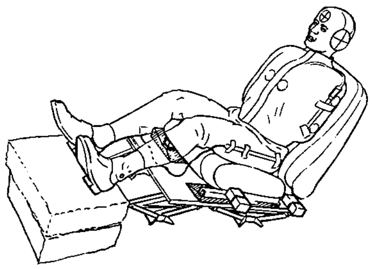


Figure 4. The Seat Frame

The Retension Arrangement

A vertical safety net was placed across the direction of the dummies' movement for the purpose of eliminating damage which can occur on the dummy and its cables after the course of the test. A large mattress was spread out on the floor in front of the net for the same purpose.

A brake cable was fitted right at the back of "the small barrier". The length of the cable was adjusted so that the barrier was braked 500 mm after it had come into contact with the dummy seat. With this arrangement the brake distance was approximately 2 metres.

This design of test equipment was the result of a number of modifications, mainly on "the seat frame" which in the beginning gave an incorrect movement.

Excitation

To run the test, the moving barrier is accelerated up to a velocity approximately 1 m s above the chosen test velocity. The velocity of the barrier during the course of the test is, on the whole, decreasing, but during the time for the contact against the dummy it is relatively constant (see Fig. 5).

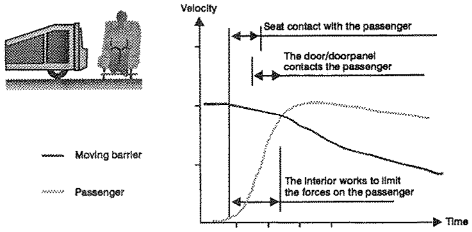


Figure 5. Typical Dynamics of DYNSUB Test Method

In order to create a correct simulation of a full-scale test, in this case car-to-car side collision, the profile of the structure's penetration velocity must be re-created in a similar manner (3).

Measurements/Analyses

The DYNSUB method has primarily used the US-SID dummy. Modifications have been done since there are no possibilities for reading of force distribution in the pelvis in the original design. The pelvis was divided into two parts with a vertical incision, see Fig. 6. These are connected with three load cells, named as follows:

- Iliac wing rear
- Iliac wing front
- Sacrum

The modifications were not done in any strict scientific way but nevertheless turned out to be of great use in the analysis in the future tests.

In order to ensure that the method is comparable to the full-scale test more parameters than just the injury criteria must be taken into consideration. The parameters were divided into two groups:

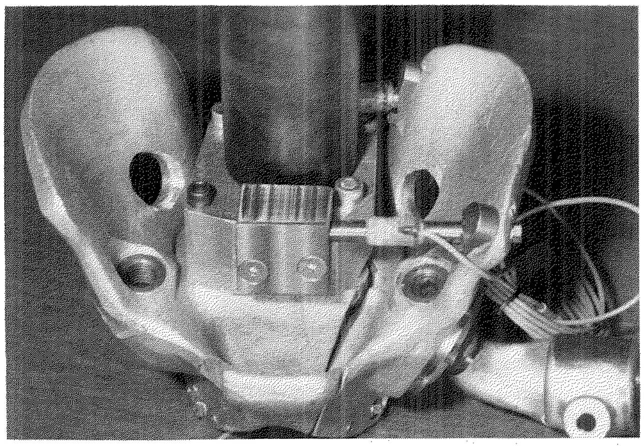


Figure 6. Modified US-SID Pelvis

- Method parameters
- Result parameters

Method Parameters

The method parameters which have been considered are the following:

- Test velocities
  - The Mean Contact Velocity, MCV, at chest height. This is defined as the penetrated side's (B-pillar) average speed during 20 ms from the time of contact between the door panel and chest. 20 ms is the normal time for the dummy's impact cycle (3).
  - The Mean Contact Velocity, MCV, at pelvis height. This is defined in a similar way as 1.1, but based on the impact point of the hip.
- Seat movement
  - The seat cushion's lateral movement as a factor of time, from the time point "0 ms" until the maximum criteria in the dummy occur.
  - The seat cushion's vertical movement as a factor of time on the impact side, from the time point "0 ms" until the maximum criteria in the dummy occur.
- Dynamic stiffness of the door substitute
  - Stiffness of the chest impact area.
  - Stiffness of the pelvis impact area.
- The seat and door's relative movements
  - The seat cushion's lateral movement relative to the B-pillar.
  - The seat backrest's lateral movement relative to the B-pillar.
- Dummy impact pattern against the door panel. A simple technique is used to register this. Stickers placed on the dummy fastened on the door panel during impact. See figure 7.
  - The impact pattern for the chest, a deviation of ±20 mm horizontally and vertically from the pattern measured before the test, in order that the test be regarded as OK.
  - The impact pattern for the pelvis, with the same tolerance as for the chest.

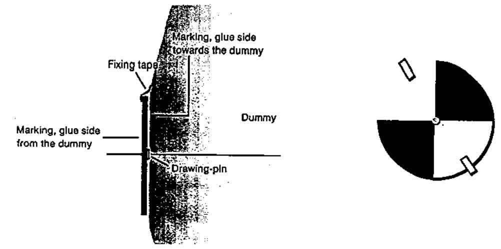


Figure 7. Marking the Pattern of Impact

Result Parameters

The choice of result parameters depends upon the type of dummy used. In order to analyse the results the following parameters are used as a base:

- Chest response
  - TTI-value calculated from upper rib.
  - TTI-value calculated from lower rib.
  - Left upper rib maximum.
  - Left lower rib maximum.
  - Upper spinal maximum.
  - Lower spinal maximum.
- Pelvis response
  - Lateral acceleration maximum.
  - Total force maximum.
  - Iliac wing rear force maximum.
  - Iliac wing front force maximum.
  - Sacrum force maximum.
- Time of events
  - Contact between trim panel and chest.
  - Contact between trim panel and pelvis.
  - Left upper rib maximum.
  - Left lower rib maximum.
  - Upper spinal maximum.
  - Lower spinal maximum.
  - Pelvis lateral acceleration maximum.
  - Pelvis total force maximum.

In addition to a comparison of parameters, an extensive study was also carried out into the shapes of the curves for the dummy response in order to understand the dynamics.

Development of the Method

The primary aim for the development of the DYNSUB test method was to make it possible in an effective, simple and quick way to solve some specific problems regarding the interior energy absorption. It should also be able to be utilized for future needs and form a base for further development of component and sub-system test methods.

An important condition during development of the method was that it should have simple and uncomplicated rigging. Wherever possible the method should use the existing in-house full-scale track. In the past, and at present, our sled test facility has been heavily overloaded with other tests.

Reference Tests

The method development was based on a "reference test". The reference test was a full-scale test according to a test method used by Volvo. The full-scale method can be described as a modified CCMC method (4).[1] A US-SID dummy was placed in the driver's position (see Fig. 8).

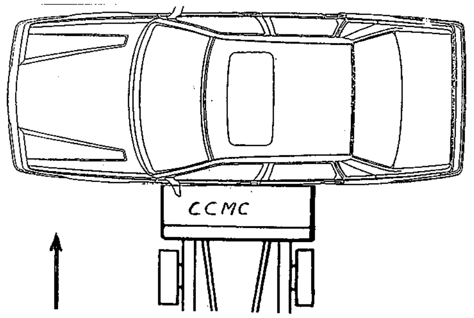


Figure 8. The CCMC Test Configuration

The results from the reference test were as follows:

- Structural performance was satisfactory. Penetration speed (measured on the B-pillar during contact of the interior with the occupant) was 10.5 m/s at chest height and 9.8 m s at pelvis height. The level of penetration speed in the time was relatively constant, there was a slight increase in speed during the contact. Penetration of the cabin was approx. 300 mm.
- The interior performance of the car was unsatisfactory, since the dummy values were high. Using supporting information from computer simulations it was judged that there was a potential to lower the criteria in the dummy by using a better balanced impedance for the interior, with retained structural performance.

The interior sections of interest were:

- The door panel
  - The design (relative position of the surfaces)
  - The deformation properties
  - Attachment to the door
  - The stiffness
- Components within the door panel. Components which cannot be deformed were found within the impact area around the occupant. This counteracted a full utilization of the available deformation stretch in the door panel.
- The structure of the seats. The backrest frame of the seat came into contact with the dummy's spine, which was indicated by both cuts in the seat foam and a very rapid increase in the acceleration of the spine during the moment when seat contact began. In addition there were suspicions that the seat's frame made contact with the pelvis in an unsatisfactory

---

[1] Since the introduction of the DYNSUB test method, the NHTSA has published their updated version of FMVSS 214, which differs from Volvo's test method in several aspects. The measuring results presented in this paper cannot be interpreted as if they were measured according to FMVSS 214's test procedure.

manner. It was, however, impossible to prove this based on the results from these tests.

In addition to the criteria measurements in the dummy, a number of other measurements and observations were carried out during the course of the crash. Included in these items were: acceleration and film measurements of the penetration of the B-pillar and side door, contact times for dummy interior, door deformation and film measurements of the movement of the seat.

Trimming of the DYNSUB Test Method

It is crucial that the results are verified in some way against an accepted evaluation procedure, in this case full-scale tests, in order to validate the results of a component test method or a sub-system test method. Approximately 5 tests were needed to be run in order to trim the method. Two examples of the trimming series are given below (see Tables 1 and 2).

- R1: Reference test as described earlier.
- T1: Tuning test 1. Test objects the same as in reference test. The movement of the seat did not comply fully with that in the reference test.
- T2: Tuning test 2. Test objects the same as in reference test and test T1. The movement of the seat complied with that in the reference test.

Table 1. Conditions for Trimming

Method parameters	R1 Ref. test	T1 Tuning test	T2 Tuning test
1 VELOCITIES			
1.1 MCV Chest	10.5 m/s	9.5 m/s	10.3 m/s
1.2 MCV Pelvis	9.8 m/s	9.2 m/s	10.0 m/s
2 SEAT MOVEMENT			
2.1 Lateral	180 mm	150 mm	190 mm
2.2 Vertical	30 mm downwards	15 mm upwards	30 mm downwards
3 DOOR STIFFNESS			
3.1 The chest impact area	- -	400 kN/m	400 kN/m
3.2 The pelvis impact area	- -	650 kN/m	650 kN/m
4 SEAT REL. DOOR			
4.1 Seat lateral	90 mm	80 mm	100 mm
4.2 Seat backrest lateral	110 mm	95 mm	120 mm

Table 2. Results of Trimming

Result parameters	R1 Ref. test	T1 Tuning test	T2 Tuning test
1 CHEST RESPONSE			
1.1 TTI upper rib	103 G	93 G	94 G
1.2 TTI lower rib	117 G	89 G	104 G
1.3 Left upper rib	79 G	98 G	71 G
1.4 Left lower rib	107 G	88 G	91 G
1.5 Upper spinal	98 G	105 G	83 G
1.6 Lower spinal	127 G	89 G	116 G
2 PELVIS RESPONSE			
2.1 Lateral acceleration	133 G	91 G	122 G
3 TIME OF EVENTS			
3.1 Trim/chest contact	18 ms	15 ms	12 ms
3.2 Trim/pelvis contact	21 ms	18 ms	15 ms
3.3 Upper rib max	32 ms	27 ms	21 ms
3.4 Lower rib max	30 ms	27 ms	23 ms
3.5 Upper spinal max	39 ms	37 ms	38 ms
3.6 Lower spinal max	33 ms	30 ms	26 ms
3.7 Pelvis lat. max	36 ms	26 ms	25 ms

Analysis Trimming

The trimming consisted primarily of adjustment of the seat's vertical and lateral movement in relation to the door.

The test speed in test T1 was almost 1 m s too low, and in addition the vertical movement of the seat was upwards. This produced a relatively lower response in the dummy throughout the course of the test. The seat affected the pelvis more noticeably than in the reference test which amongst other things can be seen in the acceleration level of approx. 25 G when the door panel starts to come into contact with the pelvis.

In principle the trimming test T2 produced the same response in the dummy as the reference test. This shows the accuracy of the method in relation to the full-scale test.

Using the Method

The DYNSUB test method has been used to study a large number of modifications, etc. This paper shows sections of two test series connected to the reference test.

- Evaluation of the effect of the seat on the occupant.
- Evaluation of door panel modifications

Evaluation of the Effect of the Seat on the Occupant

Strong suspicions existed in the reference test that the effect of the seat contributed to increase the maximum loading on the occupant. In these tests the door section on the barrier's front plate was dismantled. This was done to isolate the effect of the seat's influence by significantly delaying the impact from the door. Instead, a 70 mm thick foam block was fitted on the barrier's front plate in order to protect the dummy from injuries when the course of the seat's influence was over. In this series the MCV was calculated from the moment when the seat moves 20 mm laterally, over a period of 20 ms (see Tables 3 and 4).

A1 The seat had the same status as in the reference test, but an "incorrect" vertical seat movement, upwards instead of downwards.

A2 The seat had modifications on the backrest frame. This consisted of the backrest frame's hard sections being moved backwards 25 mm relative to the dummy's seating position. The seating position was retained by increasing the thickness of the foam in the backrest. The seat movement was the same as in test "A1" "incorrect".

A3 The seat had the same modifications as in test "A2." The seat movement in this test complied with that in the reference test.

Analysis of Test Series A

The analysis of "series A" shows that the seat can have a very significant effect on the occupant in a side collision, primarily in the pelvis and the spine.

Table 3. Conditions for Test Series A

Method parameters	A1	A2	A3
1 VELOCITIES 1.1 MCV Chest	10.0 m/s	9.8 m/s	9.8 m/s
1.2 MCV Pelvis	10.0 m/s	9.8 m/s	9.8 m/s
2 SEAT MOVEMENT 2.1 Lateral	200 mm	230 mm	240 mm
2.2 Vertical	20 mm upwards	20 mm upwards	30 mm downwards
3 DOOR STIFFNESS 3.1 The chest impact area	No door in test	No door in test	No door in test
3.2 The pelvis impact area	- " -	- " -	- " -
4 SEAT REL. DOOR 4.1 Seat lateral	100 mm	110 mm	105 mm
4.2 Seat backrest lateral	120 mm	125 mm	115 mm

Table 4. Results of Test Series A

Result parameters	A1	A2	A3
1 CHEST RESPONSE 1.1 TTI upper rib, *	54 G	31 G	Approx. 14 G
1.2 TTI lower rib, *	58 G	38 G	18 G
1.3 Left upper rib, *	46 G	23 G	Approx. 10 G
1.4 Left lower rib, *	53 G	36 G	20 G
1.5 Upper spinal, *	49 G	21 G	Approx. 5 G
1.6 Lower spinal, *	62 G	39 G	17 G
2 PELVIS RESPONSE 2.1 Lateral acceleration, *	87 G	90 G	62 G
3 TIME OF EVENTS 3.1 Trim/chest contact	34 ms	34 ms	32 ms
3.2 Trim/pelvis contact	33 ms	34 ms	31 ms
3.3 Upper rib max	33 ms	31 ms	35 ms
3.4 Lower rib max	35 ms	31 ms	35 ms
3.5 Upper spinal max	31 ms	32 ms	32 ms
3.6 Lower spinal max	31 ms	34 ms	33 ms
3.7 Pelvis lat. max	26 ms	26 ms	27 ms

(*) Before "3.1" and "3.2" respectively.

Regarding the pelvis, it was shown that the effect was primarily governed by the vertical movement of the seat during this lateral movement. The seat's effect became considerably less with a "reference-like seat movement", but still apparent.

In order to evaluate the contribution of the seat in the reference test, the pelvis acceleration level in test A3 should be read at the moment when the seat's lateral movement relative to the pelvis complies with the movement in the reference test during maximum pelvis acceleration. This means that the effect of the seat in the reference test can be estimated as approx. 20 G. If, instead, the vertical seat movement had been rising, then the effect of the seat on the pelvis acceleration would have been approx. 40 G. The total effect of the seat on the pelvis criteria depends on the time relationship for other contacts with the pelvis, primarily the contact with the door panel. Early seat impact should probably in most cases be positive, whilst a late impact risks producing a parallel force to the dominating contact from the door panel. It should be emphasized that in all the tests, the design of the seat did not produce any "hooking", but the seat contact which occurred was caused by friction forces.

The dummy's spine is significantly affected by the seat of the design in the reference test. The seat's vertical movement is also significant here, but not to the same extent as for the pelvis.

By introducing a very limited modification, the maximum possible effect of the seat on the spine could in principle be halved.

Evaluation of Door Panel Modifications

These tests were run with modified seats according to the description above ("test A3"), together with "real" seat movement according to "test A3". The test method for test series B was complete with the same construction as during trimming (see Tables 5 and 6).

B1 In this test a hard component within the panel was dismantled and the stiffness of the panel in the chest area was adjusted.

B2 In addition to the measures according to test "B1" the panel in the pelvis area was adjusted regarding the panel surface's position and stiffness.

B3 Same as test "B2" but with a slightly different stiffness in the panel.

Table 5. Conditions for Test Series B

Method parameters	B1	B2	B3
1 VELOCITIES 1.1 MCV Chest	10.5 m/s	10.2 m/s	10.6 m/s
1.2 MCV Pelvis	10.2 m/s	9.9 m/s	10.3 m/s
2 SEAT MOVEMENT 2.1 Lateral	210 mm	190 mm	215 mm
2.2 Vertical	35 mm downwards	30 mm downwards	25 mm downwards
3 DOOR STIFFNESS 3.1 The chest impact area	400 kN/m	400 kN/m	400 kN/m
3.2 The pelvis impact area	650 kN/m	650 kN/m	650 kN/m
4 SEAT REL. DOOR 4.1 Seat lateral	100 mm	100 mm	105 mm
4.2 Seat backrest lateral	125 mm	125 mm	125 mm

Table 6. Results of Test Series B

Result parameters	B1	B2	B3
1 CHEST RESPONSE 1.1 TTI upper rib	91 G	93 G	106 G
1.2 TTI lower rib	96 G	91 G	113 G
1.3 Left upper rib	82 G	80 G	88 G
1.4 Left lower rib	93 G	75 G	102 G
1.5 Upper spinal,	81 G	93 G	74 G
1.6 Lower spinal	100 G	107 G	123 G
2 PELVIS RESPONSE 2.1 Lateral acceleration	130 G	91 G	107 G
2.2 Total force	14.4 kN	10.6 kN	11.2 kN
2.3 Iliac wing rear	3.5 kN	4.8 kN	5.0 kN
2.4 Iliac wing front	4.2 kN	4.3 kN	3.6 kN
2.5 Sacrum	6.8 kN	2.6 kN	3.7 kN
3 EVENTS 3.1 Trim/chest contact	11 ms	10 ms	10 ms
3.2 Trim/pelvis contact	13 ms	13 ms	13 ms
3.3 Upper rib max	26 ms	19 ms	20 ms
3.4 Lower rib max	24 ms	21 ms	23 ms
3.5 Upper spinal max	35 ms	33 ms	34 ms
3.6 Lower spinal max	27 ms	25 ms	25 ms
3.7 Pelvis lat. max	26 ms	23 ms	23 ms
3.8 Pelvis force max	26 ms	25 ms	24 ms

Analysis of Test Series B

In test B1 the lower spinal acceleration was reduced by approx. 15 G, and thereby also TTI. This occurs in spite of a somewhat high test speed. The pelvis response remained at the same level as in the reference test. The force measurement in the pelvis showed that the greatest portion of the forces was led into the lower section of the pelvis via the hip-joint.

The maximum response on the pelvis was reduced dramatically in test B2, by approximately 35 G. At the same time the force dispersion in the pelvis became more even. The chest response remained at the same level as in test B1.

In test B3 the test speed was 0.4 m s higher than in test B2. This resulted in that the response from the dummy increased, primarily in the left lower rib, in the lower spine and the pelvis.

Verification of Measures in Full-scale Test

A full-scale test was run in order to further confirm the tested effects of the interior modifications in the DYNSUB test method and to verify the test method.

The verification test was carried out in the same way as the reference test, i.e. a Volvo-modified CCMC full-scale test.

Simultaneously, the verification test had been carried out on a number of modifications to the car body structure. Some of these were shown to have an unexpected, significant effect on the performance of the car's structure. Both the profile and the level of the speed of penetration differed significantly from the reference test.

The following are shown for comparison (see Tables 7 and 8):

V1 Verification test
R1 Reference test
B3 The DYNSUB test whose conditions best comply with those in the verification test.

Table 7. Conditions for Verification

Method parameters	V1 Ver. test	R1 Ver. test	B3
1 VELOCITIES			
1.1 MCV Chest	9.0 m/s	10.5 m/s	10.6 m/s
1.2 MCV Pelvis	10.5 m/s	9.8 m/s	10.3 m/s
2 SEAT MOVEMENT			
2.1 Lateral	200 mm	180 mm	215 mm
2.2 Vertical	35 mm downwards	30 mm downwards	30 mm downwards
3 DOOR STIFFNESS			
3.1 The chest impact area	--	--	400 kN/m
3.2 The pelvis impact area	--	--	650 kN/m
4 SEAT REL. DOOR			
4.1 Seat lateral	105 mm	90 mm	105 mm
4.2 Seat backrest lateral	110 mm	110 mm	125 mm

Table 8. Results of Verification

Result parameters	V1 Ver. test	R1 Ref. test	B3
1 CHEST RESPONSE			
1.1 TTI upper rib	69 G	103 G	106 G
1.2 TTI lower rib	81 G	117 G	113 G
1.3 Left upper rib	50 G	79 G	88 G
1.4 Left lower rib	74 G	107 G	102 G
1.5 Upper spinal	92 G	98 G	74 G
1.6 Lower spinal	88 G	127 G	123 G
2 PELVIS RESPONSE			
2.1 Lateral acceleration	135 G	133 G	107 G
2.2 Total force	16.0 kN	NA	11.2 kN
2.3 Iliac wing rear	5.2 kN	NA	5.0 kN
2.4 Iliac wing front	5.4 kN	NA	3.6 kN
2.5 Sacrum	5.7 kN	NA	3.7 kN
3 EVENTS			
3.1 Trim/chest contact	18 ms	18 ms	10 ms
3.2 Trim/pelvis contact	20 ms	21 ms	13 ms
3.3 Upper rib max	31 ms	32 ms	20 ms
3.4 Lower rib max	34 ms	30 ms	23 ms
3.5 Upper spinal max	45 ms	39 ms	34 ms
3.6 Lower spinal max	38 ms	33 ms	25 ms
3.7 Pelvis lat. max	39 ms	36 ms	23 ms
3.8 Pelvis force max	39 ms	NA	24 ms

Analysis of Verification

The verification test confirmed that the improvments which were strived for could be attained in a full-scale test as well.

The changed structural performance does, however, cause a dramatic change in the dummy criteria. A structural analysis was carried out with the aim of surveying the various effects of the structure modifications on the changed structure performance. This analysis meant that with the removal of the "negative" modifications, the structural performance for a front seat occupant should be:

Chest height: 9.5 m s, MCV
Pelvis height: 10.0 m s, MCV.

Earlier computer simulations have shown that there is a definite correlation between MCV Mean Contact Velocity and the dummy criteria TTI and Amax-Pelvis. Based on these simulations and experience gained from the DYNSUB testing, an estimation of the dummy criteria was carried out for the structurally analyzed car body design.

Using the newly developed DYNSUB test method, the car's side collision performance has been improved in a simple and relatively quick way.

The new total estimation gave the following results, when compared with the reference test. Most of the improvements could be attributed to the modifications which have been developed with the DYNSUB test method (see Table 9).

Table 9. Improvement via the DYNSUB Test Method

Dummy response	R1 Ref. test car	V1 Ver.test car	Car corrected for V1 structural changes
TTI (G)	117	81	90 (−23%)
Amax Pelvis (G)	133	135	105 (−21%)

Advantages with the Method

The simplicity of the method has made it possible for two engineers and a mechanic to carry out two tests per day. The method has produced sufficient information to permit a decision regarding car design changes.

The method has the potential to be developed and become a very usable development tool, particularly when coordinated in the development work with computer simulations, similar to the method used in CTP tests (5).

Adapting the Method for Various Needs

The described DYNSUB test method can be used in several different situations. Using the described method of usage as a base, the various needs can be divided up into two groups:

- Changes in car design
- Changes in test method evaluation method

The changes in design can have several causes, among other things:

A. The need to improve the interior performance (due to high dummy response values) in an existing car design, as in the described case.

B. Design or other property-dependent causes. These changes require checking in a simple and quick manner.

C. Development of new car models. It can save a lot of time and money if the interior performance can be established during early concept development, when access to complete cars is severely limited.

D. Development of new protection systems, for example side collision airbag.

The changes in test method evaluation method can, for example, be made up of some of the following examples:

A. Variation of speed severity with the view to evaluating interior performance for various crash speeds. This should be done to avoid optimization for only one speed.

B. Change of bullet. Different bullets produce different deformation of the door. This in turn affects its stiffness from the inside, which the occupant experiences. The door stiffness can be the part which dimensions the contact forces against the occupant for many car designs with a relatively ineffective interior.

C. Change of dummy.

D. Change of criteria.

If the structural performance is unknown for a "new" crash speed or if it is a question of a new car body design, it must be estimated. This can probably be done using complete car simulation or by interpolation/extrapolation of known crash speed structure performance relationship.

The important door stiffness is difficult to simulate. The method described earlier is only suitable for bullets with a flat front (for example CCMC), where the door receives a relatively even crumpling. For bullets with a marked bumper (e.g. NHTSA), another form of substitute is better. The way in which the door substitute should be geometrically designed can be determined by taking a basic view of an already crashed door, or alternatively by carrying out a "dry crash" on the drawing table computer. It should be noted that a crashed door is often not nearly as tightly packed after a test as it was during the course of the test. This makes it unsuitable to use a crashed as well as an uncrashed (undeformed) door such as the door substitute in the DYNSUB test method. A suitable principle design for the door substitute for a "bumper bullet" is to fit a deformed bumper section onto the front plate of the DYNSUB test method barrier. Additional "undeformable" components such as for example, lift motor, lock unit, door member, etc should also be fitted to the front plate. A door inner plate (as complete as possible) is then fitted over these.

Conclusion and Summary

The increased interest in side collisions around the world has meant that the need for evaluation methods at various levels has increased. The DYNSUB test method, through its simplicity, fulfills an important function by in many cases replacing expensive full-scale tests and by being a link between full-scale tests and computer simulation.

The DYNSUB test method reflects the most important mechanisms from the full-scale tests. This gives a good platform for further developing of the method for the large and varying needs which can be anticipated in the future.

Computer simulations have shown that the DYNSUB test method complies very well with full-scale tests.

The method has produced sufficient information to bring about decisions regarding car design changes.

In order to really have the benefit of the DYNSUB test method it is valuable to coordinate the tests with computer simulations.

The DYNSUB test method is far from being a fully-developed method and in the future, at Volvo, it will be made both more usable and more effective.

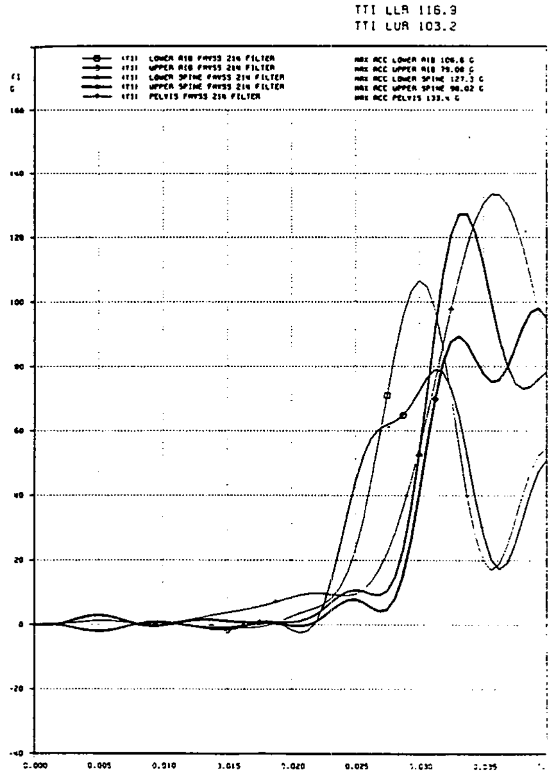
References

(1) C. A. Hobbs, The influence of Car Structure and Paddings on Side Impact Injuries. Twelfth International Technical Conference on Experimental Safety Vehicles, Göteborg 1989.

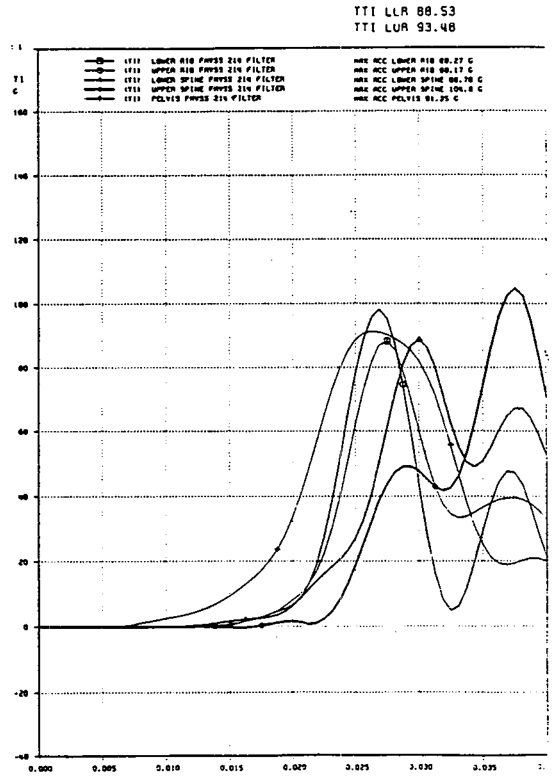
(2) N. Shimoda, Effects of Belt Restraint Systems on Occupant Protection Performance in Side Impact Crashes. Twelfth International Technical Conference on Experimental Safety Vehicles, Göteborg 1989.

(3) Y-C. Deng, The Importance of the Test Method in Determining the Effects of Door Padding in Side Impact. 33rd STAPP Car Crash Conference, Washington DC 1989.

(4) M. Nilsson, Volvo Side Impact Testing. Tenth International Technical Conference on Experimental Safety Vehicles, Oxford 1985.

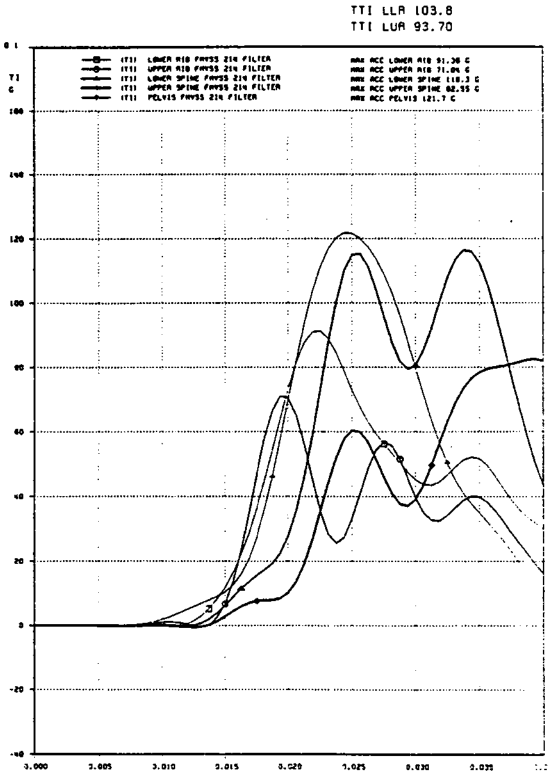


Appendix I. Dummy Response Reference Test

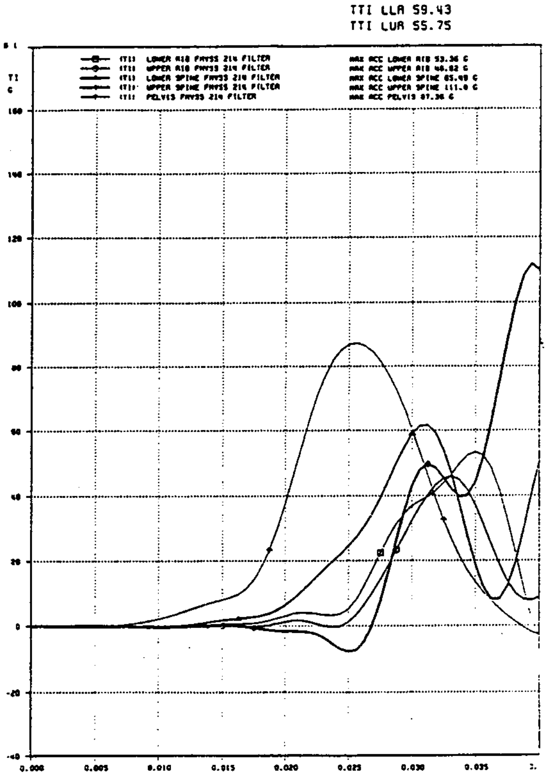


Appendix II. Dummy Response T1

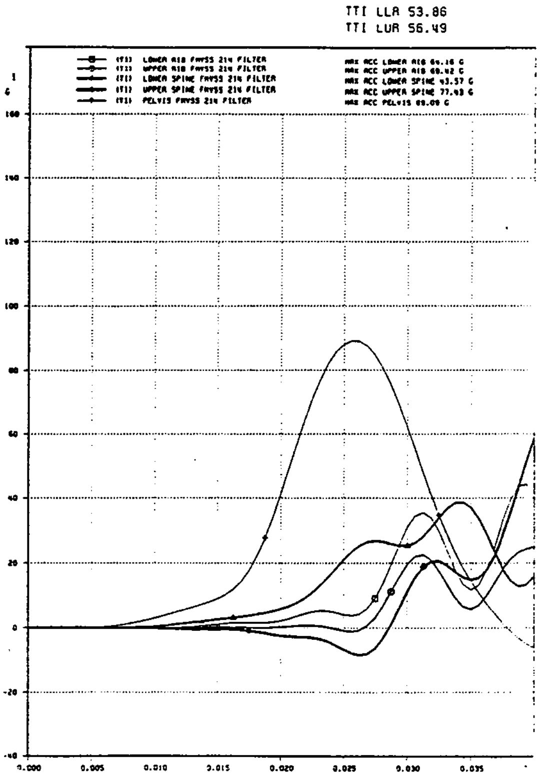
(5) B. Richter, The Composite Test Procedure (CTP)—State of the art. Twelfth International Technical Conference on Experimental Safety Vehicles, Göteborg 1989.



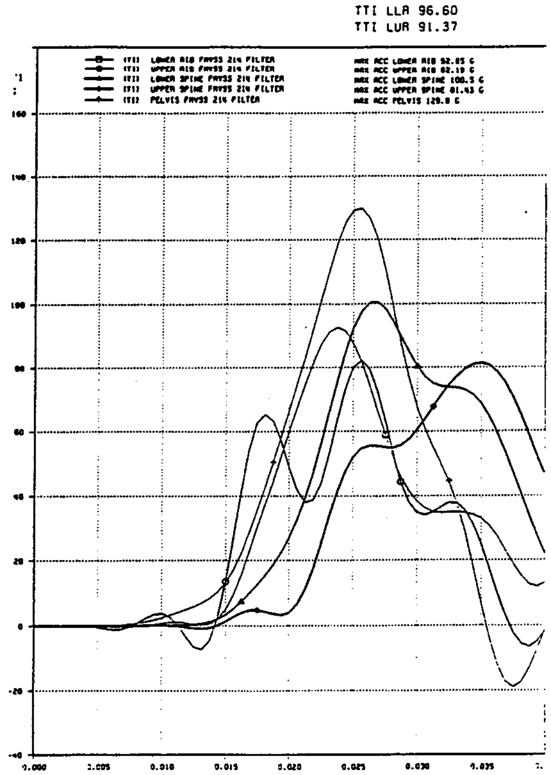
Appendix III. Dummy Response T2



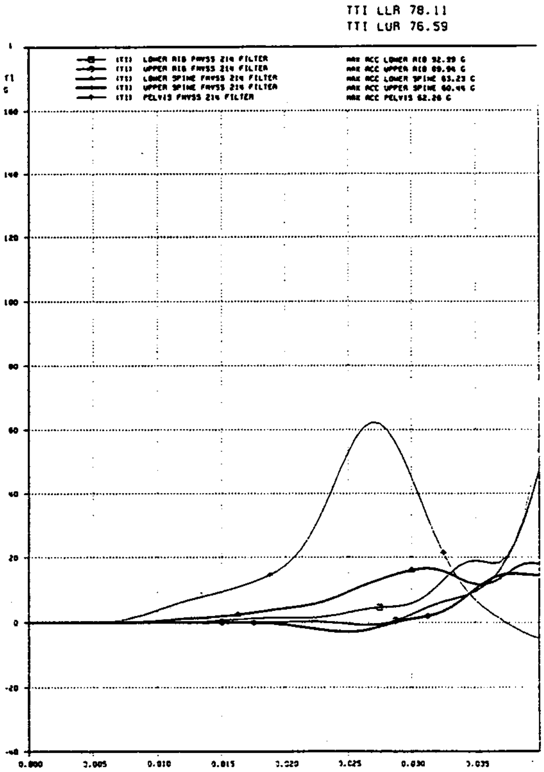
Appendix IV. Dummy Response A1



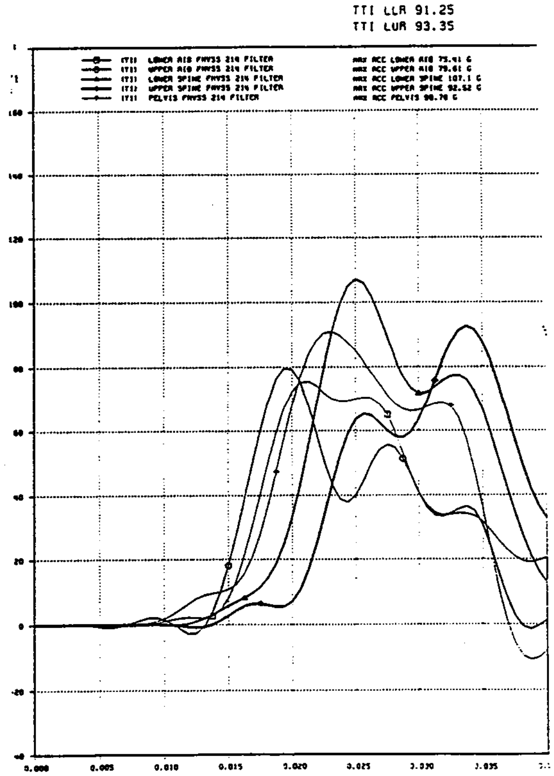
Appendix V. Dummy Response A2



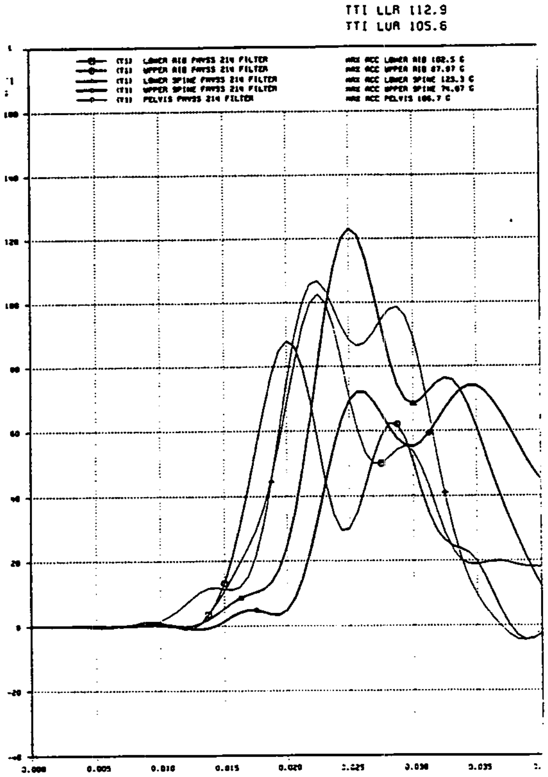
Appendix VII. Dummy Response B1



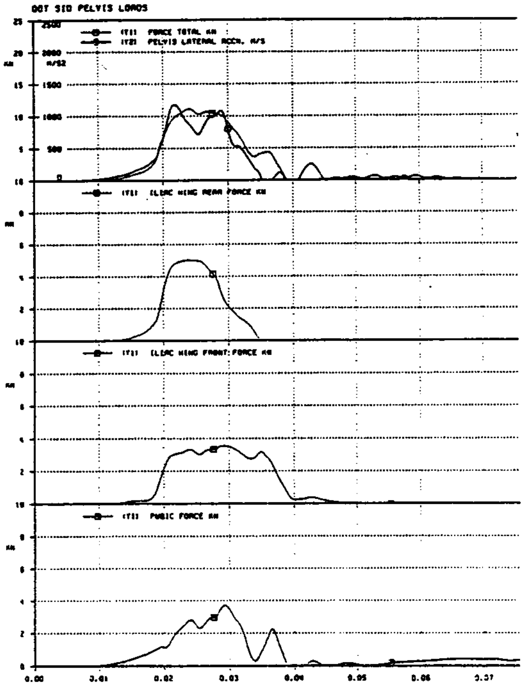
Appendix VI. Dummy Response A3



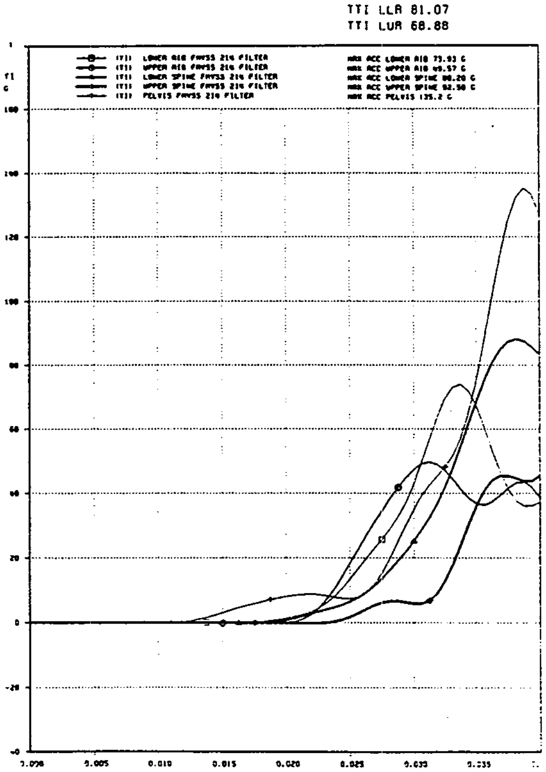
Appendix VIII. Dummy Response B2



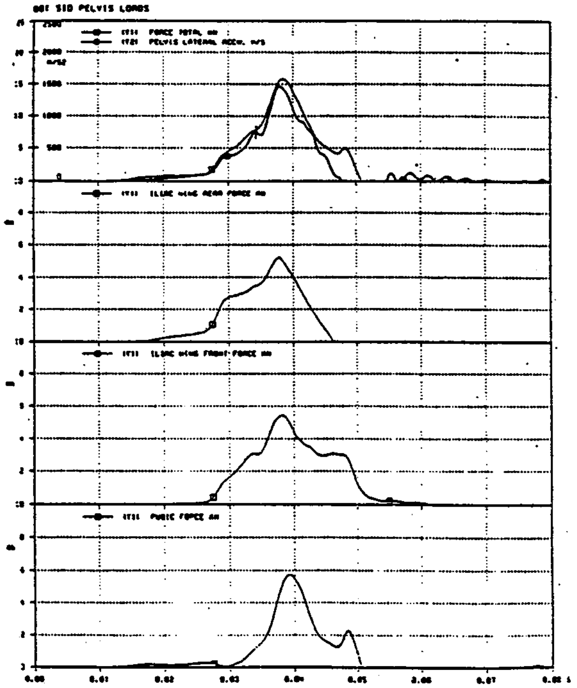
Appendix IX. Dummy Response B3



Appendix XI. Pelvis Forces B3



Appendix X. Dummy Response Ver. Test



Appendix XII. Pelvis Forces Ver. Test

S5-O-20

Door Impact Test Procedure and Crush Characteristics for Side Impact Occupant Protection

Satoshi Fukushima, Shuji Yamaguchi, Tomoyuki Fukatsu, Kenichi Asano
Toyota Motor Corporation

Abstract

This paper discusses the relationship between dummy responses and door crush characteristics in side impact tests, and shows an effective door impact test procedure for the prediction of dummy responses in full-scale side impact tests. Dummy responses in side impact tests are affected by door crush characteristics. Therefore, dummy tests using various kinds of pads in place of doors were carried out to determine the relationship between dummy responses and pad crush characteristics. Based on results of such tests, a prototype door with diversified crush characteristics was designed, and door impact tests and full-scale side impact tests were carried out. It was found that the door impact test procedure was sufficiently effective for the control and prediction of dummy responses, though complete prediction of dummy responses in full-scale side impact tests could not be done. The door impact test procedure to be introduced in this paper is one of the effective tools for the design and development of vehicles.

Introduction

FMVSS 214 in the US was revised in October, 1990, which specified dummy injury indices in full-scale side impact tests. Vehicles to be produced in September 1993 ('94 model year vehicles) and thereafter are required to meet the standard.

It was found from studies done thus far that dummy responses were affected greatly by (1) the side rigidity of the impacted vehicle, and (2) crush characteristics of the member (= door) against which the dummy impacted.

Hence, dummy impact tests which simulated full-scale side impact tests were carried out to study the effect of (2) above to determine door crush characteristics, aimed at the reduction of dummy injury indices. Moreover, the door impact test procedure was developed for the control and prediction of dummy responses in full-scale side impact tests.

This paper reports results of the study done on the rib acceleration (G) of DOT-SID (Side Impact Dummy).

Study on Force-Stroke Characteristics for Reduction of SID Rib G

Waveform of Force-Stroke Characteristics in Terms of SID Thoracic Structure

The thoracic structure of SID is to connect rib and spine by means of dumper (Figure 1). Therefore, the mass of the rib, a factor that determines the rib acceleration, increases by the amount of the reaction force from the damper, and changes as time passes. The rib effective inertia mass-time diagram will also change if the dummy-door impact velocity and door crush characteristics changes, which makes effective measures even more complex (Figure 2).

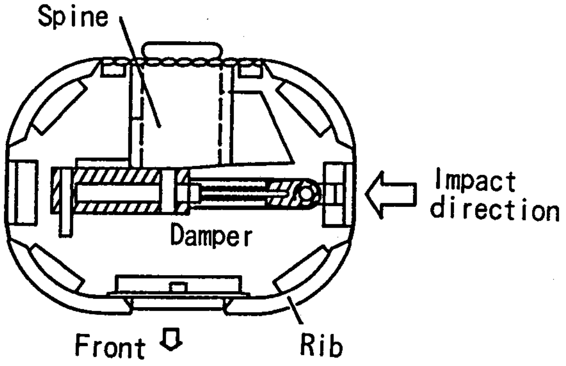


Figure 1. DOT-SID Thoracic Structure

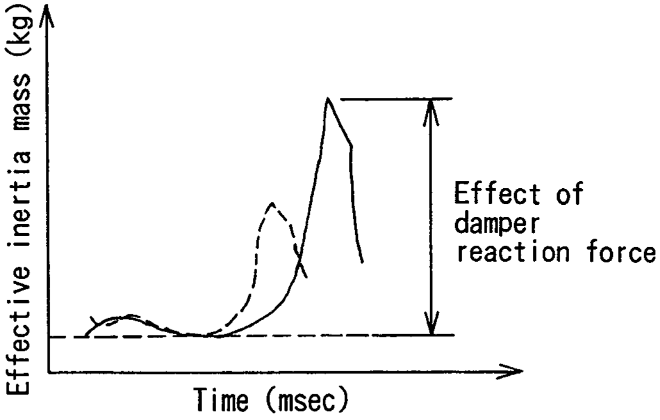


Figure 2. Rib Effective Inertia Mass-Time Diagram

In case where the change in the rib velocity is the same, it is most effective to make the rib G-time waveform trapezoidal. In order to do so, it is most effective to increase the force in the right-upward direction according to the increment of the rib effective mass, in terms of the force-stroke characteristics (Figure 3).

Study on Rib G Reduction by Dummy Impact Tests

Test Method

Phenomena observed in the full-scale side impact tests were simulated, and a padded surface impactor equipped with pads was impacted against the stationary dummy, in order to find the relationships among the pad force-stroke characteristics, impactor velocity, deceleration and rib G (Figure 4).

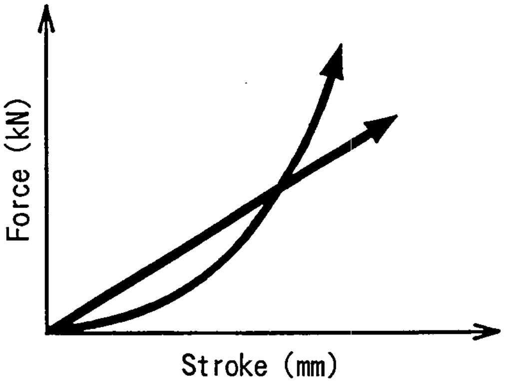


Figure 3. Effective Waveform of Force-Stroke Characteristics in Terms of SID Thoracic Structure

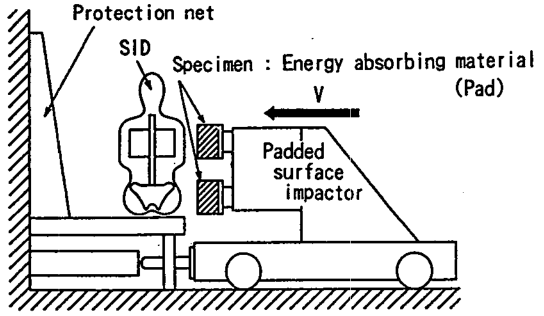


Figure 4. Dummy Impact Test Procedure

Examination of Equivalence to Full-Scale Side Impact Tests

The equivalence between the dummy impact test procedure described above and the full-scale side impact test was subjected to examination tests as described below. Pads to be used in the dummy impact test were installed at the front door where the chest and the pelvis of the dummy were to be impacted, and the full-scale side impact tests were carried out (Figure 5). Rib G-time diagrams of the full-scale side impact tests and those of the dummy impact tests were roughly the same (Figure 6). Thus it was found that the test procedure described earlier was effective for the study on the rib G reduction.

Force-Stroke Characteristics of Thoracic Pad Employed. Rib G-time diagrams of full-scale side impact tests often show two peaks. Hence each thoracic pad force stroke diagram is divided into two parts-the former half in which the first peak of rib G appears, and the latter half after the appearance of the second peak. Seven kinds of pads in total were used in this series of tests, with the combination of three patterns of the former half and four patterns of the latter half (Figure 7). The same kind of a pelvic pad was used in each test.

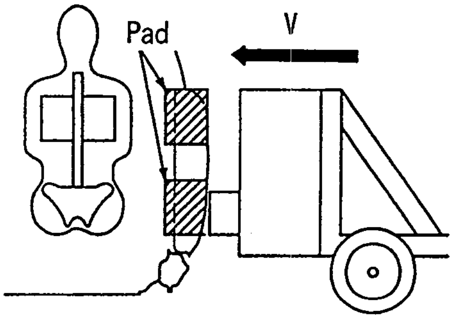


Figure 5. Test Procedure for Examination of Equivalence to Full-Scale Test

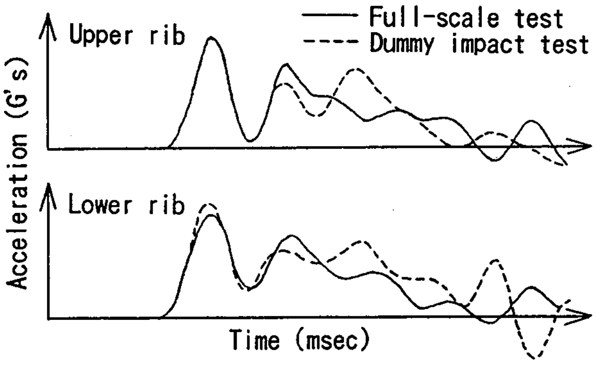


Figure 6. Rib G-Time Diagrams

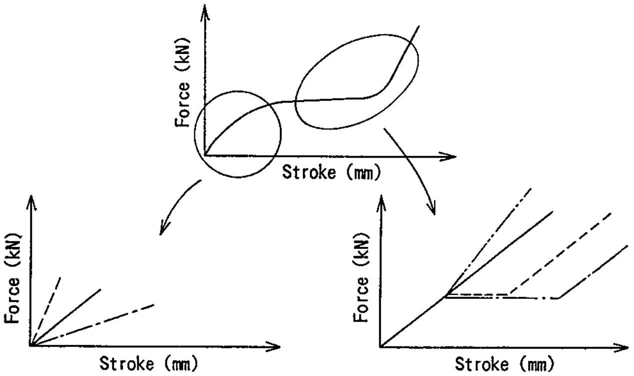


Figure 7. Force-Stroke Characteristics of Thoracic Pad Employed

Results of Dummy Impact Tests

First Peak of Rib G. The relationship between the former half of the thoracic pad force-stroke characteristics and the first peak of rib G is as follows. The thoracic pad force-stroke characteristics (the characteristics measured in the tests) of the most typical example of the series of the tests carried out under this study are shown in Figure 8, while the rib G-time diagram is shown in Figure 9.

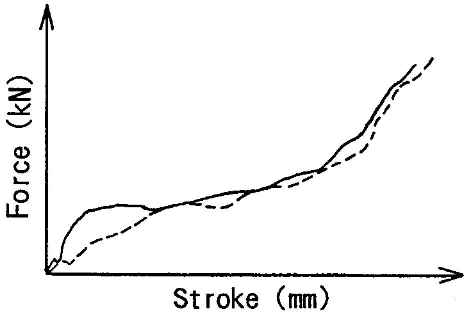


Figure 8. Force-Stroke Characteristics (Thoracic Pad)

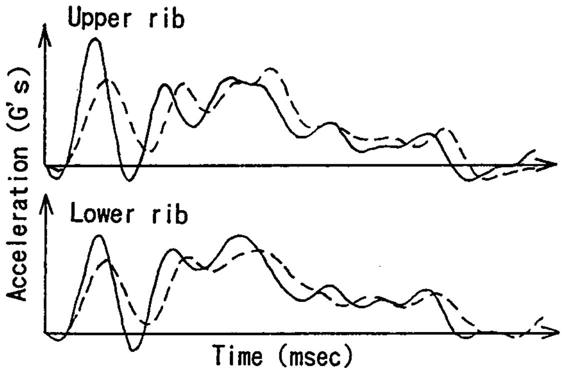


Figure 9. Rib G-Time Diagrams

According to the results of the tests, it is found that the first peak G becomes higher as the gradient (force increment) in the initial stage of the force-stroke characteristics becomes steeper. It is thus deduced that the higher peak value is attributable to the following phenomenon—i.e., as the gradient in the initial stage of the force-stroke characteristics becomes steeper, the force on occurrence of the first peak of rib G becomes higher, and the peak value becomes higher as a result of such a phenomenon.

According to the foregoing, it can be said that the first peak of rib G is correlated with:

(1) the force on occurrence of the first peak of rib G, and

(2) the gradient of the force-stroke characteristics up to the occurrence of first peak of rib G (Figure 10).

In this series of the tests, the correlation coefficient (r) was higher in (2) above.

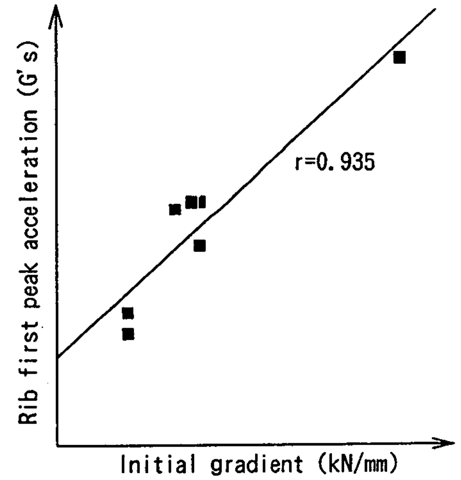


Figure 10. Relationship Between First Peak of Rib G and the Gradient of the Force-Stroke Characteristics

Rib Peak G's After the second Peak. The relationship between the latter half of thoracic pad force-stroke characteristics and peak G's after the second peak of rib G is as follows. The thoracic pad force-stroke characteristics (the characteristics measured in the tests) of the most typical example of the series of the tests are shown in Figure 11, while the rib G-time diagram is shown in Figure 12. It is found that each peak value excluding the final peak G (insignificant peaks for the determination of peak value of rib G is excluded) is proportional to the force on occurrence of the each peak. The values of the final peak G of three cases are different, however, despite the fact that the three cases are roughly the same (Figure 13). In case of the force-stroke characteristics with tendency of relatively flat middle part and the bottomed latter half, it is also found that the final peak G is higher and the valley between the first peak and second peak is deeper than the other two cases. Such differences are presumable due to the relatively low input force to the rib, compared with the rib effective mass increased by the reaction force of the dumper.

Figure 11 shows absorbing energy of individual thoracic pads, where the lowest absorbing energy is assumed as 100. It is found from the figure that the amount of energy that must be absorbed would increase in case where the middle portion of the force-stroke characteristics is flat.

Therefore, it is found that the right-upward increases of force-stroke characteristics estimated by SID thoracic structure are desirable in terms of both deformation stroke and absorbing energy, in order to make the rib G-time waveform trapezoidal for the reduction of the rib peak G.

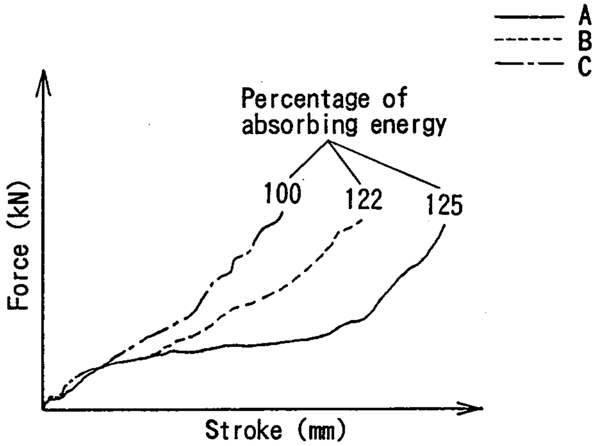


Figure 11. Force-Stroke Characteristics (Thoracic Pad)

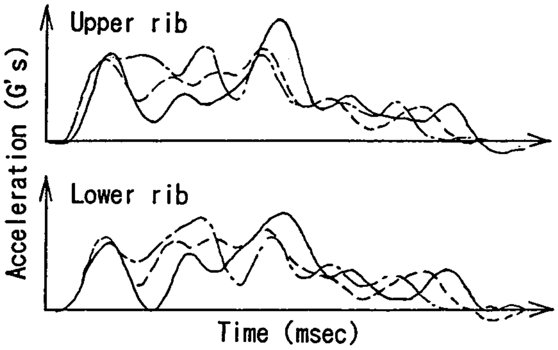


Figure 12. Rib G Diagrams

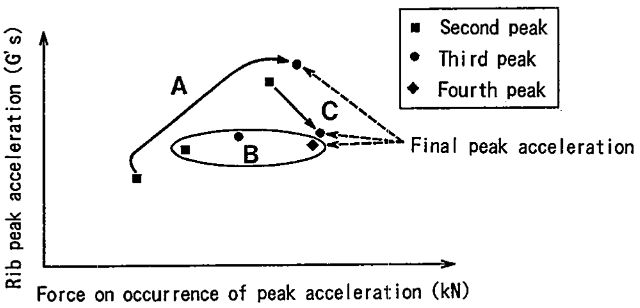


Figure 13. Relationship Between Rib Peak G's After the Second Peak and the Force on Occurrence of the Peak G

Effects of Impact Velocity. Figure 14 shows the thoracic pad force-stroke characteristics (the characteristics measured in the tests) with three different levels of impact velocities, and Figure 15 shows the rib G-time diagrams. Effects of impact velocities may be summarized as follows.

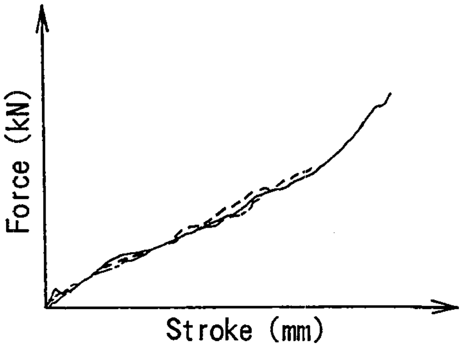


Figure 14. Force-Stroke Characteristics (Thoracic Pad)

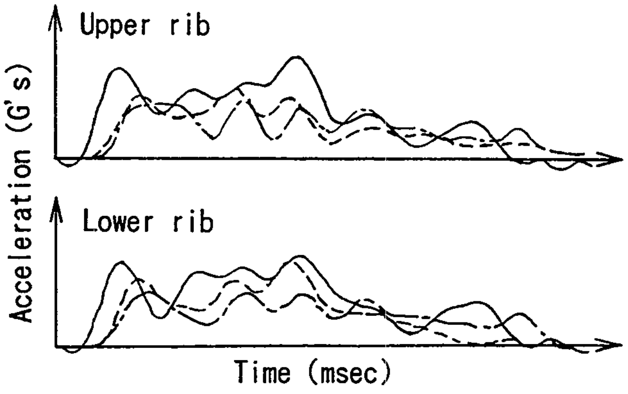


Figure 15. Rib G-Time Diagrams

Thoracic pad force-stroke characteristics were roughly the same though the deformation strokes were different. That is, the effect of strain rate on the force-stroke characteristics was hardly found by the three different levels of the impact velocities in the series of the tests carried out under this study.

As for the rib G-time diagrams, each peak G dropped as the impact velocity dropped, while the duration did not change (Figure 15).

The first peak of rib G is proportional to the impact velocity (Figure 16).

The thoracic pad absorbing energy is proportional to the square of the impact velocity (Figure 17).

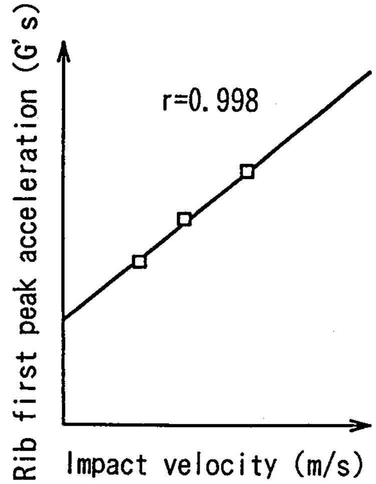


Figure 16. Relationship Between First Peak of Rib G and the Impact Velocity

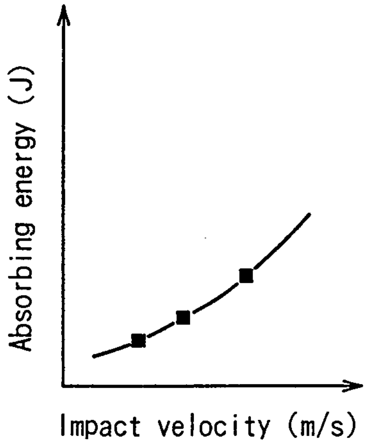


Figure 17. Relationship Between the Absorbing Energy and the Impact Velocity

Test results described so far are those obtained by impacting the padded surface impactor against the dummy in the free running condition. Hence the impactor was hardly decelerated in the impact against the dummy as the mass of the dummy was very small compared with that of the impactor. In actual full-scale side impact tests,however, the MDB (Moving Deformable Barrier) is decelerated gradually by the impact against the vehicle. In order to check on the effect, tests to decelerate the impactor gradually from the moment of impact against the dummy and the pads were also conducted.

Effects of Deceleration of Impactor. Figure 18 shows the impactor velocity-time diagrams of deceleration tests in which the impactor was impacted at three different levels of decelerations. The diagram of the MDB in full-scale side impact tests is also shown in the figure. The velocities of MDB where the time = 0 (msec) is slid down and shown in the figure (due to the fact that the velocity of MDB at the moment of contact between door and dummy was lowered by the deceleration due to the impact against the test vehicle compared with the velocity at the moment of impact). The thoracic pad force-stroke characteristics are shown in Figure 19, while the rib G time diagram is shown in Figure 20.

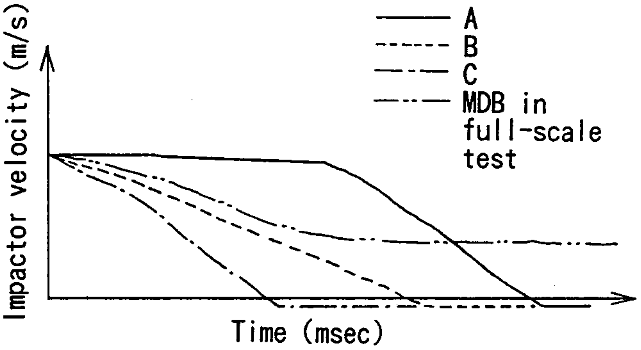


Figure 18. Padded Surface Impactor Velocity-Time Diagrams

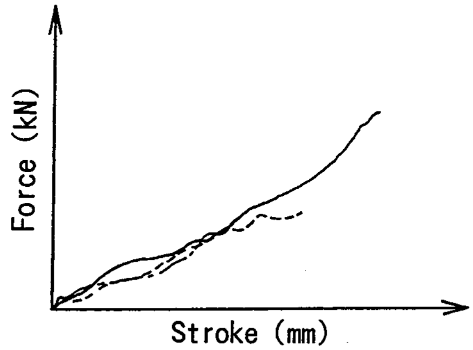


Figure 19. Force-stroke Characteristics (Thoracic Pad)

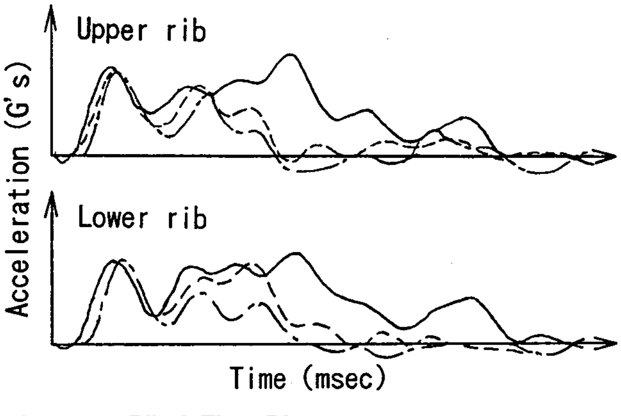


Figure 20. Rib G-Time Diagrams

Effects of deceleration of the impactor may be summarized as follows.

The thoracic pad force-stroke characteristics (of the three cases) are roughly the same while the deformation strokes are different (Figure 19).

First peak of rib G are roughly the same, while the second and subsequent peak G are lowered by greater decelerations. Further, the duration of rib G is reduced by greater decelerations (Figure 20).

The thoracic pad absorbing energy is in inverse proportion to the impactor deceleration (Figure 21).

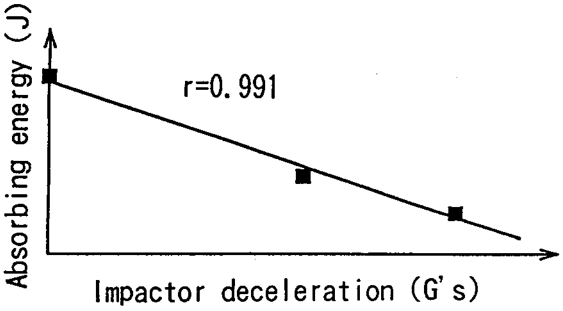


Figure 21. Relationship Between the Thoracic Pad Absorbing Energy and the Impactor Deceleration

Summary

Factors for the control of rib G in full-scale side impact test may be summarized as follows.

- Factors for the control of the rib first peak G
  - Force on occurrence of the peak G
  - Gradient of force-stroke characteristics in the initial stage (force increment)
  - Velocity of contact between door and dummy
- Factors for the control of the rib second and subsequent peak G
  - Force on occurrence of each peak G (excluding the final peak G)
    The final peak G: waveform of the force-stroke characteristics up to the occurrence of the final peak G
  - Velocity of contact between door and dummy
  - Door intrusion velocity-time hysteresis

Effective Door Crush Characteristics

Figure 22 shows the most effective door crush characteristics for the rib G reduction under the most severe conditions (both impact velocity and impactor deceleration) of the series of tests carried out under this study.

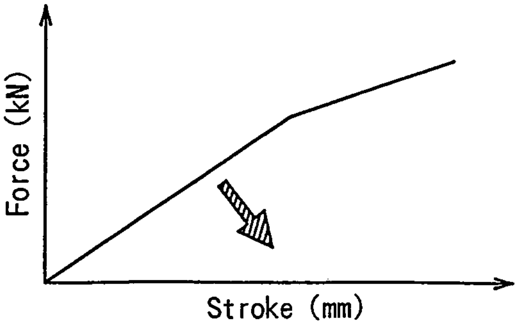


Figure 22. Effective Door Crush Characteristics

The crush characteristics shown in the figure have the highest advantages in terms of deformation stroke and absorbing energy, for the control of the rib G under a given value. It is also possible, however, to control the rid G under a given value by some other characteristics as long as the necessary amount of energy can be absorbed at a lower force level than the above.

Examination by Full-Scale Side Impact Tests Using the Prototype Door

A prototype door that could attain the most effective crush characteristics described in the foregoing was developed, and full-scale side impact tests were carried out to examine that the SID rib G-time diagram could be controlled as intended.

Door Impact Test Procedure

Door impact test procedure is shown in Figure 23. This procedure is given dynamic impact with impactor which simulated SID thorax, wherein the door is not only fixed at the hinges and the latch but also clamped at the lower end.

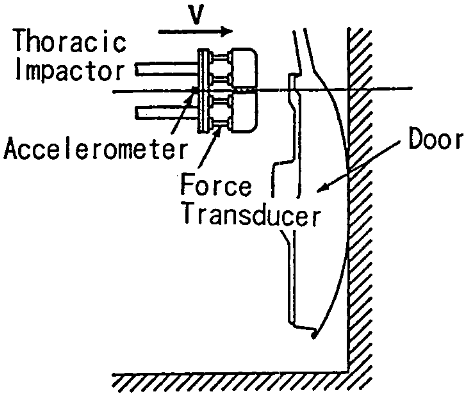


Figure 23. Door Impact Test Procedure

Door Crush Characteristics and Results of Full-Scale Side Impact Tests

Crush characteristics of three doors are shown in Figure 24. The effective crush characteristics described above are also shown in the figure. The rib G-time diagrams of the three doors obtained by full-scale side impact tests are shown in Figure 25. The door A is the prototype door developed to attain the effective crush characteristics (the lower force level was compensated for by changing the stroke). The rib G-time diagram became trapezoidal, consequently, rib peak G are reduced as intended.

As for the relationship between the door crush characteristics and rib G for doors B and C according to results of dummy impact tests, it is deduced as follows.

- Door B: The higher second peak G is presumably due to lower levels of force and the absorbing energy crush characteristics than those of the effective crush characteristics, which resulted in the complete crush of the door in the full-scale side impact test.
- Door C: The higher first peak G is presumably due to the steeper gradient of the crush characteristics in the initial stage that exceeded over the effective line.

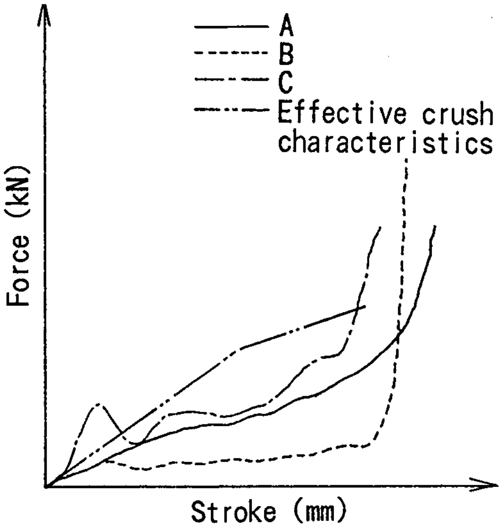


Figure 24. Door Crush Characteristics

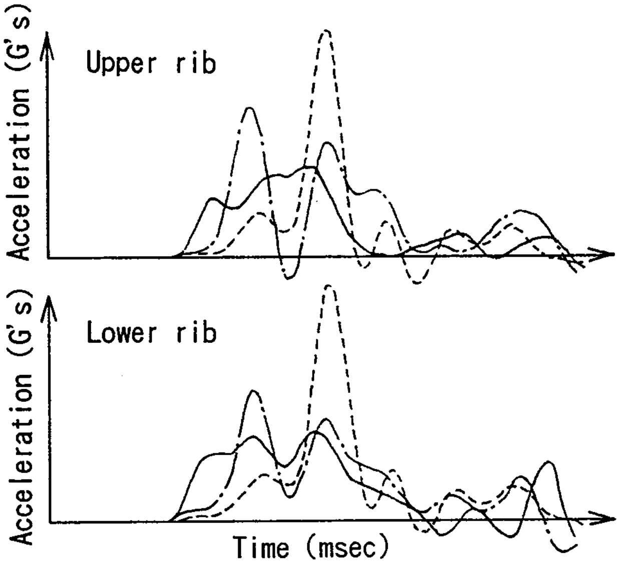


Figure 25. Full-scale Side Impact Test Results

In this manner, the rib G-time diagrams in the full-scale side impact tests can be roughly anticipated from the door crush characteristics.

Conclusions

- Effective door crush characteristics for the control of SID rib peak G under a given value have attained.
- Rib G-time diagrams of the full-scale side impact tests can be controlled by controlling the door crush characteristics in door impact tests.

Therefore, the door impact test procedure is one of the effective tools for the design and development of vehicles.

Postscipt

Although rib G waveforms of full-scale impact tests can be roughly predicted (estimated) by the door impact test procedure introduced in this paper, it is necessary to take account of the fact that the door contacts the dummy while being deformed in the full-scale side impact test, in order to enhance the accuracy in prediction. It is, however, extremely difficult to do so. In order to ensure the complete accuracy, measurements of crush characteristics by means of CC-CTP (Computer Controlled-Composite Test Procedure) and the like (the method to apply impact forces from the outside and inside of the vehicle) will be necessary.

S5-O-21

Crash-Rate and Door-Padding Effects in Side Impact Simulations

Ran Cohen
Armament Development Authority
Edwin M. Sieveka, Walter D. Pilkey
University of Virginia

Abstract

The main purpose of this study was to investigate the importance of introducing crash-rate sensitivity factors into the computer simulations of side impact crashes. In earlier studies, it was assumed that dynamic effects have little influence on the structure and occupant responses. However, experimental work on structural components does show different results for static and dynamic tests. It was felt, therefore, that further study of the influence of these effects on occupant responses in side-impact simulations was needed.

The effects of two crash-rate parameters were studied: the crash rate sensitivity of the car structure, and the crash rate sensitivity of the door-padding. A previously developed, lumped spring-mass model was employed and was solved by using the CRUSH program. The simulations were performed for two crash speeds and for several cases of door-padding thickness. The effect of the door-padding thickness was approached in two different ways. One approach was to keep the occupant-door spacing constant and to change the total door thickness to account for the padding thickness; the other approach was to keep the size of the car structure constant while changing the occupant-door spacing to accommodate changes in padding thickness. Three thoracic injury criteria, including old and new TTI and V*C, were calculated and plotted as functions of the padding thickness, showing the influence of both rate factors and padding thickness on these criteria.

Introduction

In previous side-impact studies [1,2], it was assumed that dynamic effects have little influence on the structure and occupant response and that no rate-sensitive factors need to be introduced to the crash simulations. Experimental studies, however, show different behavior in static and dynamic tests with various crash speeds. JAMA's work [3] shows these differences in impact tests on a door structure. Therefore, it was felt that a better understanding of the magnitude of dynamic effects on car occupant response in side impact simulations would be of value to the automotive safety community.

In this study, the sensitivity of thoracic injury criteria to two rate-dependent vehicle components was investigated:

1. the strain-rate behavior of the car's outer door structure;
2. the crush-rate behavior of visco-elastic door-padding material.

The strain-rate properties of the door structure were modeled through the application of a multiplicative factor to static force/deformation (F/D) data. The door padding material was modeled with combinations of spring and damper elements. In addition to rate sensitivity, a wide range of padding thicknesses and occupant-to-door spacings were also considered. The effects of all of these factors were examined for both the old and new definitions of the Thoracic Trauma Index (TTI) and for the Viscous Criterion (V*C).

Model Description

A one-dimensional lumped mass model was used for this study and was solved using the CRUSH program. The model is based on that of Trella and Kanianthra [2], except for several changes which were introduced to investigate the crash rate effects. Also, another approach to the effect of padding thickness was introduced here.

Padding Model

In [4], a viscoelastic model is described which uses springs and dampers for door padding, with an analytical expression for each model component. Since in the CRUSH program there is no standard input for analytical expressions, a non-linear spring and a linear viscous damper in parallel were chosen for the energy absorbers that represent the door padding between the door and the rib and between the door and the pelvis, as described in [5]. In that report, the viscous coefficient of the damper was determined by comparing simulation results of a simple door-padding model to test results for various crash speeds made by MGA [6]. Using a damping coefficient of 0.001 Klbs/(in/sec), the simulated F/D curves agreed quite well with the test results, but started from an initial force value at zero deflection. In this study, in order to improve the agreement and have the F/D curves start from the origin of the coordinate system, a linear spring was added in series with the damper, as shown in Figure 1. Since each node in CRUSH needs to have a mass, a small mass was introduced between the damper and the spring. Figure 2 shows how the new padding model (Fig. 1) was incorporated into the full occupant/vehicle model between the occupant and the door. This expanded model was used for the injury measure studies described in the results section.

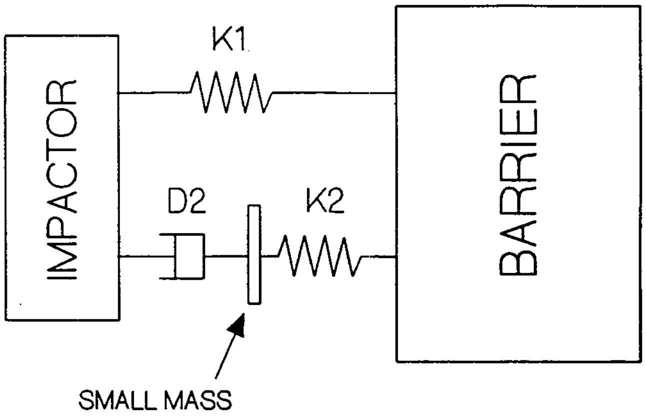


Figure 1. Simple Door-padding Model

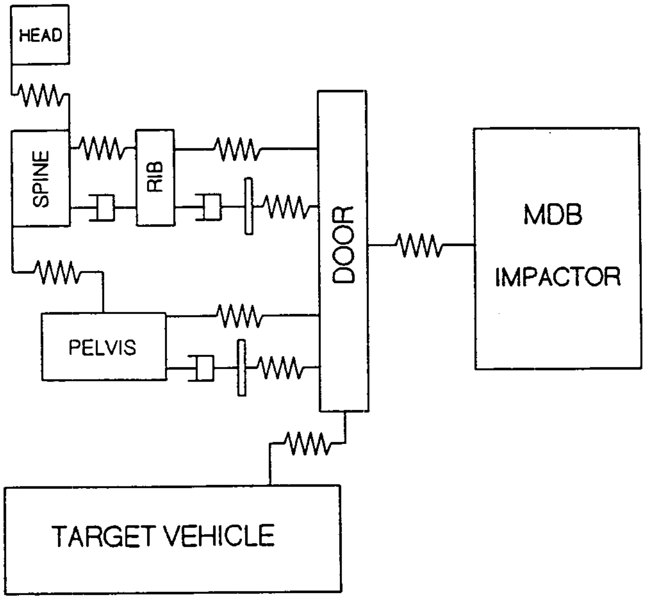


Figure 2. Side Impact Model

Figure 3 shows the results from MGA tests, and Figure 4 shows the simulation results using the new CRUSH door-padding model. The coefficient of the damper remains 0.001 Klbs/(in/sec). Good agreement with the measured data is obtained once again and the behavior of the simulation at zero deformation is much more realistic.

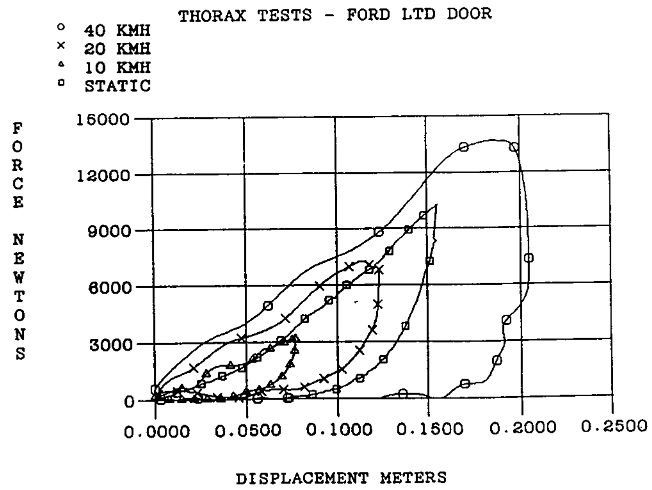


Figure 3. Force/Deformation Curves, 5" Door Padding (MGA, [6])

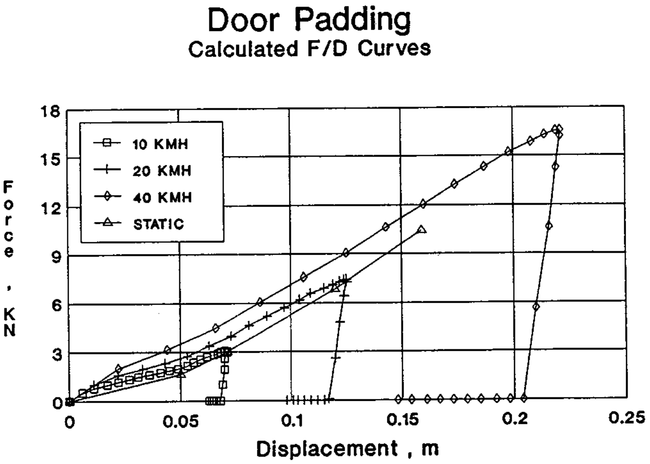


Figure 4. Force/Deformation Curves for Simple Door-Padding Model (Figure 1)

Crash-Rate Sensitivity of the Structure

In order to account for crash-rate effects in the car's structural response, the CRUSH program's "CV Factor" was used. With this feature, each value of the force in the quasi-static F/D curve is multiplied by the CV factor, which is a function of the crash rate (deformation rate) of the energy absorber. In CRUSH there are several types of CV factors. Here, a CV factor of type "3" was chosen, which takes into account the strain-rate sensitivity of the material of the structure. The CV factor type 3 is given by

$$CV = 1 + KR * LN (CR/SCR)$$

where:

KR is the material factor

CR is the absolute value of the instantaneous crash rate

SCR is the crash rate of the quasi-static test on the structural member

A value of 0.0622—for hot-rolled steel with 0.15% carbon—was chosen for KR.

A value of .03333 in/sec recommended in CRUSH manual was chosen for SCR.

The results of the simulations show good agreement with the average "dynamic factor" presented in [3].

The CV Factor was applied to the energy absorbers between the impactor and the door and between the door and the compartment (see Figure 2).

The TTI and V*C Injury Measures

The primary quantitative measure employed by the DOT for evaluating chest injury is the Thoracic Trauma Index or TTI. TTI is defined in terms of the peak rib and spine accelerations by the following formulae:

$$\mathrm{TTI(old)} = 1.4 * \mathrm{AGE} + 0.5 * (\mathrm{ARIB} + \mathrm{ASPINE})$$

$$(\mathrm{ARIB} = 0.5 * \mathrm{ARIB} + 30, \text{ if ARIB} > 60 \text{ G's})$$

$$\mathrm{TTI(new)} = 1.4 * \mathrm{AGE} + 0.5 * (\mathrm{ARIB} + \mathrm{ASPINE}) * \mathrm{MASS/STDMASS}$$

$$\mathrm{TTI(dummy)} = 0.5 * (\mathrm{ARIB} + \mathrm{ASPINE}).$$

The first two formulae resulted from a series of cadaver studies and hence include the subject's age. In the old TTI formula, ARIB is the maximum of the upper and lower rib peak accelerations, while in the new formula the peak middle rib acceleration is also considered. In each case, ASPINE is the peak lower spine acceleration. The standard body mass, STDMASS, in the new formula is equal to 165 pounds. The last formula, calculating TTI(dummy) or TTI(d), is used in experiments involving mechanical dummies instead of cadavers.

Another injury measure has been proposed by General Motors and is known as the viscous criteria or V*C. In the V*C formula, V is the velocity time history, and C is the displacement time history scaled by the maximum possible crush of the chest (about 6 inches in side impacts). The viscous criteria is thought to have advantages for predicting the onset of soft tissue injuries such as lacerations or ruptures of internal organs.

So far, the relationships of these injury measures to actual injury levels have not been firmly established, but, for the purpose of this study, representative values have been chosen from the literature to define "acceptable" and "unsafe" regimes. In a paper by Lau and Viano [7], it is reported that experiments with anesthetized swine showed evidence of significant liver laceration when the V*C peak value exceeded 1.2 meters/second (47.25 inches/second). In that same paper, a value of 80 G's for TTI(d) was mentioned as a target level for safety researchers. In TTI calculations in this paper, the cadaver formulas were used with AGE equal to 40 years. Adding 1.4 times 40 to 80 gives a TTI of 136. This agrees closely with plots by Eppinger et al. [8] which show a dramatic rise in injuries, with an AIS level of 4 or greater, near a TTI of 130. On the basis of this information we have used V*C = 47.25 in/sec and TTI = 136 G's as the levels above which the impact is considered unsafe. The simulation results for each criterion have been normalized by these values so that, in the plotted results, a value of 1.0 indicates the transition from acceptable to unsafe.

Simulation Results

Rib and Spine Acceleration Time-Histories

Simulations were performed with the model, with crash velocities of 25 and 30 MPH, in four configurations:

1. CV = O, DMP = O (no structural rate effect and no damper in padding)
2. CV = 0, DMP = 0.001 (no structural rate effect, but with padding damper)
3. CV = 3, DMP = O (with type 3 rate factor, but without padding damper)
4. CV = 3, DMP = 0.001 (with type 3 rate factor and with padding damper)

The simulation matrix is shown in Table 1.

Table 1. Simulation Matrix

Config. #	CV	DMP
1	0	0
2	0	0.001
3	3	0
4	3	0.001

Figures 5 and 6 show the rib and spine acceleration time histories for all four configurations, for a nominal padding thickness of 4 in. (door-rib slack 8", door-pelvis slack 5").

It can be seen that both the CV Factor and padding dampers generally decrease the calculated acceleration levels in the thorax. Introducing both factors together can reduce the acceleration levels significantly, particularly the rib acceleration at 30 MPH where the peak value was reduced from 95 G's to below 55 G's. In all cases, the primary peak was reduced, but, in the case of the rib curves, the size of the secondary peaks actually increased in some cases. It will be shown later that this behavior is sensitive to the treatment of the rib-spine energy absorber and is an important modeling consideration since it can affect the injury measure calculations.

The above results demonstrated that occupant response is sensitive to the dynamic behavior of the car structure and the door padding. Next, these parameters were coupled with a wide variety of padding thicknesses to examine their combined effect on the TTI and V*C injury criteria.

*Effect of Padding Thickness and Rate-Dependence on the TTI and V*C Injury Measures*

The effect of padding thickness on the TTI and V*C injury criteria was studied here using two approaches. In one approach, which was used by Trella and Kanianthra [2], and is also described in [5], the padding thickness was changed while keeping the occupant-padding spacing ("slack") constant; therefore the total occupant-door distance was changed. This approach may represent an

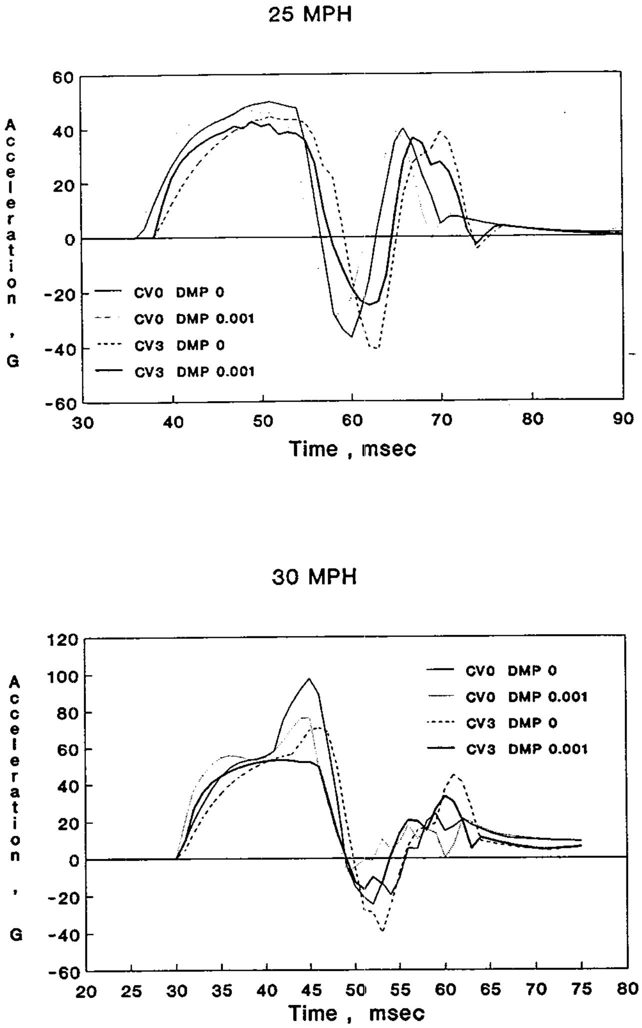


Figure 5. Rib Acceleration Time-Histories for Various Rate Factor Configurations, with 4" Padding

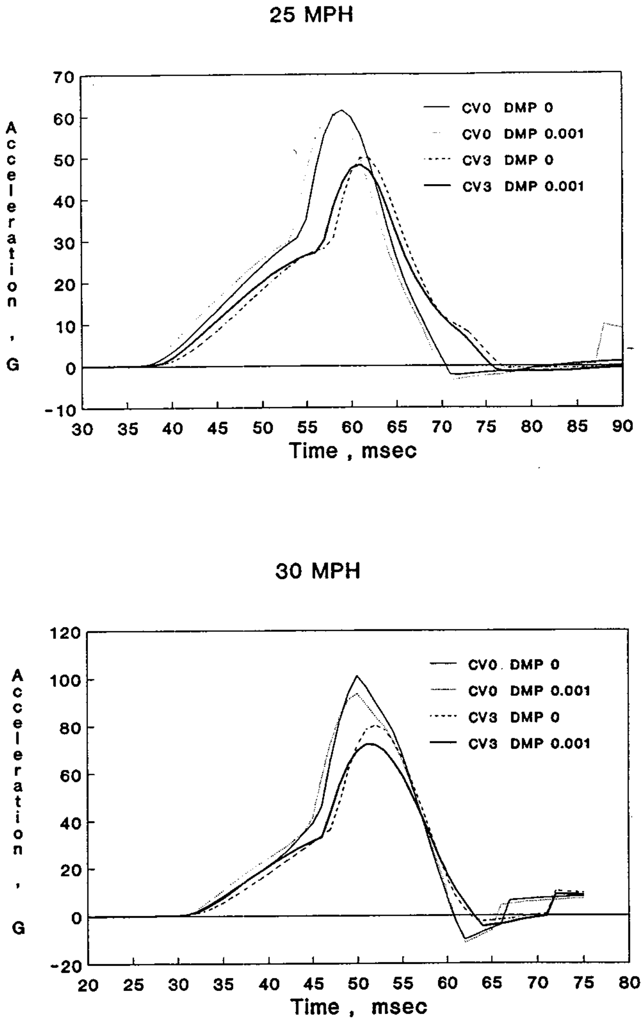


Figure 6. Spine Acceleration Time-Histories for Various Rate Factor Configurations, with 4" Padding

early stage of the car design, when the total width of the car can be altered, and the effect of the door-padding thickness is separated from the occupant-padding spacing. It will be referred to as the "constant slack" approach, with the door-rib and door-pelvis spacings chosen to be 8 inches and 5 inches respectively.

The other approach, which was used in [9], suggests keeping the total distance constant, while changing the space between the occupant body and the door-padding (slack) with the change in the padding thickness. This approach may represent a later stage, where the car structure is already designed and the effect of padding thickness is separated from that of the structure geometry. It will be referred to as the "varying slack" approach. In this case, the total distance between the rib and the door was 12 inches, and between the pelvis and the door was 9 inches. The slack between the occupant and the door padding changed from 12 inches to 4 inches for the rib and from 9 inches to 1 inch for the pelvis as padding thickness increased.

Table 2 summarizes the slack configurations for the two approaches.

Table 2. Slack Configurations for Various Padding Thicknesses

Constant Slack

Padding Thickness	Door-Rib Slack	Door-Pelvis Slack	Door-Rib Distance	Door-Pelvis Distance
0"	8"	5"	8"	5"
2	8	5	10	7
4	8	5	12	9
6	8	5	14	11
8	8	5	16	13

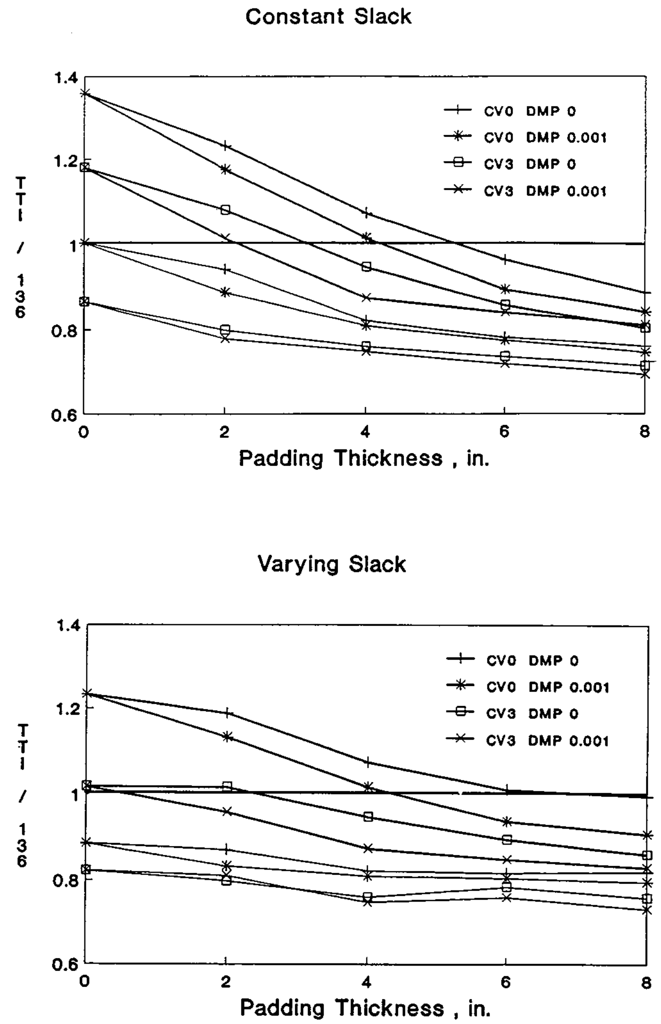
Varying Slack

Padding Thickness	Door-Rib Slack	Door-Pelvis Slack	Door-Rib Distance	Door-Pelvis Distance
0"	12"	9"	12"	9"
2	10	7	12	9
4	8	5	12	9
6	6	3	12	9
8	4	1	12	9

Figures 7, 8, and 9 show the relative values of the three injury criteria as calculated from the results of the simulations, as a function of the padding thickness. Both slack approaches and both crash speeds are shown for each criterion. The thick lines in the figures represent 30 MPH runs, while 25 MPH runs are plotted with thin lines. With regard to constant slack versus varying slack, the curves are steeper for the constant slack approach since the total occupant-to-door distance is changed with the padding.

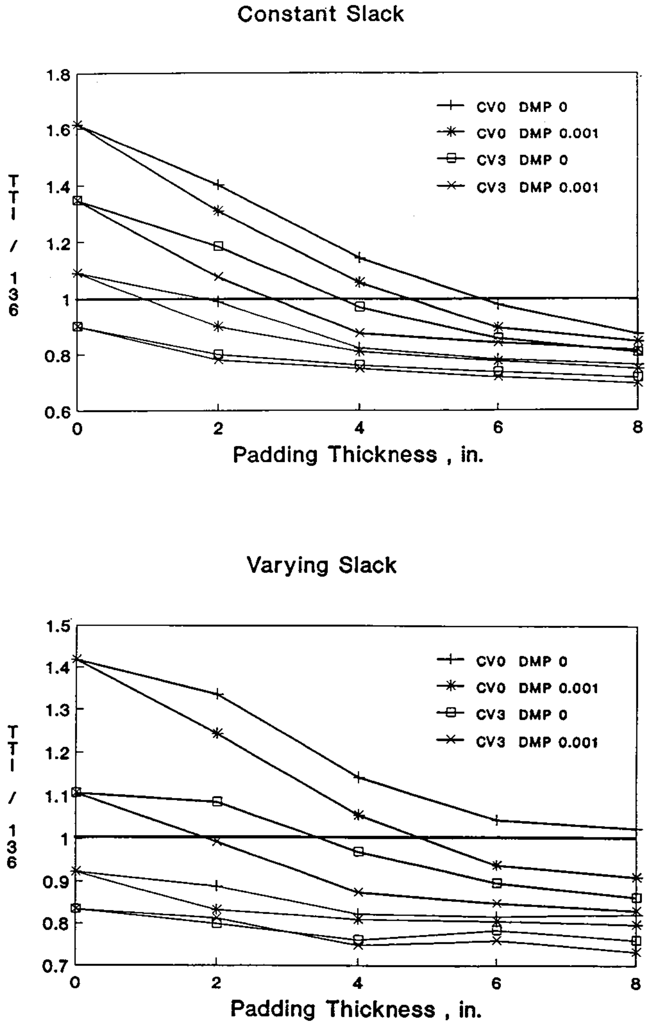
It can be seen that both crash-rate factors decrease the criteria values. The effect is more pronounced for 30 MPH cases in which the injury levels are higher than at 25 MPH. In all cases, the CV Factor always reduces the injury levels. The reduction is in the range of 4 to 35% (lower with thicker paddings and higher with thinner paddings). Therefore, it can be concluded that injury levels calculated using data from quasi-static structural tests should represent a worst case scenario, and the dynamic effects would contribute safety factors to the design.

Padding thickness, in particular, has a much greater effect at 30 MPH than at 25 MPH. For a 25 MPH crash, the criteria values are in the "safe" region for most padding thicknesses and the slopes of the curves are quite gentle, indicating only modest sensitivity. In the case of 30 MPH, however, moderate amounts of padding can determine whether the injury measures fall in the dangerous region or in the safe region. For example, for padding thicknesses of 4" and above, the combination of the two rate factors brings the injury curves below the critical line, with reductions of 10 to 25% in the criteria values. Below 4 inches the effect is even larger, though values remain in the dangerous range. It is important to note how much a 5 MPH difference affects the occupant response, especially since 30 MPH is a typical vehicle speed on neighborhood streets where the speed limit is 25 MPH.


Constant Slack

Varying Slack

Figure 7. Normalized TTI Criterion (old version) vs. Padding Thickness for Various Rate Factor Configurations


Constant Slack

Varying Slack

Figure 8. Normalized TTI Criterion (new version) vs. Padding Thickness for Various Rate Factor Configurations

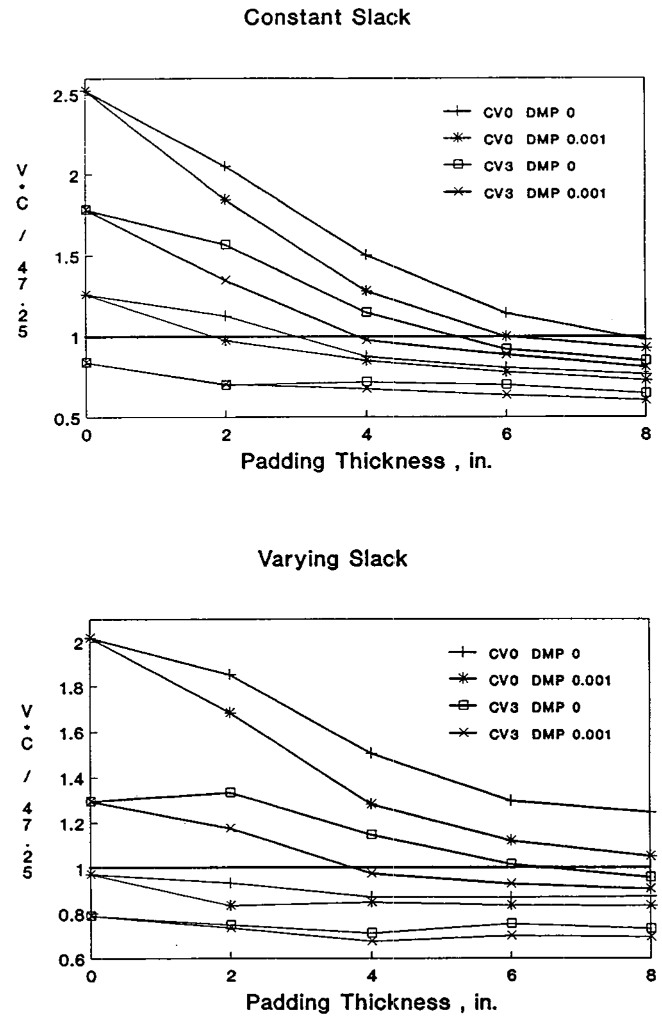


Figure 9. Normalized V*C Criterion vs. Padding Thickness for Various Rate Factor Configurations

Injury Measure Sensitivity to the Thorax Model

At several points on the curves, especially on the 25 MPH curves, the criterion value increases with the padding thickness, and then decreases again. This is due to the fact that, in some cases, the absolute value of the maximum rib acceleration occurs in a negative acceleration peak (rebound), or in the second positive acceleration peak. This phenomenon is quite sensitive to the stiffness of the energy absorber between the rib and the spine. In the original model [2], the spring component of the chest has a zero value for the first 1.4 inches of deformation.

To check this issue, the model was run with small modifications to the spring F/D curve of the chest. Figure 10 shows the modified curves and the rib acceleration time-history (with CV factor, padding damper, 2 inches padding, and 25 MPH). In the original curve the maximum occurs in the negative peak. Small changes in the F/D curve decrease the values of the negative and second positive peaks, and cause the maximum to occur in the first acceleration peak.

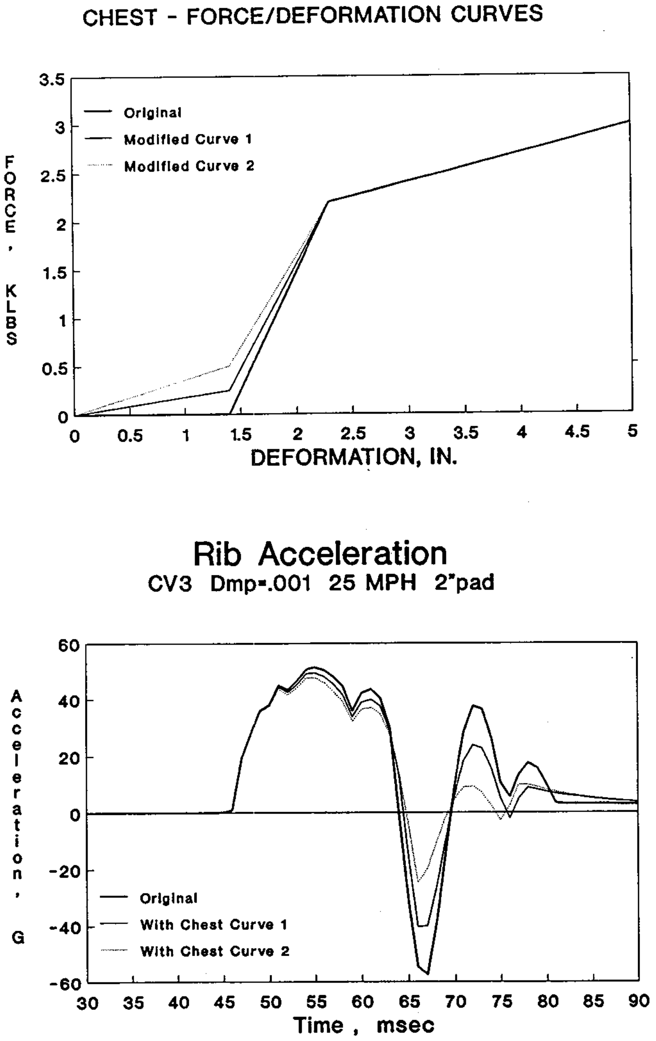


Figure 10. Effect of Chest Stiffness on Rib Acceleration: Force/Deformation Curves for Various Chest Curve Configurations

Summary

The response of the occupant in side-impact simulations was presented in this paper. The existing model and its modifications were described, and simulation results were presented. It was shown that the two crash-rate parameters—the CV Factor and a padding damper had significant effects on reducing the acceleration levels and the thorax injury criteria of the occupant. Therefore, when designing a vehicle's safety performance based on injury criteria predicted by simulations using quasi-static test data, without considering the dynamic effects, a certain margin of safety is obtained. The effects of padding thickness were also examined and it was shown that near 30 MPH the appropriate use of padding can push injury measures down below the level of serious injury. Lastly, it was demonstrating that modeling efforts should consider the properties of the thorax carefully since injury measure calculations are sensitive to the thoracic stiffness.

References

1. Richter, R., J. Oehlschaeger, R. Sinnhuber, and R. Zobel, "Composite Test Procedure for Side Impact Protection," SAE Paper 871117, 1987.
2. Trella, T. J. and J. N. Kanianthra, "Application of Derived Characteristics from Dynamic Test Data for Simulation of Car-to-Car Side Impacts Using a Lumped Mass Approach," SAE Paper 851187, 1985.
3. JAMA, "Preliminary Report of Door Impact Test," (ISO/TL22/SC10/WG1N1891/b), ISO Meeting, Turin 1989.
4. Hung-Hsu Chen and D. A. Guenther, "Computer Simulation and Evaluation of the Effect of Padding on the Thorax in Lateral Impact," 32nd Stapp Car Crash Conference, SAE Paper 881722, 1988.
5. Pilkey, W. D. and E. M. Sieveka, "The Development of a Side Impact Test Procedure," Final Report, MVMA Contract No. UVA-8812-C8135A, 1989.
6. "Door Padding Tests," MGA Research Corp. Report No. C88A-12.1
7. Lau, I. V. and D. C. Viano, "How and When Blunt Injury Occurs—Implications to Frontal and Side Impact Protection," 32 Stapp Car Crash Conference, SAE Paper 881714, 1988.
8. Eppinger, R. H., J. H. Marcus, and R. M. Morgan, "Development of Dummy and Injury Index for NHTSA's Thoracic Impact Protection Research Program," SAE Paper 840885, 1984.
9. Yih-Charng Deng, "Design Considerations of Occupant Protection in Side Impact—A Modeling Approach," SAE Paper 881713,1988.

S5-O-22

Evolution and Current State of Development of the Computer-Controlled Composite Test Procedure

B. Richter
ACEA/JAMA/MVMA

Abstract

The Composite Test Procedure ("CTP") has been under discussion for about four years as an alternative to the lateral Full-Scale Test ("FST"). In 1988 the European car manufacturers represented by the CCMC decided to promote this alternative method. This approach was then also supported by American and Japanese car manufacturers and is now being developed in a joint effort by ACEA, the new association of European car manufacturers, JAMA and MVMA. Proposals for an ISO Standard and a Draft Directive for the United Nations Economic and Social Council have been formulated for the CTP. Within its working party, WP 29, it was decided to set up an ad hoc group demonstrating the equivalence of the CTP and FST. A work program has been defined and will be started this year.

The new approach in automotive compliance testing consists of the combination of quasi-static testing and calculation, thus providing dynamic outputs like the FST, but in laboratory conditions. This kind of approach may be the first step towards future compliance testing. In general the CTP provides a variety of advantages when compared with FST.

The CCMC and JAMA approaches initially consisted of a step-by-step procedure with one body interior loading device. During the new computer-controlled CTP ("CC-CTP") test with independent thoracic and pelvic loading devices, a personal computer controls the motion of test rig cylinders to measure the force/deflection characteristics of the front and side structure and the interior door padding. These characteristics are used to compute the dynamic event, occupant and vehicle loads of the simulated lateral FST.

In order to evaluate these loads, a mathematical model of the colliding vehicles and of the occupant was developed in a first step for the US-SID and EUROSID. In a second step, data required for the modelization of the human being will be collected.

To perform CTP tests, a test rig has been developed which consists of mechanical equipment, actuators, hydraulic supply system, digital and analog electronics. Any barrier can be used as an exterior loading device. The shape of the interior loading devices is related to the simulated occupant.

The first results demonstrate that the CC-CTP can be seen as an alternative to FST with good repeatability and low cost.

Why CTP?

Developments in the field of safety legislation over the past few years have created long debates among motor vehicle manufacturers and regulatory authorities. A characteristic of this development is the proliferation of anthropomorphic test dummies required for full-scale tests.

The weaknesses of the full-scale test (FST) and the deficiencies of the component test methods have led motor vehicle manufacturers to the development of the Composite Test Procedure (CTP).

This new approach in automotive compliance testing consists of a combination of quasi-static testing and calculation, thus providing dynamic outputs like the FST, but in laboratory conditions.

During the new computer controlled test (CC-CTP), a personal computer controls the motion of test rig cylinders to measure the force/deflection characteristics of the front and side structure and the interior door padding. These characteristics are used to compute the dynamic event, occupant and vehicle loads of a simulated lateral FST.

In general the CTP provides a variety of advantages when compared with the FST.

- A fully equipped vehicle or body-in-white, with all relevant components for lateral impacts fitted, can be used in the test, allowing the safety characteristics of the vehicle to be evaluated at an early stage.
- The CTP does not use a mechanical dummy. The loads to which occupants are subjected are calculated with the help of a simulated (mathematical) occupant. As the characteristics of this occupant are not subject to scatter, the CTP offers superior overall test repeatability.
- Everything indicates that a mathematical occupant is better suited than a mechanical dummy to simulate human behaviour because an increased level of sophistication can be incorporated which relates much more accurately to actual human characteristics. In addition, less time and money is required to modify a mathematical occupant as new biomechanical findings emerge, which is not the case for a mechanical dummy.
- The CTP offers deeper insight into the collision process. It is therefore not only suitable as a test procedure, but can also be used as a development tool. As in the case of full-scale tests, the designer is free to select the countermeasures he wants. He can exploit the options in terms of structure as well as padding to protect the occupants.
- Although the CTP results are developed from a specified collision speed and vehicle/barrier mass, results for other speed and masses can, within certain limits, be derived from the same test. Thus, other accident situations can be evaluated from a single test, which is not possible with an FST.

Car manufacturers have developed the CTP because of the benefits for

- the consumer
- governments and
- car manufacturers themselves.

To understand this, it is necessary to review briefly the characteristics of real world lateral collisions.

Accident studies show that the people exposed to serious injury in side impacts have an even wider age distribution than in other collision types. Comparisons of front seat occupant age distribution in frontal and side impacts show that the older person is highly represented in lateral car-to-car collisions (Figure 1). Moreover, they are much more vulnerable to injury from a biomechanical point of view than younger persons.

Accident studies illustrate the variations in crash severity of lateral collisions with cumulative frequency curves, which illustrates the range of velocity changes of the struck vehicle which occur in serious injury lateral collisions (Figure 2).

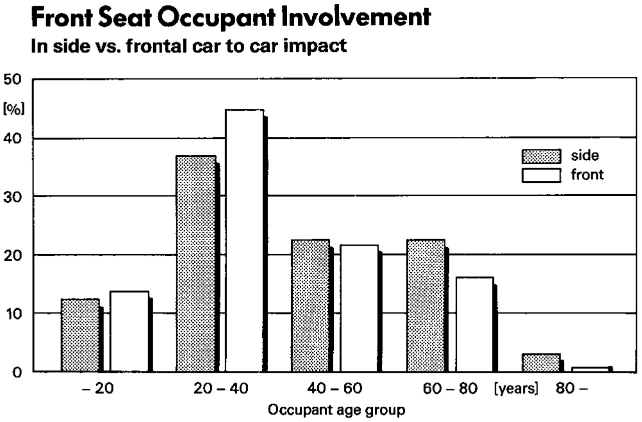


Figure 1. Front Seat Occupant Age in Frontal and Side Impact Car-to-Car Collision

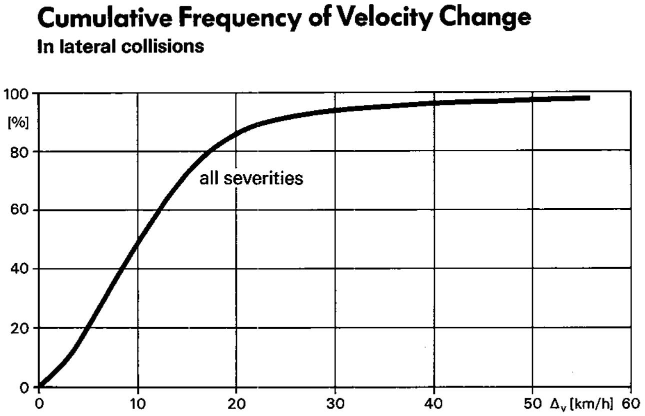


Figure 2. Range of Velocity Changes of Struck Vehicles in Lateral Impacts

In addition to age, other factors fundamentally influence biomechanical responses. These are: the mass of the occupants (Figure 3), varying by a factor of at least 2 from 40 to 80 kg for 90 % of lateral collisions; bone strength (Figure 4), which varies significantly even within age groups because of sex and other differences.

So, people in car-to-car side impacts have significantly different physical characteristics. Furthermore, side impacts vary greatly in terms of collision speeds and the weight and structure of the striking objects.

The benefits of the CTP approach for the consumer are that the CTP can take into account these variations in occupant characteristics, collision speed, barrier mass and barrier compliance.

The CTP can not only replicate the behaviour of mechanical dummies, but what is more important, it has the potential to replicate the real human being directly. By incorporating real human biomechanical characteristics in the computer model, the CTP can bypass the intrinsic limitations which the rather primitive physical dummies have.

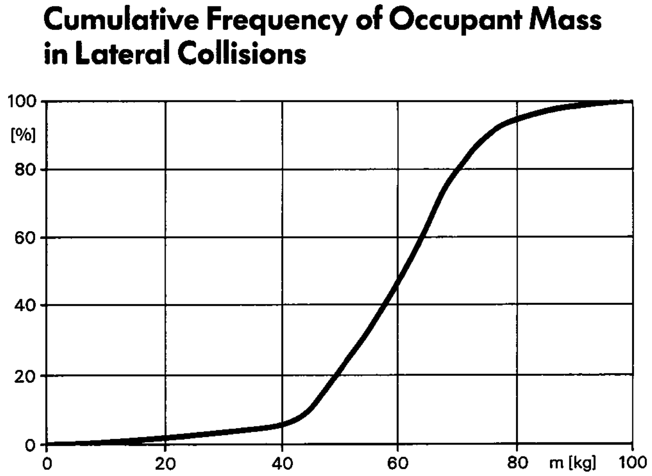


Figure 3. Range of Occupant Mass

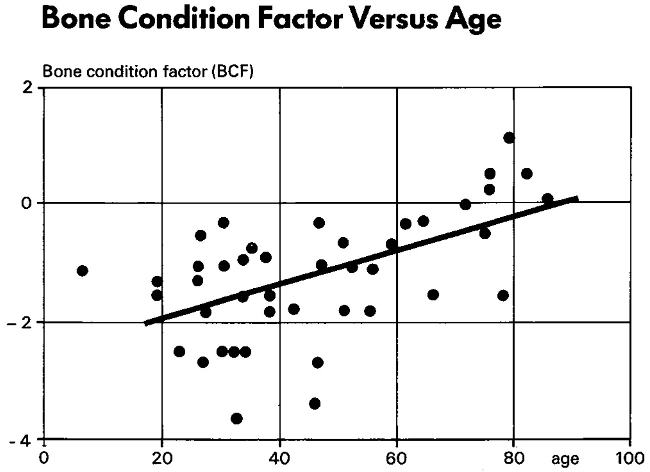


Figure 4. Occupant Age Dependent Bone Condition Factor

The alternative of a single point global test, with a simple pass/fail criterion cannot adequately cover these ranges of real world accident characteristics, nor the biofidelity of real human responses to impacts. The danger of a single point global test is that it will encourage design to be optimized around that single point requirement. If the global test is set for a severe condition, then designs will evolve which are not effective for the vulnerable segments of the population in the more numerous lower speed crashes. If it is set for a more modest severity, then the higher energy collisions will not be taken into account adequately.

Hence, the benefits of the CTP approach for governments are to provide a technique which allows these various conflicting requirements to be optimized, by correlating test results with accident statistics. This optimization process is ultimately a political judgement as to the level of protection and to whom it should be applied. The CTP provides a tool for a logical approach to these population issues on the basis of only one test. The other desired information is obtained by computer simulation. A single point global test cannot take these principles into account.

Besides benefits for the consumer and governments, the car manufacturer will also have some advantages. The CTP procedure can be applied earlier in the process of developing a new car. A body-in-white with the relevant components for lateral impacts fitted can be used, allowing the safety characteristics to be evaluated and improved at an early stage of development. The CTP offers better insights into the collision process and can itself be a development tool. Like with an FST the designer is free to examine the options in terms of geometry, structure and padding, for a variety of conditions. Furthermore, by reducing the randomness of the poor repeatability of the FST, the uncertainties of certification at a very late stage in the development of a new car can be avoided.

Some examples of Step-by-Step and Computer-Controlled Composite Tests demonstrate the good repeatability of the CTP (Figures 5 to 10).

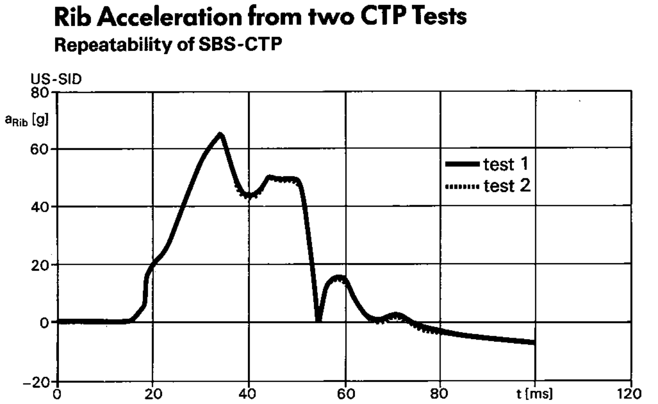


Figure 5. Rib Acceleration, Repeatability of Two SBS-CTP Tests (CCMC Barrier, US-SID)

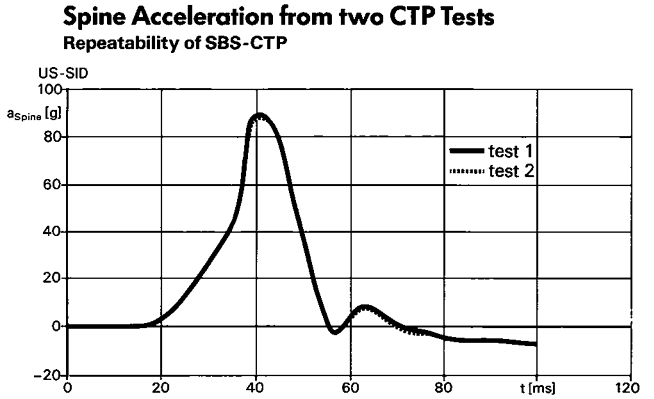


Figure 6. Spine Acceleration, Repeatability of Two SBS-CTP Tests (CCMC Barrier, US-SID)

In addition to providing more scientific information, the CTP approach will be less expensive as a certification process. This must ultimately benefit the consumer in that costly full-scale crash testing, late in the production process which could lead to enormously expensive changes in design, can be avoided. For small volume car manufacturers, such changes could be commercially

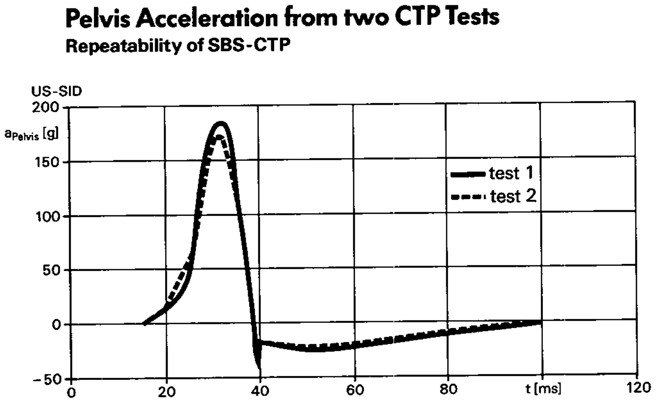


Figure 7. Pelvis Acceleration, Repeatability of Two SBS-CTP Tests (CCMC Barrier, US-SID)

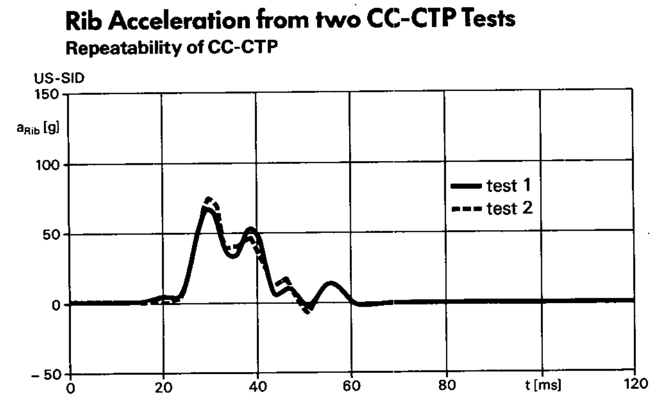


Figure 8. Rib Acceleration, Repeatability of Two CC-CTP Tests (NHTSA Barrier, US-SID, FIR)

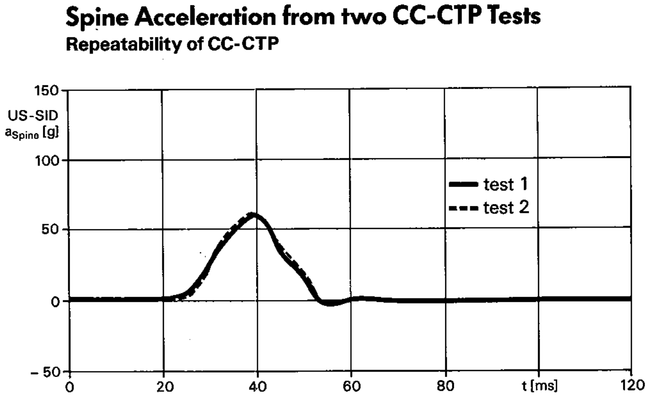


Figure 9. Spine Acceleration, Repeatability of Two CC-CTP Tests (NHTSA Barrier, US-SID, FIR)

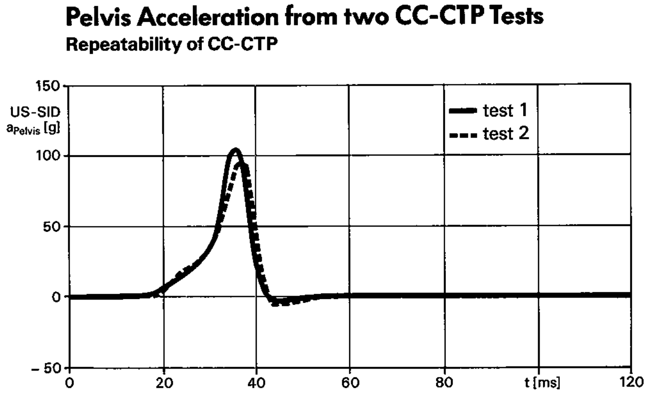


Figure 10. Pelvic Acceleration, Repeatability of Two CC-CTP Tests (NHTSA Barrier, US-SID, FIR)

disastrous. If the global test approach is chosen, the viability of certain manufacturers may be brought into question, with ultimately a reduction in choice for the consumer.

In principle, the CTP approach introduces the idea of a new type of compliance testing—computer-aided compliance. This is the logical development towards the next generation of safety standards where variations in population and crash characteristics can be evaluated rationally to optimize protection with regard to real world accident exposure.

CTP History

A brief review of major events in the evolution of the CTP follows.

The CTP was introduced to the public for the first time in May 1987 [1] at the government/industry meeting in Washington and at the VDI Conference [2] in Wolfsburg by Volkswagen, as a means of designing the side structure of a car for effective occupant protection.

In April 1988 [3], the European car manufacturers (CCMC) presented the CTP as an alternative procedure for side impact testing to a number of government officials and to representatives of the European Commission. A further presentation was made by Volkswagen at a TUV Rheinland Symposium [4].

Since that kind of approach cannot be a local one, a CTP Steering Committee including CCMC, JAMA and MVMA was established in order to coordinate the development of the CTP. This group had its first meeting in October 1988.

In April 1989 [5], CCMC presented an improved mathematical occupant at the Institution of Mechanical Engineers, London.

In June 1989 [6], the CTP approach was introduced to GRSP, a subgroup of WP 29, in Geneva and since that date, it has been permanently on their agenda. In June 1989 [7] also, the very first results were obtained with the Computer-Controlled CTP and presented at the ESV Conference.

Since CCMC and also the CTP Steering Committee found that institutions responsible for legislation should be kept informed closely about the CTP, briefings were conducted for this purpose with the Japanese MOT and again with the European Commission in July 1989.

Another briefing took place in Bruxelles with the Commission and NHTSA in November 1989. The advanced test methodology for side impact protection was presented at the 13th FISITA Congress [8].

In September 1990 a working group was established by GRSP in order to prepare a plan and a test matrix for the comparison of the FST and CTP. The work program has been defined.

The most recent presentation of the CC-CTP took place in Wolfsburg in 1991 [9]. It was attended by European Government representatives, Institutes and car manufacturers. It was the first time that a CC-CTP test had been performed with the new ACEA test rig installed at Volkswagen.

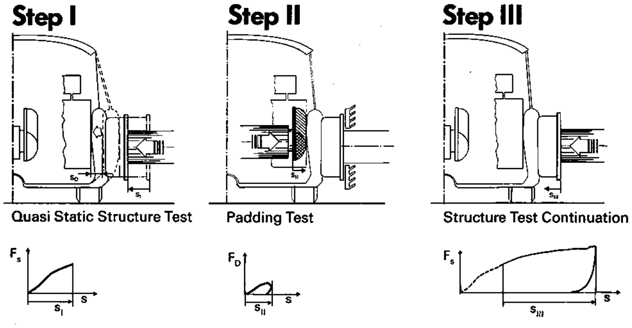
Stages of the CTP Development

A short description of the evolution of the CTP may help to understand the basic principle of the CTP.

Step-by-Step (SBS) CTP

In Step I, the door was loaded by an exterior barrier until there was contact between the door and the occupant (Figure 11). During Step II, a single interior loading device then measured the interior door response. This was followed by Step III which was a continuous deformation of the vehicle by the external barrier until the energy level of the chosen crash severity was reached. Step IV then consisted in using the computer-based dummy to give biomechanical outputs such as thoracic accelerations, TTI values, etc.

Composite Side Impact Test Procedure



Composite Side Impact Test Procedure
Step IV: Evaluation of Test Results

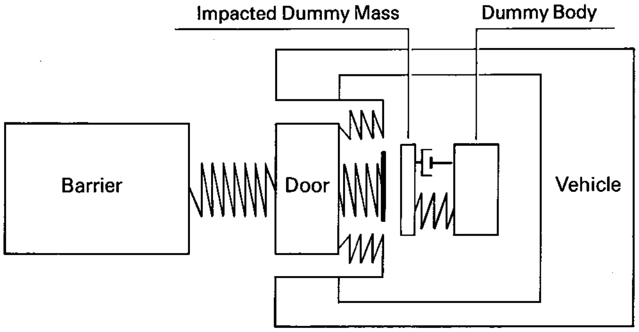
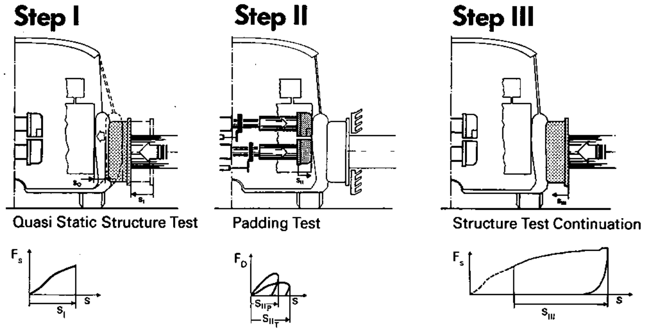


Figure 11. Four Steps of Step-by-Step CTP with One-Body ILD

This composite application of physical testing with computer calculation gave the CTP its name.

CCMC SBS-CTP Approach. The next stage of the CTP development (Figure 12) introduced separate thoracic and pelvic interior loading devices (ILD), together with an additional segment below the thorax to assess abdominal loads in accordance with the EUROSID. In turn, the computer dummy was developed to give a more accurate response and to give additional time-based outputs in terms of rib accelerations, chest deflection, viscous criterion, pelvic load, etc. As with the JAMA approach, the SBS-CTP in general activates the external deformable loading device (EDLD) and the ILDs separately so that the relative position between them is not in conformity with the kinematics of the FST simulated by that. This generally unreal loading of SBS-CTP sometimes causes different test results when compared with the FST.

Composite Side Impact Test Procedure



Composite Side Impact Test Procedure
Step IV: Evaluation of Test Results

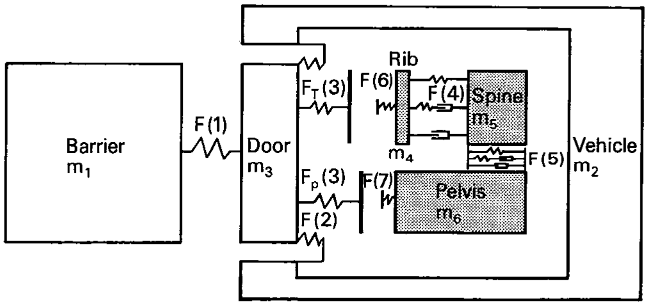


Figure 12. Four Steps of Step-by-Step CTP with Two-Body ILD

JAMA SBS-CTP Approach. In January 1989, JARI/JAMA started their research activities on the CTP. The one-body interior loading device with the thoracic and pelvic segments was loaded by one hydraulic cylinder. Both were connected with a hinge element (Figure 13). The CTP computer occupant was based on the CCMC model.

Computer-Controlled (CC) CTP

The current and final stage is the Computer-Controlled CTP (Figure 14). This is a procedure in which the 4

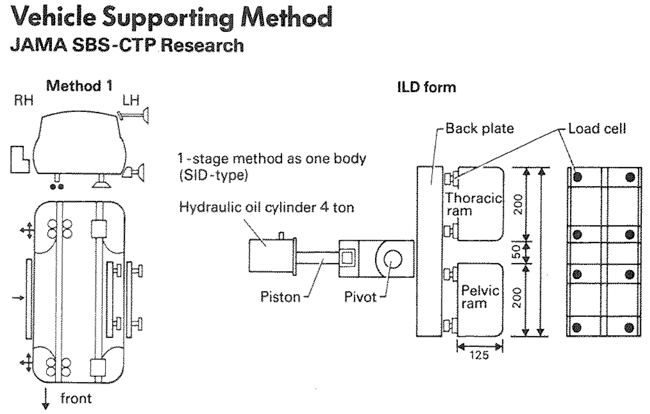


Figure 13. JAMA SBS-CTP, Vehicle Fixation and Pivot Mounted Thoracic and Pelvic ILD

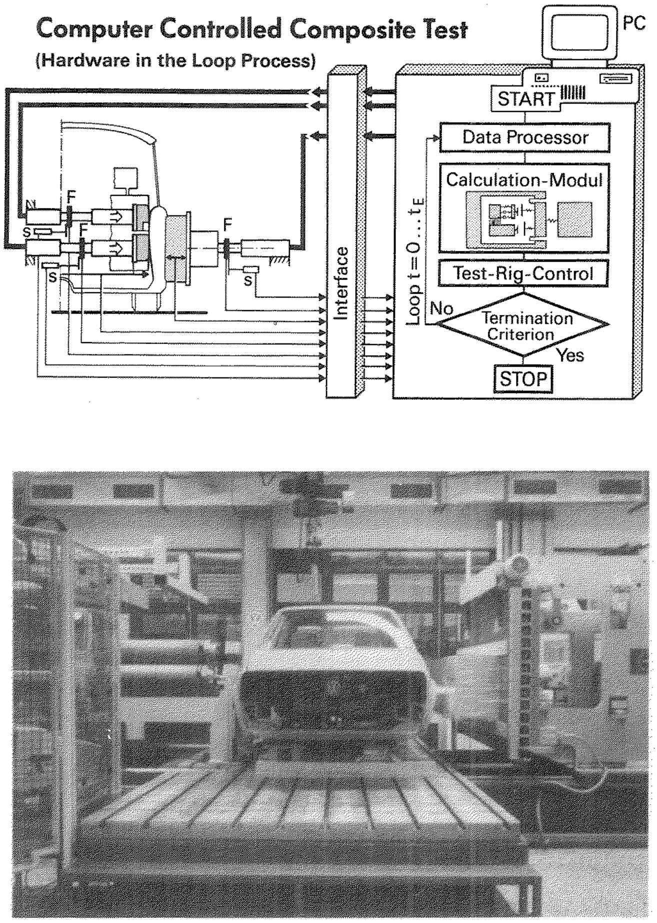


Figure 14. CC-CTP Hardware in the Loop Process and ACEA Test Stand

step-by-step stages are replaced by continuous measurement and calculation controlled by one computer. Here, the calculation determines the data which is required in the loop process between the hardware inputs of the test, the structure and ILD responses, the computer-based occupant dummy, and controls the test rig accordingly at any particular moment. Since all this takes place in a quasi-static way, the whole process can be considered as a slow motion sequence of the full-scale test.

ACEA CC-CTP Approach[1]. Following the "hardware-in-the-loop" philosophy, Figure 14 shows the bi-directional communication of the test stand and CTP calculation module via the interface.

The Composite Test Procedure has the goal of determining occupant responses during lateral impact. For simulating this event, the CTP uses a lumped mass model where rigid masses are connected by non-linear energy-absorbing elements. Input data for this kind of simulation are the weights of the colliding vehicles and the characteristics of the energy-absorbing materials in terms of force/deflection curves. These curves are derived from a quasi-static test with a body-in-white or fully equipped vehicle. Within the CC-CTP, the calculation itself determines the data which is required from the test stand.

Dynamic effects: The quasi-static simulation of a dynamic event has to address the following effects:

- speed depending effects
- inertia effects

Research on the effect of strain rate sensitivity of sheet metal members has shown that this effect is of minor importance.

To improve the correlation between FST and CTP, it appears that speed-dependent influences in general may be approximated by a simple formula:

$$F_{dyn} / F_{stat} = 1 + \alpha \cdot |v_r|$$

α, dynamic factor (fixed)
$|v_r|$, absolute value of the relative velocity between two masses
where α is a constant factor.

Door inertia: Special emphasis must be laid on the problem of the door inertia, which leads to the so called "static door effect." This effect appears when following the requirement that the side structure deformation in the static case be equal to that in the dynamic case. Only a strategy which fulfills this requirement is able to obtain the right time-management regarding the determination of forces and deflections for use in the simulation. Consequently, the displacement of the barrier relative to the vehicle in the simulated FST is not equal to the stroke of the main ram on the test stand. Figure 15 explains this fact in the case of positive door acceleration. In a dynamic event, the barrier is loaded by the deformation resistance of the side structure *and* the door inertia. Adjusting the main ram to the force level of the barrier needed for a simulated FST would lead to too much side structure deformation. The main goal is that the door movement/time history relative to the vehicle is equal during CC-CTP test and simulated FST. This

[1] Major parts of the strategy were developed by J. Bohle as part of his doctoral thesis.

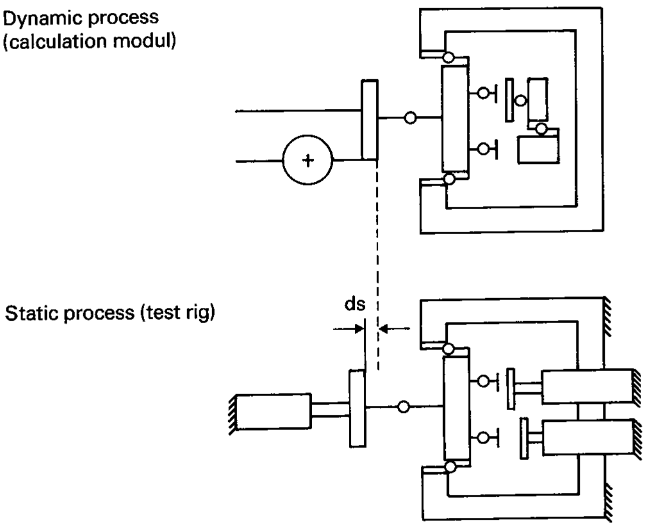


Figure 15. Barrier Movement Control to Compensate the "Static Door Effect"

means that the main ram is adjusted by the relative displacement between the door and the vehicle (= side structure deformation).

To compensate for the absence of door inertia in a CC-CTP test, it is necessary to use for the simulation a pre-set force/deflection (FD) characteristic of the EDLD taken from a frontal fixed barrier impact.

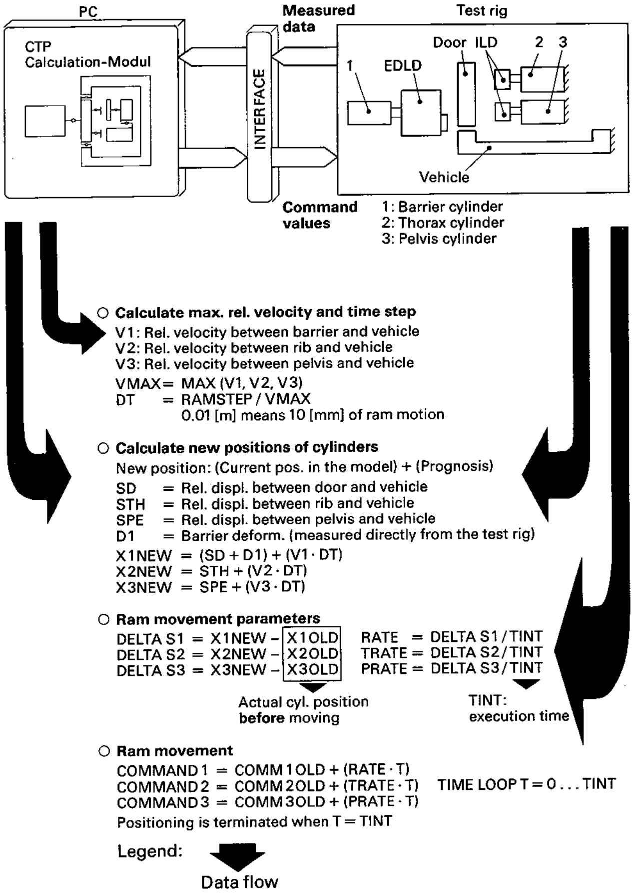
Strategy: Based on these assumptions, a strategy was developed which satisfied at any particular moment of the calculation the kinematics and corresponding FD characteristics. The deformation and force levels of the structures are determined according to the time elapsed in the simulation model. While structural data in terms of FD curves are available for the CTP program, the simulation continues to run. If the information about a certain characteristic is limited, the calculation model "asks" the test stand for more FD data. At this point, the simulation is stopped and the strategy shown in Figure 16 is implemented.

Calculate max. relative velocity and time step: The current displacements and velocities are known from the "frozen" state of the simulation model. The maximum relative velocity (car-related, because the car is fixed on the test stand) is now coupled with the maximum ram step (arbitrary value, defined here to e.g. 2 mm to provide high accuracy) of the test stand.

Calculate new positions of cylinders: The determination of new cylinder positions contains two items:

- Update of the test stand to the actual deformation level of the simulation model
- Prognosis of the further deformation

The update is an adjustment according to the positions of the corresponding masses of the simulation. The prognosis is essential because the simulation model needs known structural data for calculating; e.g. see initial condition at crash time t = O ms. All forces, displacements and deflections are zero. Only the prognosis according to the relative velocity between barrier and vehicle provides a movement of the main ram.



○ **Calculate max. rel. velocity and time step**
V1: Rel. velocity between barrier and vehicle
V2: Rel. velocity between rib and vehicle
V3: Rel. velocity between pelvis and vehicle
VMAX = MAX (V1, V2, V3)
DT = RAMSTEP / VMAX
0.01 [m] means 10 [mm] of ram motion

○ **Calculate new positions of cylinders**
New position: (Current pos. in the model) + (Prognosis)
SD = Rel. displ. between door and vehicle
STH = Rel. displ. between rib and vehicle
SPE = Rel. displ. between pelvis and vehicle
D1 = Barrier deform. (measured directly from the test rig)
X1NEW = (SD + D1) + (V1 · DT)
X2NEW = STH + (V2 · DT)
X3NEW = SPE + (V3 · DT)

○ **Ram movement parameters**
DELTA S1 = X1NEW − X1OLD   RATE = DELTA S1 / TINT
DELTA S2 = X2NEW − X2OLD   TRATE = DELTA S2 / TINT
DELTA S3 = X3NEW − X3OLD   PRATE = DELTA S3 / TINT
Actual cyl. position before moving
TINT: execution time

○ **Ram movement**
COMMAND 1 = COMM 1OLD + (RATE · T)
COMMAND 2 = COMM 2OLD + (TRATE · T)   TIME LOOP T = 0 . . . TINT
COMMAND 3 = COMM 3OLD + (PRATE · T)
Positioning is terminated when T = TINT

Figure 16. ACEA Strategy to Control the EDLD and ILD Ram Motions During CC-CTP Test

The corresponding related positions of the occupant rams (thorax, pelvis) are equal to the displacements of rib mass and pelvis mass relative to the vehicle. The position of the main ram is determined by the relative displacement between the door and the vehicle, added to the barrier deflection, measured directly at the test stand.

Ram movement parameters: The step width for each cylinder is achieved from the difference between the current position at the test stand and the new (calculated) position.

Basic research on the effect of sequential loading of structure requires that all three rams move simultaneously and reach their final position within the same time interval. Otherwise, there could be another force and deflection level of equilibrium, if the rams are moved sequentially. In order to take this fact into account, a time interval named TINT is applied to ensure that all three rams move at the same time (see Figure 17). In other words, TINT is the execution time of the ram movement.

Ram movement: Each step width of a cylinder was divided by TINT to use a time loop to increase the command values for ram motion (ramp input). When TINT is elapsed, the new forces and deflections are

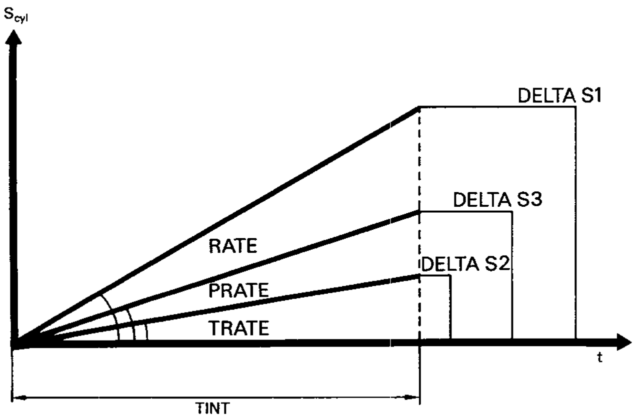


Figure 17. Displacement of Each Cylinder During the Execution Time TINT

measured. These values are prepared for prolongation of the FD curves, required by the CTP program. The scheme is shown in Figure 18.

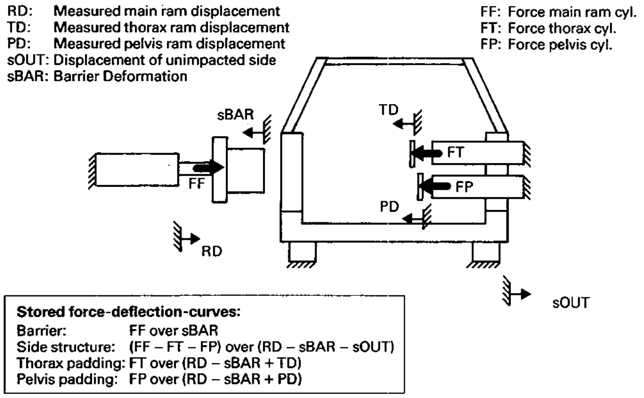


Figure 18. EDLD and ILD Ram Motions to Determine the FD-Characteristics of Side Structure and Padding

JAMA CC-CTP Approach. The JAMA approach follows the idea to adjust the cylinders as closely as possible to the equivalent position of the simulation model.

For that reason, the EDLD is moved on towards the tentative target position s_{target} = (side structure deformation + barrier deformation) obtained from integration calculations after the time interval Δt. During the movement the ram displacement and ram force are continuously measured. At every reading of measured data, the barrier deformation is calculated from the barrier force using a known (pre-set) barrier FD curve. The side structure deformation of the vehicle on the test stand (named quasi-static side structure deformation) is calculated by main ram displacement minus barrier deformation.

This quasi-static side structure deformation is compared with the dynamic side structure deformation calculated with the simulation model. If the quasi-static side structure deformation is equal or greater than the dynamic side structure deformation, the movement stops and the integration continues.

As with the ACEA approach, the JAMA strategy also requires that the static side structure deformation be equal to the dynamic side structure deformation in the model.

After every integration step, the ram movement velocities are achieved from the velocity of the corresponding masses divided by a "time expanding scale" of 12 000. This means that 0,1 ms dynamic simulation time corresponds to 1,2 sec static CTP test stand time.

During the ram movement, the main ram force and displacement are continuously measured. The barrier deformation is in this method calculated on the basis of the pre-set FD curve. The ram displacement minus barrier deformation equals the quasi-static performed side structure deformation. This calculated side structure deformation is now compared with the dynamic side structure deformation calculated in the simulation.

Final CC-CTP. Today, both CC-CTP strategies have shown that they are suitable to control the CC-CTP. Within the CTP Steering Committee, work is in progress to have only one optimized CC-CTP method. The JAMA approach seems to be simpler than the ACEA approach and is, with no doubt, more closely connected to the positions of the equivalent masses in the simulation model. However, it depends on the barrier force/deflection curve, derived from a 35 km/h rigid wall impact. ACEA is using also a pre-set barrier curve for simulation, but uses for the determination of the side structure and padding FD characteristics the measured deformation of the barrier face. Today the deformation of the barrier is not measured by JAMA. It is possible, if necessary. During the run-in-phase of ACEA's test stand in Wolfsburg, a lot of special cases were tested and the control algorithm showed a good stability.

ACEA's CC-CTP strategy is using the RUNGE-KUTTA method of the fourth order with a step width control to provide high accuracy.

The RUNGE-KUTTA method needs the force data for the differential equations not only at the actual position, but also slightly ahead ("looking into the future" according to the current step width). In order to meet the requirements of the RUNGE-KUTTA method, ACEA's control algorithm provides a little bit more of the force/deflection characteristics than is necessary for performing the actual integration step. JAMA cannot use the RUNGE-KUTTA method, because they directly measure the forces of the side-structure and padding, whenever it is needed by the differential equation (at any integration step). For that reason, JAMA uses the EULER method.

CTP Occupant

A major advantage of the CTP over the current full-scale tests is that with the CTP there is no need for a mechanical dummy. In the CTP, occupant loads are evaluated by means of a mathematical occupant. Since the properties of a mathematical occupant are free of scatter, the repeatability of the CTP promises to be superior to that of the FST.

Mathematical Modelization. Although the CTP's ultimate goal is to obtain a humanlike response, it has to be demonstrated that the CTP can produce results equivalent to those obtained in dynamic tests with a physical dummy. Therefore, it is necessary to have a mathematical modelization of the US-SID and the EUROSID which are the dummies used in FSTs. Based on biomechanical knowledge acquired from postmortem human subjects (PMHS) testing, APR is developing the real human model so that the computer model can be validated against real biomechanical data for a range of the exposed population. This establishes the advantages of a computer-based occupant model over a physical dummy, as it is possible to relate the CTP occupant loads directly to the accident scene, not only by having actual human compliance parameters but also by having the ability to vary those parameters according to the segment of the population to be examined.

The mathematical modelization and parameter identification of the US-SID and EUROSID(O) are performed by APR and described in the Appendix. PMHS modelization and parameter identification are in progress. The first results will be presented during the ESV Conference.

Interior Loading Devices. To correctly simulate the dummy loading, the shapes of the thoracic and pelvic interior loading devices (ILD) should reflect either of the two dummies, US-SID and EUROSID(1) (Figure 19) or alternatively, the shape of the real human being under loaded conditions. The location of the ILD must also correspond to the locations of the thoracic, abdominal and pelvic zones of the occupant used.

Initially, a single ILD was used (Figure 11). At the IMechE Conference, an improved mathematical occupant with a two-stage model was presented (Figure 12). This introduced separate thoracic and pelvic ILDs, together with an additional segment at the thoracic ILD to assess abdominal loads in accordance with the EUROSID.

CC-CTP Test

The CTP reproduces a 90° side impact with a barrier and lateral impacted vehicle. To perform CTP tests, a test rig has been developed (Figure 14) with exterior (EDLD) and interior (ILD) loading devices which are controlled by a PC to assess the FD characteristics of the side structure and padding of tested vehicles (see above). The FD information is used to continuously update the computer calculation to determine the kinematics of a simulated test to control the EDLD and ILD cylinders and to evaluate occupants loads. During the process, the loading devices and the computer evaluation run simultaneously.

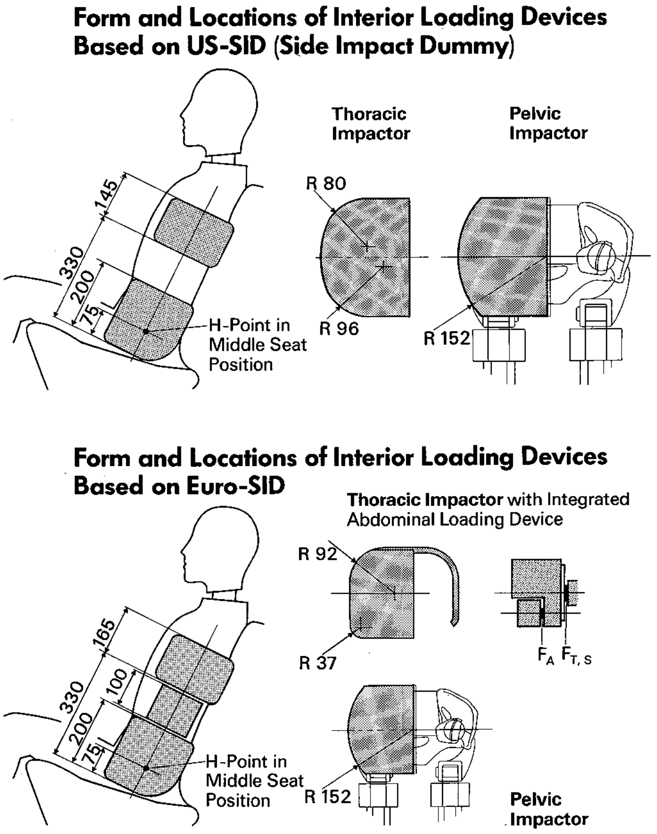


Figure 19. Shapes of the US-SID and EURO-SID ILD

Test Rig

The test rig is 8,000 mm long, 6,500 mm wide and 4,500 mm high. Its weight is about 400 kN.

The EDLD hydraulic actuator has a piston stroke of 1,000 mm and a load capacity of 350 kN. The ILD hydraulic actuators have a piston stroke of 700 mm and a load capacity of 80 kN.

There is a free space of 2,200 mm between the ILD and the EDLD. Based on vehicle coordinates, the EDLD is positioned in z direction by motor drive and in x direction manually. The ILD are positioned in all directions by motor drive. The range of positioning takes into account front and rear occupants and left and right side impacts of all passenger cars, multipurpose vehicles and vanagon types of cars. The ILD support can turn around the y-axis (+ 30°) in accordance with the different seat back angles.

Test Description

To perform a CTP test, the location of the EDLD relative to the vehicle in FST test condition has to be marked, as well as the H-Point on the interior door panel according to the selected seat position.

Vehicle fixation: The body of the vehicle to be tested is secured on a rigid T-stone plate (Figure 20). The body shell fixation points for the front and rear wheel suspension systems are used (Figure 21). The non-impacted side of the vehicle is rigidly secured.

The impacted side of the vehicle is secured only in the vertical direction to be able to rotate and to move in any horizontal direction. To prevent lateral and/or rotational movement of the vehicle during the test, the non-impacted side is supported in lateral direction at the sill and the roof (Figure 22).

Positioning of EDLD and ILD: After preparation and fixation of the vehicle, the EDLD and ILDs are positioned via remote control according to the H-Point and EDLD marks at the vehicle and the seat back angle. The remaining strokes of the three cylinders have to reflect the computer-controlled strokes for the CC-CTP run.

Instrumentation: To measure the deformation of the EDLD in the ILD impact area, two string potentiometers are installed. The actual deformation relates to the maximum value of one of the string potentiometers. Two string potentiometers at the non-impacted side of the vehicle, placed at the level of the ILD cylinder axis (z-direction) at the B-pillar, are measuring the lateral movement and the rotation of the tested vehicle.

For research reasons, it is in general possible to measure 29 channels, 9 via the digital cylinder control device and 20 via extra amplifiers. Forces are measured with four load cells, one at the EDLD, two at the thoracic (EURO-SID) and one at the pelvic ILD.

The pre-test phase ends with the calibration, loading of the computer with the input data (e.g. masses of colliding vehicles, impact velocity, barrier and occupant characteristics stored in the library, and test description) and starting of the CC-CTP test which is controlled according to the described strategy. Immediately after the test, the computer automatically starts filtering the channels according to given specifications. Test data are stored on a floppy disk. The time to perform the test is about ten minutes. About half a day is needed to prepare the test.

CC-CTP Computer Program

The CTP program package offers a lot of features for side impact simulation:

- Simulation with measured or assumed FD curves, to study the sensitivity of certain parameters like padding thickness or padding force/level.
- Filtering of simulation data (SAE and FIR filtering)
- Determination of dummy loads like VC, TTI, peak values, 3-ms cumulative values, etc.
- Comparison of CTP-data with full-scale test data.

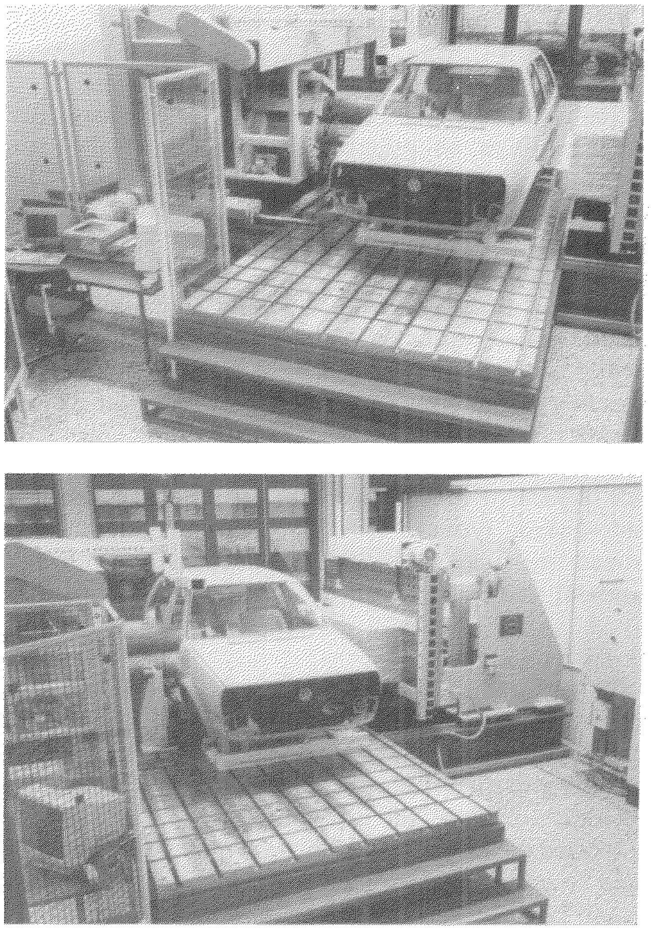


Figure 20. Vehicle Fixation at the ACEA Test Stand

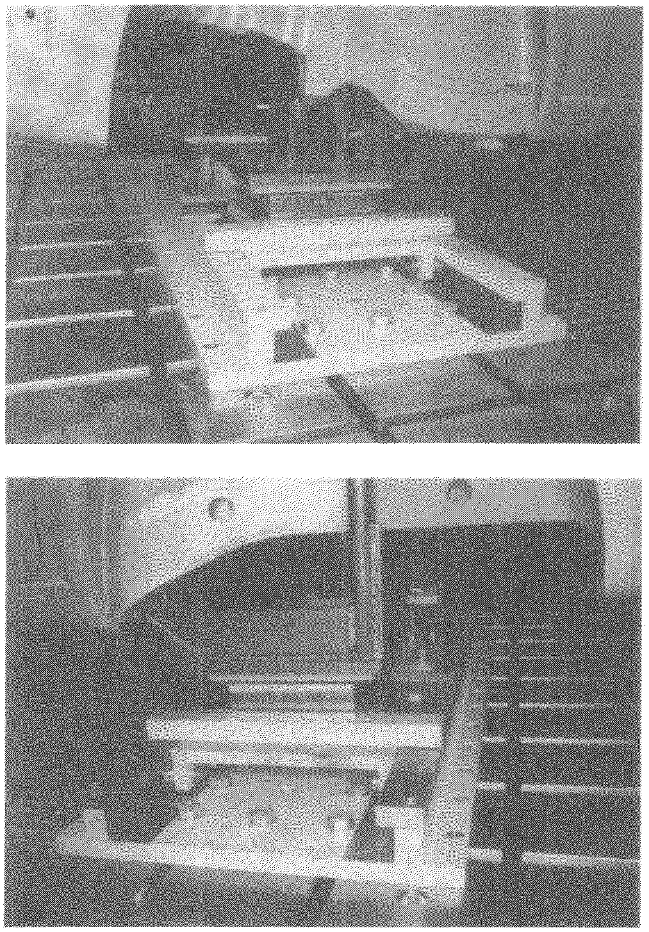


Figure 21. Body Shell Fixation at Impacted Side at the ACEA Test Stand

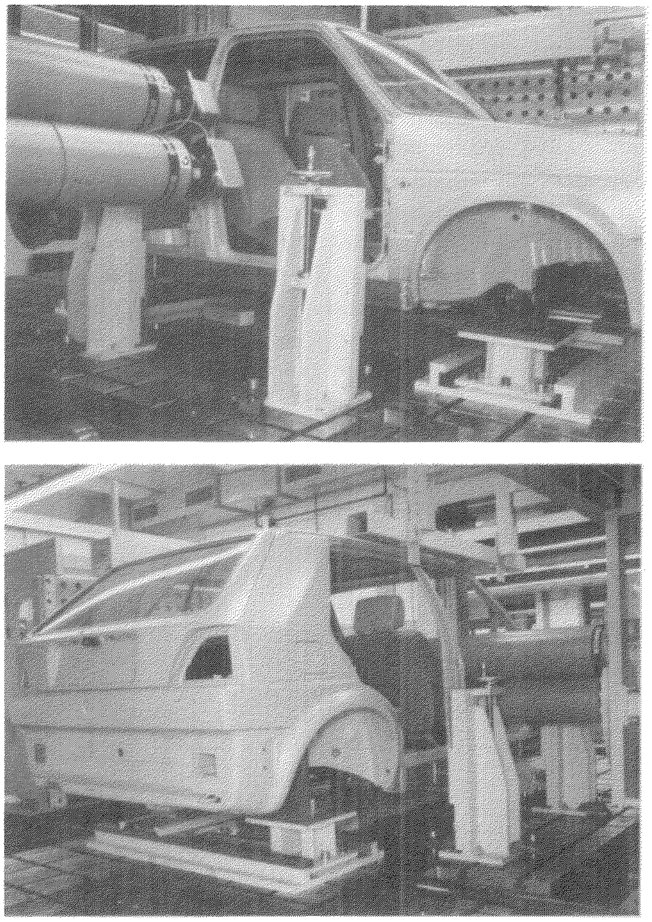


Figure 22. Vehicle Fixation at Non-Impacted Side at the ACEA Test Stand

- Plotting of time-histories and FD curves.
- Running of the CC-CTP

The last feature offers the access to the test site. This access is password-protected. If the CC-CTP request of the CTP menu is chosen, 5 sub-requests are offered:

- Test Description
- Transducer Identification
- Positioning of Cylinders
- Test Control Parameters
- Perform Test

The CTP program runs on an IBM-compatible PC (OLIVETTI CP 486) with an INTEL 80 486 processor and 8-MB ram and at least 30-MB hard-disk unit. An HP Laser Jet II for the output is recommended. The program also runs on an 80 386/80 387 or 80 286/80 287 PC with a 1-MB ram, but the performance becomes worse. The operating system DOS 3.3 is supported. There are a lot of C programs to run the user-shell, and two FORTRAN programs to run the simulation with given FD curves (post-processing and standalone-simulation for a sensitivity analysis of the parameter study) and to run the Computer-Controlled Composite Test Procedure (CC-CTP).

Historically, the CTP was started with a small computer program, running on an ATARI, and written in BASIC. This was very easy to handle and gave all the necessary information quickly. Unfortunately, the requirements increased and the CTP became therefore a package with a lot of programs. One of the requirements of CC-CTP testing was to prevent data manipulation. This is ensured by the following facts: when a CC-CTP is intended to be run for compliance purposes, the officials of a government can reformat the computer (now a PC with DOS 3.3 operating system) and install the CC-CTP program from their own diskettes. This ensures that an agreed program version is running and nothing else. Then the test site can be initialized by the REMOTE-CONTROL (sub-menu of POSITIONING OF CYLINDERS) feature. A feature, called TRANSDUCER BALANCING (sub-menu of TRANSDUCER IDENTIFICATION) allows to control whether the program really uses the values measured at the test site. Because the agreed program version runs, it is ensured that also the following start of the CC-CTP after this initialization uses the measured data.

The program has to meet different requirements:

a) Running of the CC-CTP test
Plotting of the measured data
Post-processing of the CC-CTP test (filtering and evaluation of test data, TTI, VC, ...)
Plotting of the results of the post-processing
b) Running of a CTP simulation with an input tape chosen by the user
c) Comparison of CTP and/or FST results
d) Filtering of data
e) Plotting of data
f) Handling of library-stored input parameters of different dummies (EUROSID(O), EUROSID(1), US-SID, Human Being, ...)
g) Handling of library-stored input parameters of different barriers types (EEVC barrier, NHTSA barrier, CCMC barrier, . . .)

When (a) is requested, an automatic procedure with 3 sub-requests runs to avoid manipulation:

- Identification of the test conditions:
  - Barrier Type
  - Dummy Type
- Initialization of the test stand:
  - Positioning of the cylinders
  - Checking whether all transducers work properly
- Starting of the program to run the test

The program runs the CC-CTP, the CTP post-processing and the plot program for documentation of the results. (No user intervention is possible at this stage except for the emergency exit and HOLD.)

The HOLD menu allows to interrupt the cylinder motion and to check the test stand for photo documentation, or to make a detailed checkup of the vehicle. When the user requests this HOLD, no data manipulation is possible.

When the user chooses the barrier or dummy type, the data of that barrier or dummy are requested from the barrier or dummy library and included into the input tape of the CC-CTP simulation. Another input tape describes the transducers. The program is flexible to use different transducer combinations.

Figure 23 shows a flow chart of the main actions taken to run the CC-CTP. There is a user-controlled initialization: test input data, selecting the dummy and barrier parameters. There is the CC-CTP program itself, which is a CTP simulation run with the only difference that it requests the FD curves from the test site. Then the results are presented by automatically running the post-processing and plot programs.

The CC-CTP-Request

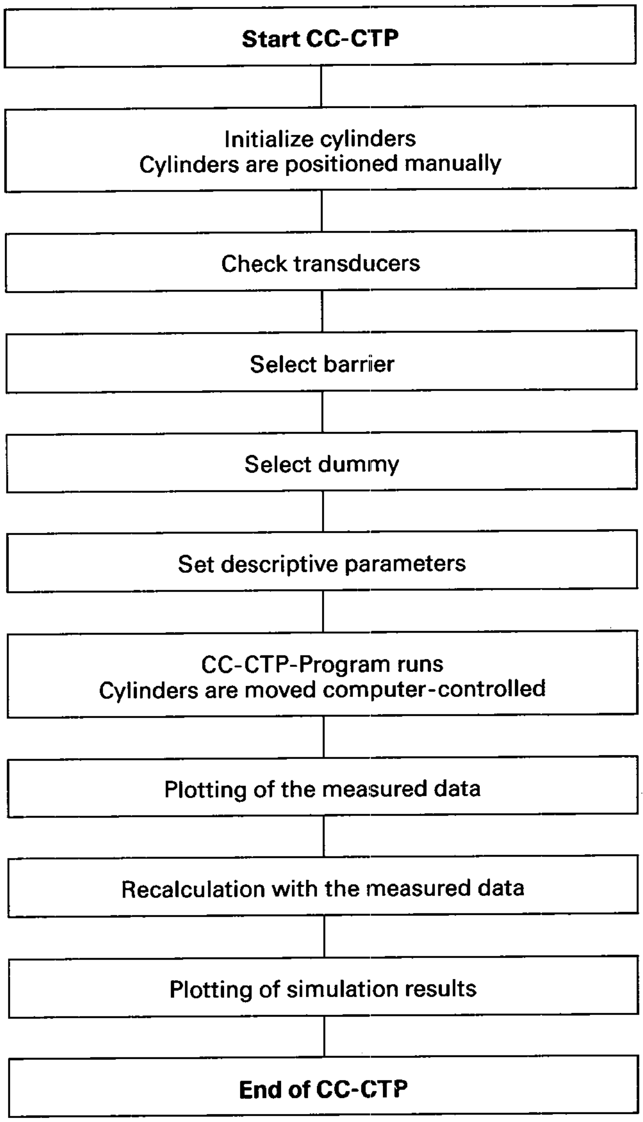


Figure 23. The CC-CTP-Request of the Main-Menu of the CTP User-Shell

Figure 24 shows the CC-CTP program in detail. When the forces are to be computed, it is decided whether a prior measurement offers enough FD information. If this is true, the computation is continued, otherwise it is interrupted for a new motion of the cylinders. All cylinders are moved simultaneously into the kinematically correct position in the first step. After this interruption, it is checked again whether enough FD information is available. If the first step did not prolong the FD curves sufficiently, the cylinder, which is responsible for the FD curve that needs more deformation, is moved separately. Normally, the first step is sufficient. Sometimes, a second step is needed.

The CC-CTP-Program

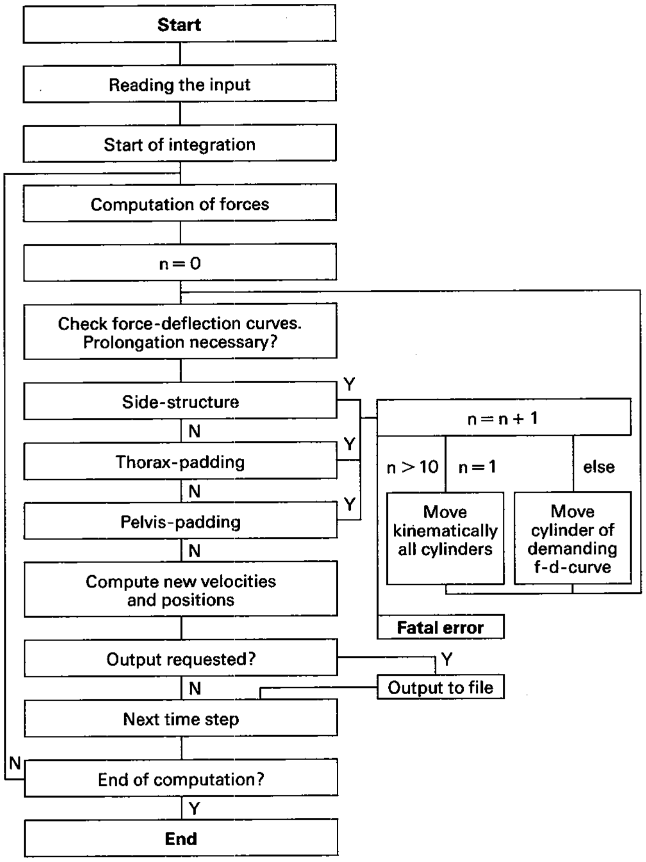


Figure 24. Overview of the Flow-Chart of the CC-CTP Program

If more than 10 steps of a separate motion are not successful in prolonging the FD curve, the test is stopped with a fatal error. This did occur only in the beginning of the CTP development, when the strategy of the cylinder motion was not correct. For details of the description of the strategy of the cylinder motion, see above.

Suitability of CC-CTP

To demonstrate the suitability of the new CC-CTP in connection with the new ACEA test rig and computer program, CTP and FST test results of one vehicle are compared to give an example (Figures 25-30). Tests were performed according to the NHTSA procedure, with the NHTSA barrier and the US-SID.

The actual US-SID CTP occupant was used which relates to the mathematical modelization developed by APR (see Appendix). The time phase and the peak values of FST and CTP results have certain deviations. To be able to conclude on this, more FST and CTP tests are needed to know the scatter of results of both procedures. This will be part of the defined GRSP project. As an example, test results of two identical CC-CTP tests are compared. The acceleration time histories are equal (Figures 8-10).

Future Steps

The final CC-CTP should be available at the end of 1991. The CC-CTP versions developed in Europe and Japan have to be unified into one procedure. This appears to be a task that can be solved, since the procedures are—due to the coordination of the CTP Steering Committee—in general quite similar.

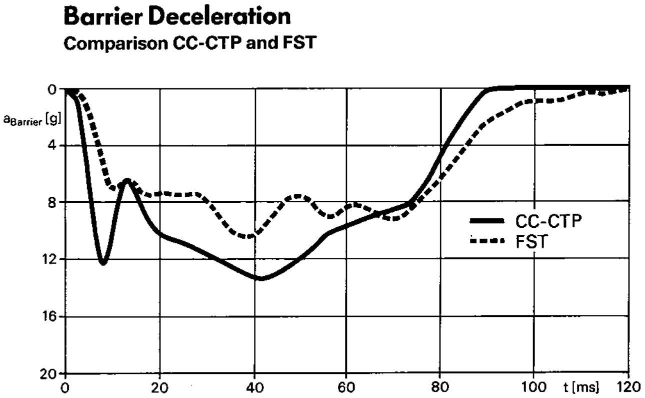


Figure 25. Barrier Acceleration, Comparison CTP and FST (NHTSA Barrier, US-SID, SAE CFC 60)

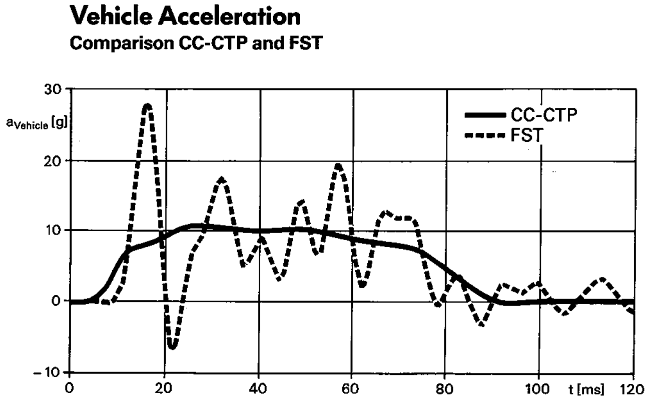


Figure 26. Vehicle Acceleration, Comparison CTP and FST (NHTSA Barrier, US-SID, SAE CFC 60)

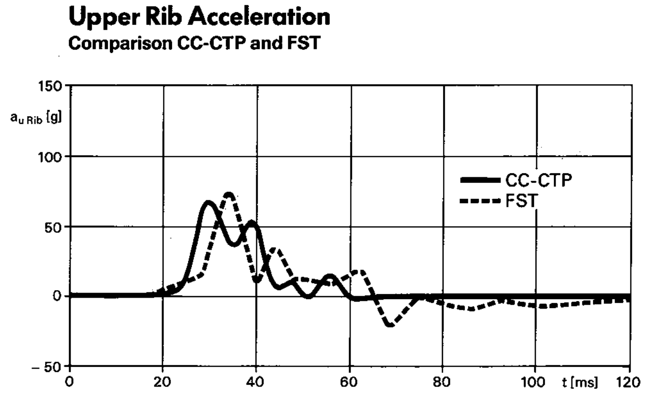


Figure 27. Upper Rib Acceleration, Comparison CTP and FST (NHTSA Barrier, US-SID, FIR)

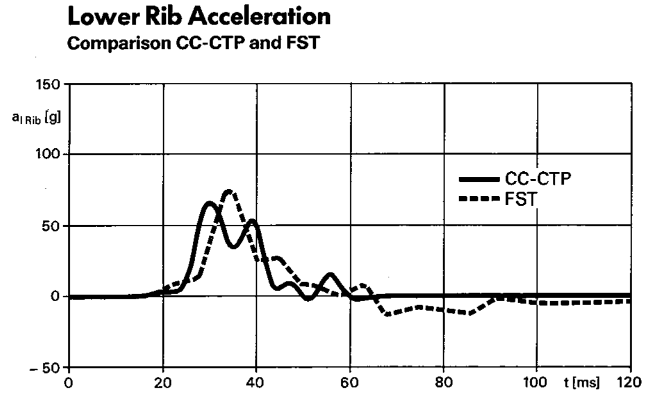


Figure 28. Lower Rib Acceleration, Comparison CTP and FST (NHTSA Barrier, US-SID, FIR)

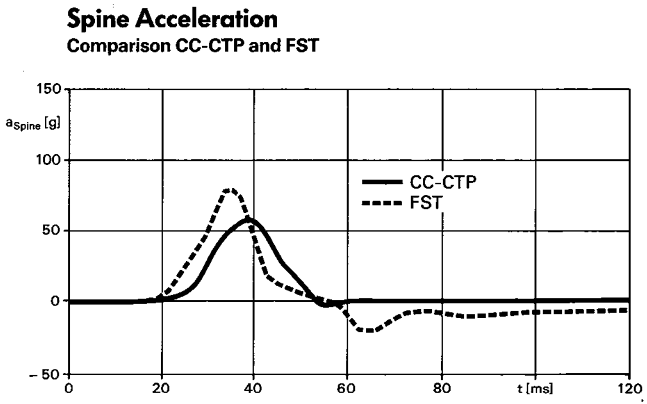


Figure 29. Lower Spine Acceleration, Comparison CTP and FST (NHTSA Barrier, US-SID, FIR)

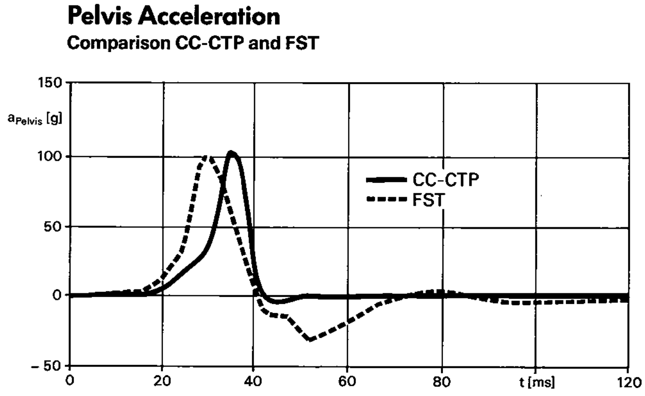


Figure 30. Pelvis Acceleration, Comparison CTP and FST (NHTSA Barrier, US-SID, FIR)

As far as the occupants are concerned, ACEA stopped all efforts of parameter identification with respect to the EUROSID(0) because this dummy was outdated and has been replaced by the EUROSID(l). The new mathematical modelization of this dummy performed by TNO will be implemented and evaluated. The development of the computer occupant representing the human being will be finalized in 1992.

The results of performed research projects also have to be analysed, and if necessary, inserted in the procedure. The CC-CTP algorithm is open to further improvements, if requested.

Finally, it has to be proven officially that the CTP is an alternative test procedure to full-scale testing. This is a task which GRSP has set up. After two meetings, the work program was defined and the test matrix established. It will start at the end of this year. Statistical rules are determined in order to decide whether the CTP is equivalent to the FST or not.

Conclusion

Among the various test procedures available for the evaluation of side impact protection, the COMPOSITE TEST PROCEDURE offers a greater potential for providing optimum and meaningful counter-measures. Compared with full-scale testing, the following advantages of the CTP are evident:

- It is easier to perform.
- It provides results which are easier to reproduce.
- It makes it easier to incorporate new biomechanical findings.
- It can be applied at an earlier stage of the vehicle development.
- It offers a new approach as regards the harmonization of the legislation on side impact collisions.
- It allows a wider approach to vehicle designs, resulting in solutions which are more efficient for a wider range of occupants, impact velocities and striking vehicle masses.
- It has the potential to transform test results directly into the accident scene and to optimize vehicle designs accordingly.

This new approach in automotive compliance testing is seen as an alternative test procedure to full-scale testing. The final suitability will be investigated by GRSP within the defined complex project. The first test results obtained with the new ACEA and JAMA test rigs (the ACEA machine has been installed at UTAC) show good conformity with results of a full-scale test and good repeatability.

References

[1] B. Richter, H. Oehlerking, R. Sinnhuber, R. Zobel "Composite Test Procedure for Side Impact Protection" Government/Industry Meeting, Washington, May 1987, SAE 871117

[2] R. Sinnhuber, B. Richter, H. Oehlschlaeger, R. Zobel "Rechnerunterstutztes Testverfahren zur Beurteilung des Seitenschutzes von PKW" VDI Symposium Wolfsburg, 1987, VDI-Berichte Nr. 665

[3] CCMC Booklet "Composite Test Procedure for Side Impact Protection An Alternative Approach" Exchange of views between European Commission and Government representatives and the CCMC Car Technical Commission Brussels, 28 April 1988

[4] B. Richter, R. Sinnhuber, R. Zobel "Vergleich von Ganzfahrzeugtests, Komponententests und theoretischer Simulation beim Seitenaufprall" TUV Kolloquium Unfallschutz der Fahrzeuginsassen in Europa Koln, 1988

[5] CCMC "The Composite Test Procedure, State of the Art" IMechE Symposium, Legislative Proposals for Car Occupant Protection in Lateral Impact London, April 1989

[6] CCMC, JAMA, MVMA "Composite Test Procedure for Side Impact Protection, An Alternative Approach" United Nations, Economic and Social Council, Economic Commission for Europe, Principal Working Party on Road Transport (TRANS, SCl), Working Party on the Construction of Vehicles (WP 29), Group of Rapporteurs Passive Safety (GRSP), Geneva, November 1989 (1991, January, TRANS/SCl/WP29/GRSP/R.48/Rev. 1)

[7] CCMC Booklet "Composite Test Procedure for Side Impact Protection" 12th ESV Conference, Gothenburg, June 1989

[8] B. Richter "An Advanced Test Methodology for Side Impact Protection" 13th FISITA Congress, Torino, May 1990

[9] CCMC Booklet "Composite Test Procedure for Side Impact Protection, An Alternative Approach" CTP Presentation, Wolfsburg, April 1991

S5-O-23

Current Status of Correlation Between CTP and FST

Shuji Yamaguchi
Japan Automobile Manufacturers Association Inc.
Katsunori Taneda
Japan Automobile Research Institute Inc.

Abstract

The current status on the extent of correlation between full-scale test results and the dummy responses obtained by CTP test is herein reported. It is based on the cooperative operations of ACEA, MVMA, and JAMA. First, an outline of the course of the JAMA/JARI

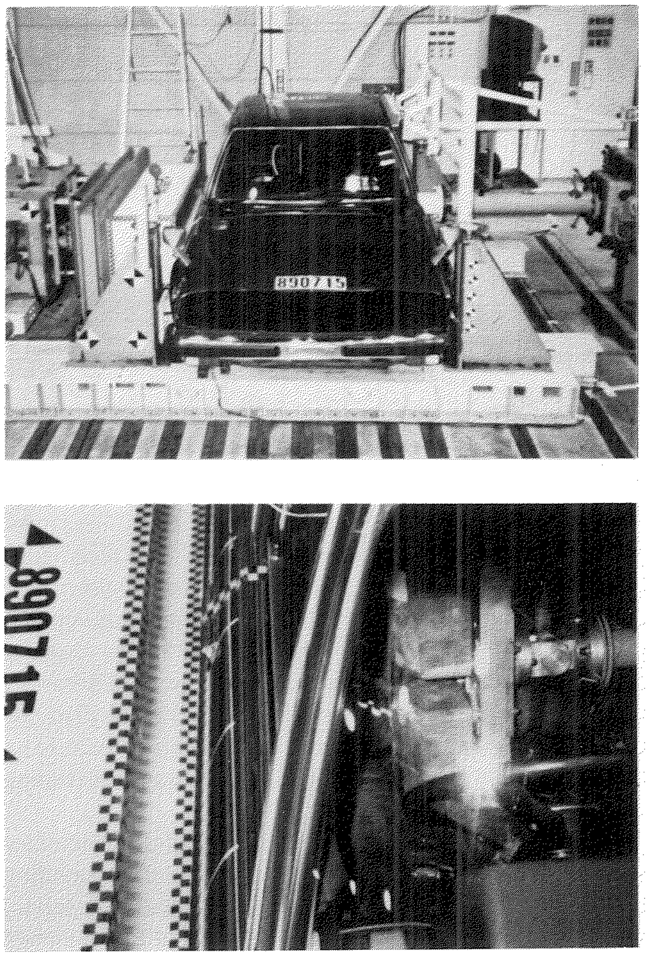


Figure 2. JAMA/JARI SBS-CTP Test Stand

Parameters for mathematical dummy model. The coefficients of the springs and dampers in each part of the mathematical dummy Version-1(V1) used in the initial Step-By-Step CTP were based on the analysis of the data from the thoracic and pelvic impact tests at 4.3 m/s specified as the SID dummy calibration test.

However, in the actual FSTs the impact velocity in most cases was 10 m/s or greater. Accordingly, impact tests for the thorax and pelvis of the dummy of up to 6.7 to 10 m/s were implemented, and a Version-2(V2) was drawn up, revising the spring and damper characteristics.

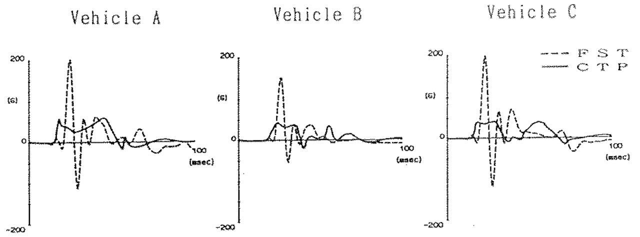
A comparison of the test data for the rib and spine accelerations waveforms for V1 and V2 at 10 m/s is shown in Figure 4. Figure 5 is a comparison of the peak acceleration values versus impact velocity for V1, V2 and the test data.

A substantial improvement can be seen in the high velocity region with V2. With the improvement from V1 to V2, the coefficients of the springs and dampers were all modified, in the most extensive modification, an idling stroke was added at the damper set between the ribs and the spine. This is referred to as Taneda's Idle Stroke (TIS) by JAMA/JARI, named after the proposer.

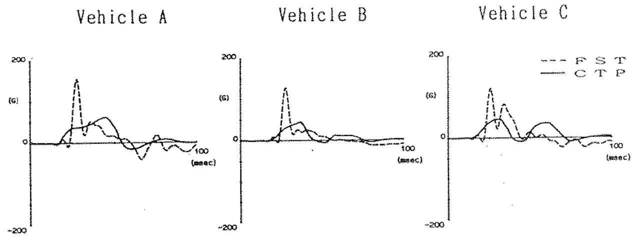
Figure 6 shows the relationship between the rib and spine acceleration and the reading of the displacement gauge between the rib and spine during SID thorax impact tests. At impact velocities between 6.7 m/s and 10 m/s, the idling portion is observed during the initial spine acceleration.

EDLD (Exterior Loading Device) loading method. During step 2 of the original SBS-CTP, the load of the

"Rib Acceleration"



"Spine Acceleration"



"Pelvis Acceleration"

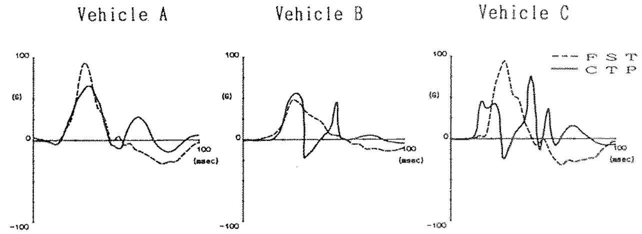


Figure 3. Comparison of Dummy Response Between FTSs and First Series of SBS-CTPs

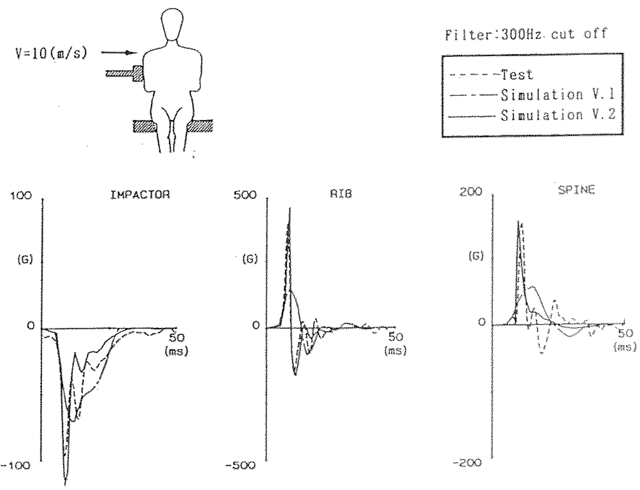


Figure 4. Comparison of Rib Acceleration in Dummy Chest Impact Test Between Mathematical Model Version 2 and Real Test

research which is all aimed at improving the correlation, i.e., a history of the improvement of the correlation of the dummy responses in full-scale tests and those in CTP tests, is introduced. Next, a description is given of the differences in the two CC-CTP systems and software developed by ACEA and JAMA/JARI, and of the extent of correlation between the results by CC-CTP and those by full-scale tests. Both methods of CC-CTP have been judged as already showing high correlation in the field of computer simulation.

Introduction

In October 1988, the CTP steering committee was formed by three organizations—JAMA, MVMA (Motor Vehicle Manufacturers Association), and what was then the Committee of Common Market Constructors (CCMC), the forerunner of the present ACEA, based on a plan proposed by CCMC.

The object of the steering committee was to focus attention on the superior potential and possibilities of the Composite Test Procedures (CTP). Since that time, data from the results of the research has been exchanged at meetings held two to three times a year.

As its share of this research, JAMA/JARI started with a feasibility study and concentrated on improving the correlation between FST dummy responses and CTP, while the MVMA research was mainly aimed at obtaining a higher level of CTP through solving problems of: the dummy load path, the effect of the crab angle, the static compression and dynamic impact characteristics of the door, etc. In addition, ACEA implemented a widespread comprehensive research program, including research into the characteristics of the human body. These three organizations have cooperatively reached the present status through these three different approaches.

The present paper has as its theme a report on "the correlation," and hence, begins with a status report on the history of the JARI/JAMA research which has all aimed at the improvement of this correlation. Thus, this report covers the history of the improvements in the correlation in the next chapter.

History of Correlation Improvements (by JAMA/JARI)

In January 1989, JARI/JAMA began implementation of CTP tests by the SBS (Step-By-Step) method. The correlation of the initial results with those obtained by full-scale tests was very poor, but improvements were subsequently obtained and the present status was reached as the result of continued process of research as in below. Figure 1 summarizes the JAMA/JARI research process in a flow chart.

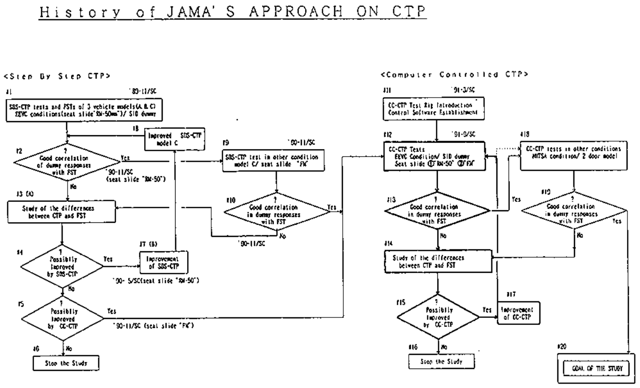


Figure 1. Flow of JAMA/JARI's CTP Research

Initial CTP Tests by JAMA/JARI

In support of the CCMC proposal, the first CTP tests were implemented as a feasibility study covering three types of Japanese-made four-door vehicles. Except the SID was used as the dummy, all EEVC (European Experimental Vehicle Committee) test conditions proposed at that time were adopted for full-scale tests, such as the EEVC barrier face, with a minimum height of 250 mm from the ground, the barrier center line impact position at the R point of the front seat, the dummy seated 50 mm from the rearmost position, and a barrier impact velocity of 50 km/h. The SID, rather than the EEVC-recommended EuroSID, was adopted because of the ease of maintenance at that time, including availability of parts.

The CTP device utilized an existing hydraulic actuator without modification, and two ILD (Interior Loading Device) heads (in places of the thorax and the pelvis) were bridged and the bridge center pivoted to the end of an ILD rod to balance two heads (Figure 2).

Figure 3 shows a comparison of the first SBS-CTP results and the corresponding FST results for the three test vehicles A, B, and C. A wave form with an extremely high peak is shown for all three vehicles in the dummy responses for the ribs and the spine for FST, while all the corresponding CTP results show large differences. A wave form with a relatively good resemblance to the FST was obtained, as shown, for the pelvis G with vehicle A, but all other wave forms are completely different.

Process of improving correlation. After the above results were obtained, a study was commenced on the effect of the following items on the correlation, and on procedures for improving this correlation.

- Review of parameters for the mathematical dummy model.
- Modification of the EDLD loading method.
- Initially set position of the ILD.
- Method of determining door mass.
- Methods of securing body.
- Relationship between dynamic and static crush characteristics of door and door pad.

Because the dummy response for the three vehicles showed wave forms with a mutual resemblance, the study was implemented using only one vehicle (vehicle C) and by adopting two cylinders for the ILD.

EDLD should be kept, but in the initial series of tests the stroke of the EDLD was simply stopped because of equipment capability. Accordingly, the load of the EDLD dropped greatly during step 2 (Figure 7).

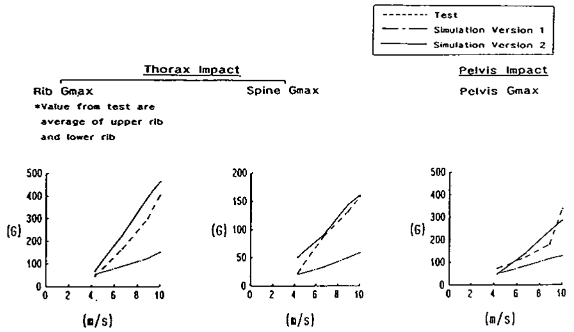


Figure 5. Peak Acceleration Values vs. Impact Velocity in Dummy Chest Impact Tests and Corresponding Simulations

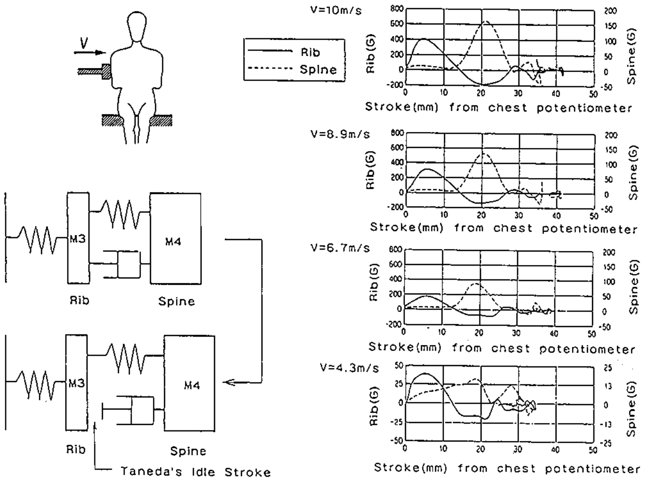


Figure 6. Idle Stroke in SID Chest Damper

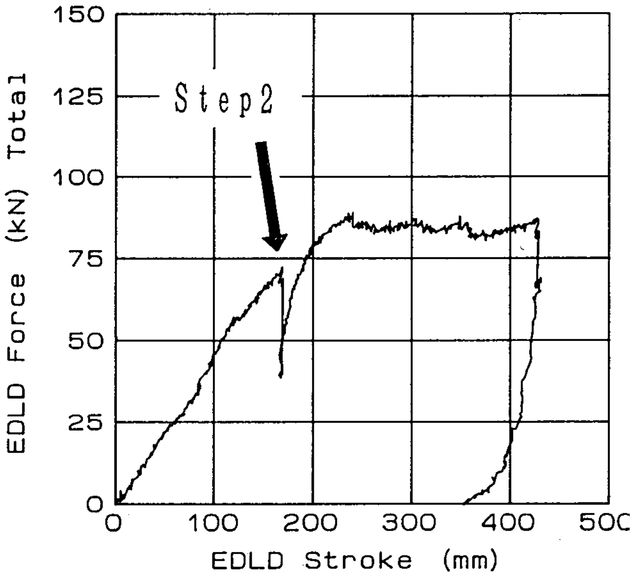


Figure 7. EDLD Force Drop During 2nd Step of JAMA/JARA SBS-CT

Because there was concern that this load drop would also cause the ILD load level to drop, such an effect was investigated by the following method.

The ILD heads were set at the initial position of the dummy and secured. Then the EDLD was advanced until the inside of the door had contacted the ILD, and continued further where the ILD loads were measured. In other words, step 1 and step 2 were fused seamlessly.

Initially set position of the ILD. An extremely high peak was produced at the beginning of the FST rib acceleration waveforms for all three vehicles. This resulted from the rib impacting the B pillar. With SBS-CTP, the round head of the ILD contacted the B pillar, but slipped away from the B pillar in further loading, because of the small diameter and inadequate bending strength of the cylinder. This point was improved by larger diameters of cylinder and ILD heads.

Method of determining door mass. With CTP it is necessary to set the mass of the door, but the question arose as to whether this should be the mass of the door only, or the mass of the door including its peripheral section, and the magnitude of the effect became a problem.

Accordingly, before the definition of the nominal door mass, the magnitude of the effect where the nominal door mass provides the maximum acceleration of the dummy was studied using CTP simulation calculations. In addition, the mass of the door, the mass of the door and the peripheral section combined, and the mass of the vehicle were studied for 29 Japanese automobiles prior to these calculations (Figure 8, 9, 10). The results of calculations showed that a change in the nominal door mass had a major effect on the door acceleration, but only a small effect on the dummy response in terms of the accuracy required at that time (Figure 11).

The percentages of the actual door mass to the vehicle mass were within spans of ± 21% and ± 25% for two-door and four-door cars respectively. The effect on the dummy acceleration in these spans was ± 6%, and no particular problem was expected even when the door mass was estimated from the vehicle mass.

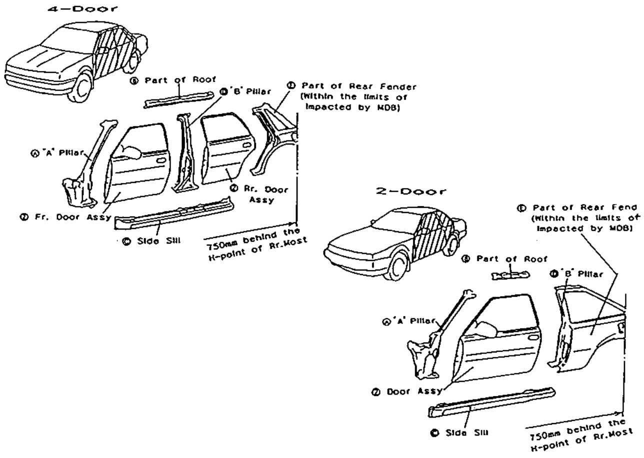
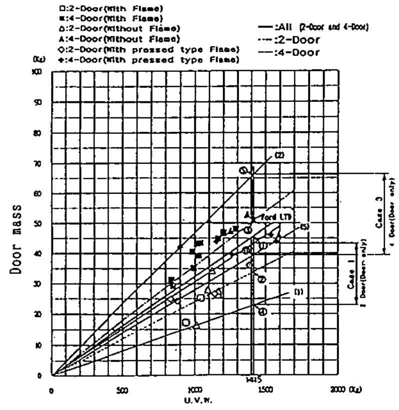


Figure 8. Parts Investigated in Weight as Door Parts in CTP Model



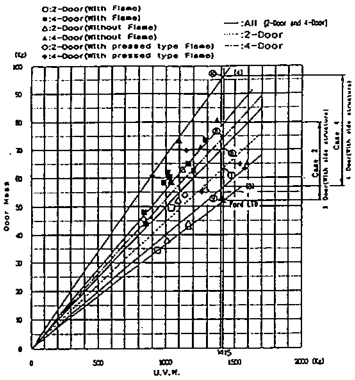
Equation of 2 door model
Average : y=0.0241x
Minimum : y=0.0163x
Maximum : y=0.0306x

Equation of 4 door model
Average : y=0.0359x
Minimum : y=0.0279x
Maximum : y=0.0468x

Equation of 2 and 4 door model
Average : y=0.0323x
Minimum : y=0.0468x
Maximum : y=0.0163x

Equation "y=ax" were calculated by least squares.

Figure 9. Relationship Between U.V.W. and Door Weight



Equation of 2 door model
Average : y=0.0450x
Minimum : y=0.0366x
Maximum : y=0.0563x

Equation of 4 door model
Average : y=0.0525x
Minimum : y=0.0402x
Maximum : y=0.0674x

Equation of 2 and 4 door model
Average : y=0.0502x
Minimum : y=0.0366x
Maximum : y=0.0674x

Equation "y=ax" were calculated by least squares.

Figure 10. Relationship Between U.V.W. and Door Weight with Side Structure

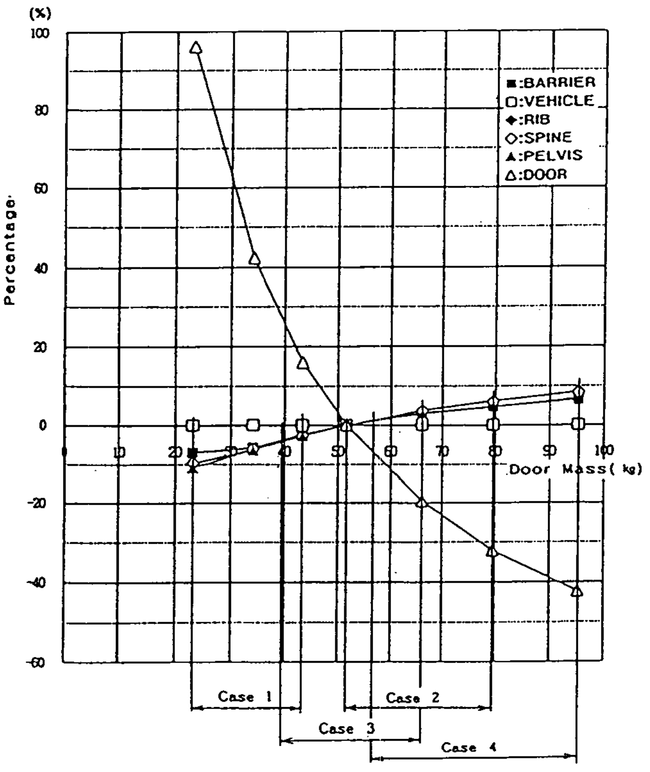


Figure 11. Percentage Variation of Peak Acceleration vs Door Weight

Methods of securing body. In addition to the CCMC-recommended method of rigidly securing the side opposite the impact and securing the impacted side in the vertical direction, studies were made on additional two methods; of gentle restraint only in the lateral direction at the wheel disk on the side opposite the impact, and of an all-rigid restraint (Figure 12). No great disparity was seen in deformation mode and in body load-displacement characteristics. The CCMC-recommended method was hence adopted.

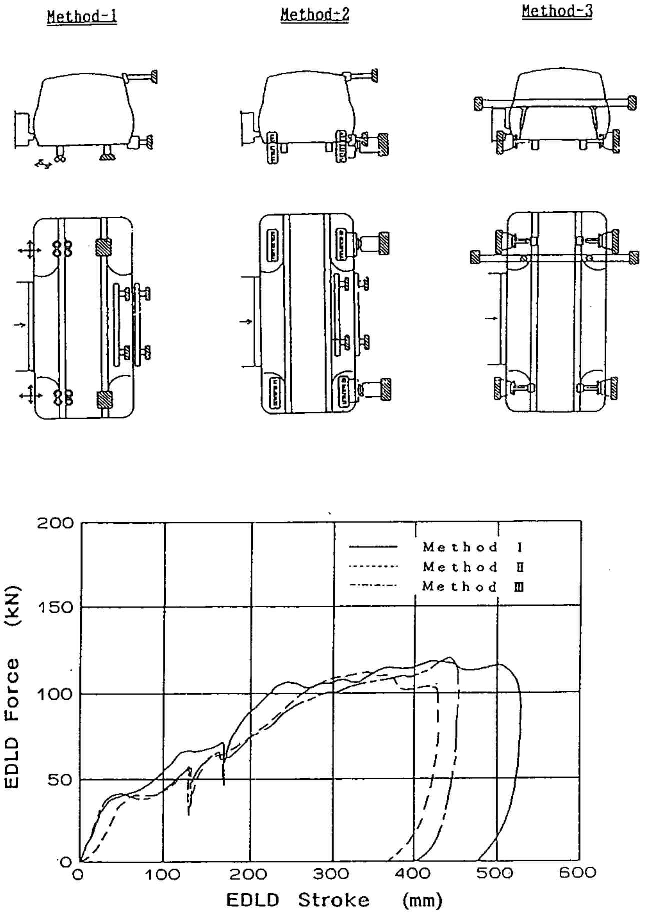


Figure 12. Comparison of Three Types of Body Fixture

Relationship between dynamic and static crush characteristics of door and door pad. Tests were carried out to obtain static and dynamic crush characteristics of the pads alone, the doors (metal sections only), and the doors equipped with pads (Figure 13).

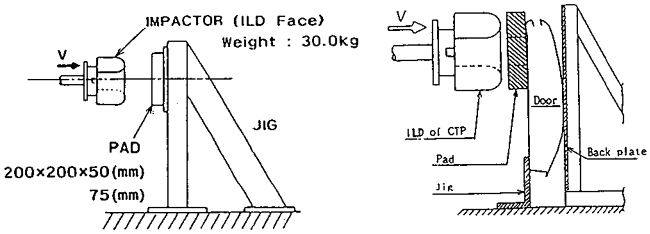


Figure 13. Dynamic and Static Crush Test Set-Up of Pad, Door and Combination of Door and Pad

Based on the results of these tests, the suitability of four equations for converting from static to dynamic crush characteristics was investigated. Specifically, the deviation between the dynamic-load curve and a curve converted from static-load curve was taken at stroke interval of 1 mm, and using these data, four equations were compared for the following three items:

(1) Simple average of deviation over total stroke, i.e., average load deviation
(2) Dispersion of deviation
(3) Dispersion of dynamic factor with respect to various materials and velocities.

For all three items, it means that the smaller a value, the higher in the accuracy when applied regardless of the door structure and the pad material (Figure 14).

<Static/Dynamic Conversion Equation>

eq. (1) $Fd=Fs \cdot (1+\gamma)$
eq. (2) $Fd=FS \cdot (1+\gamma \cdot |V|)$
eq. (3) $Fd=Fs+C \cdot |V|$
eq. (4) $Fd=Fs \cdot (1+(\dot{\varepsilon}/D)^{1/n})$

<Method of Comparison>

① Sum of Deviation / Stroke
$= \{\Sigma(F_{converted}i-F_{dynamic}i)\} / \text{stroke}$

② Dispersion of Deviation
$= \sqrt{\frac{\Sigma(F-Fi)^2}{n}}$ F: $F_{converted}-F_{dynamic}$

③ Dispersion of Dynamic Factor by using Least Squares
$= \sqrt{\frac{\Sigma(\bar{X}-Xi)^2}{n}} / \bar{X}$ X: Dynamic Factor

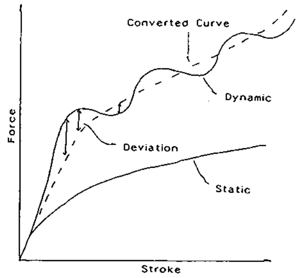


Figure 14. Static to Dynamic Conversion Equations and Comparison Method

The results showed that, among the four equations, equation 2 and equation 3 were better, but an equation applicable with high accuracy to all conditions has yet to be developed. Equation 2 was admitted after then.

Correlation in improved SBS-CTP tests. Based on the results of the above-mentioned study, a second series of SBS-CTP tests was implemented. The dummy responses are shown in Figure 15. together with the FST data and the first series SBS-CTP data. The CTP data was not subjected to an FIR filter process but the data showed great improvement in the correlation.

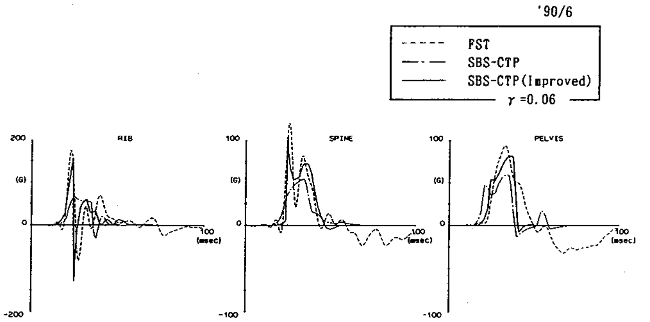


Figure 15. Correlation of Dummy Response Between FST and Improved SBS-CTP/Seat Position "RM-50mm"

Correlation under new conditions. Because the correlation in the improved SBS-CTP tests described above is extremely high, tests were performed to see if the same high correlation could be verified, even under different conditions. There might be methods of altering the vehicle, but because the waveforms of the dummy responses very closely resembled for the three types of vehicles in the first series, no alterations were made.

Instead, the following conditions were selected. The seat was placed in the frontmost position so that contact with the B pillar of the dummy thorax was avoided and the dummy could strike the door only.

The dummy responses are shown in Figure 16. The results obtained once again showed poor correlation. The cause is presumed to be a sudden rise in the pelvis ILD load so that the upper section of the inner panel of the door (thorax impact section) was also deformed, and the thorax ILD was not properly loaded. Accordingly, in order to prove this assumption, the average of two ILD loads was input to the simulation model, and the dummy responses shown in Figure 17 were obtained.

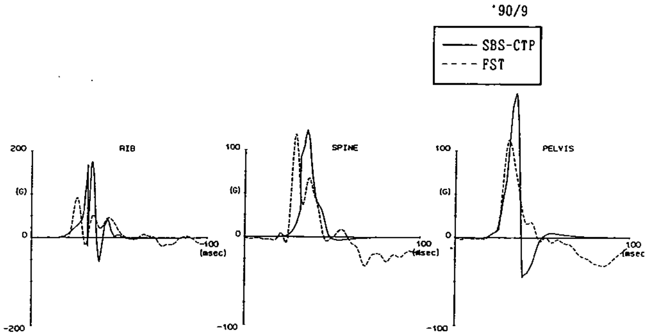


Figure 16. Correlation of Dummy Response Between FST and Improved SBS-CTP/Seat Position "FM"

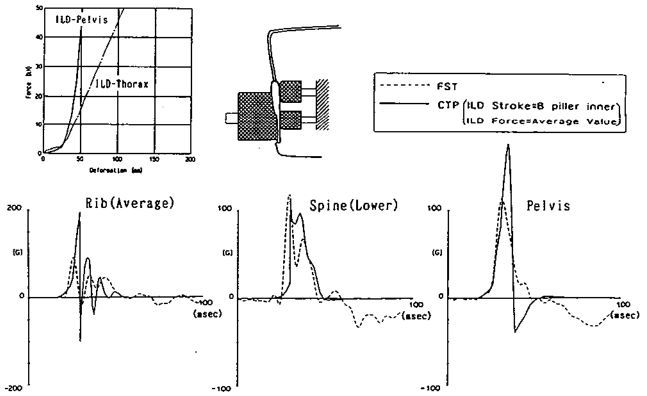


Figure 17. Correlation of Dummy Response Between FST and Improved SBS-CTP Using Average Load of ILDs/Seat Position "FM"

Because the correlation showed considerable improvement, we feel confident that the cause of the above-mentioned poor correlation was because the load that should go to the thoracic ILD went away to the pelvic ILD.

To resolve this problem, it is necessary to properly simulate the relative position of the thorax and pelvis in the FST into that of two ILDs in the lateral direction of the vehicle. This is considered to be impossible with SBS-CTP. In other words, it is judged that resolution by CC-CTP is required. At this point, JAMA/JARI halted research on SBS-CTP and switched to research on CC-CTP.

Status of CC-CTP

Two CC-CTP studies by ACEA and JAMA/JARI

Research on CC-CTP are also been conducting by three groups—ACEA, MVMA and JAMA/JARI. But, herein, two CC-CTP research by ACEA and by JAMA/JARI, which have all new developed CC-CTP test equipment, are reported.

The philosophies of these two groups with respect to CC-CTP are basically in agreement, but some points of difference in approach remain. This is because CC-CTP is a new technology and there is a possible variety in its implementation. Thus, aiming at adequately drawing out the capabilities of CC-CTP in the short term, the various researches have been proceeded independently to cover a wide range of studies.

Operation of the CC-CTP equipments of the two groups commenced this spring. Effective results are now being obtained, and adjustments are being made as the research progresses. It is agreed that the effective points of both methods are to be combined in the final stage to form an integrated test procedure.

Test equipment. The CC-CTP equipment is largely made up of four parts.

- The EDLD section, with deformable barrier face mounted on, that is rammed against the door from outside the automobile and reproduces the impact conditions between the MBD (Moving Deformable Barrier) and the door.
- The ILD section which reproduces the impact conditions between the passenger and the door, with a wooden block that simulates the thorax and pelvis of the passenger. The ILD block mounting is offset with respect to the cylinder center to avoid disturbances by the B pillar, etc. during retraction.
- The vehicle supporting device which fix the vehicle without interfering with the deformation of the test vehicle.
- The control section comprising a computer and a control device. With respect to these four basic constitutions, the ACEA and the JAMA/JARI CC-CTP equipments are in agreement, but the design details differ.

Figure 18 is a photograph of the ACEA CC-CTP equipment. The three main parts of this equipment—the EDLD, the ILD ,and the supporting device—are mounted at the same rail structure on the ground level so that it is unnecessary to provide foundations for the equipment. The test unit is therefore easy to move and install.

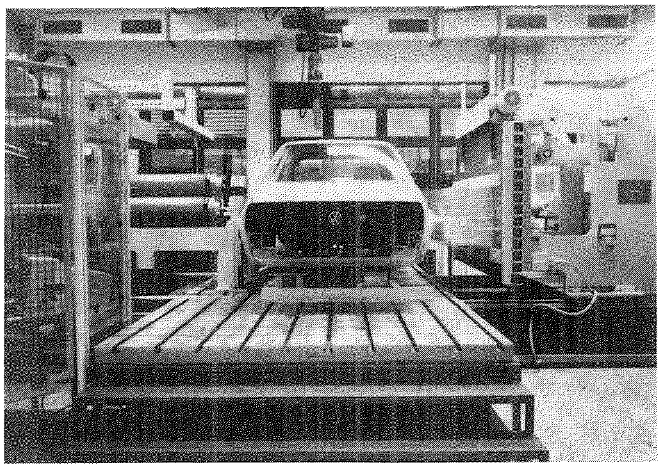


Figure 18. ACEA's CC-CTP Test Rig

EDLD consists of a large sled on the rail and a cylinder to propel this sled. The arm of loading surface is mounted on the sled by a link mechanism allowing linear motion of the arm with its another end supported by a single load cell fixed to the sled. The ILD section uses a long 1.5 meter cylinder so that an adequate stroke of retraction is available to enable reproduction of a long-duration impact.

Figure 19 is a photograph of the JAMA/JARI CC-CTP equipment. This equipment has a level plate embedded in the ground so that it is suitable for general purpose use and can handle other types of static compression tests.

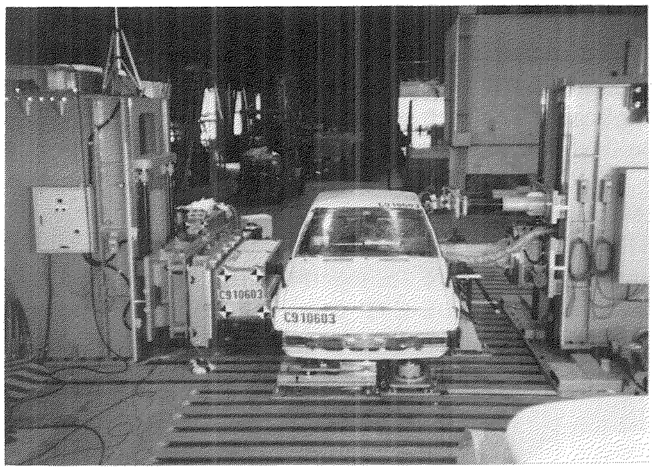


Figure 19. JAMA/JARI's CC-CTP Test Rig

The whole ILD section can be moved so that the unit can cope with changes in the size of test vehicle.

The EDLD loading surface is mounted directly on a cylinder through four load cells. The total load at the surface is obtained as the sum of those on the four load cells.

The ILD is designed specific to evaluate side-impact injuries, and a relatively short retraction stroke of 300 mm is used.

Features of algorithms. In CC-CTP, the integration calculations for reproducing the dynamic impact state and the load measurement for these calculations are performed alternately. Different algorithms are used by ACEA and JAMA/JARI for this purpose. These algorithms are illustrated in Figure 20 and Figure 21 respectively.

ACEA algorithm

With the ACEA system, three devices in the CC-CTP equipment—EDLD, ILD-thorax, ILD-pelvis—are driven, at each cycle, with a stroke increment below a fixed limit of 2 mm, and the load is measured at this time. The

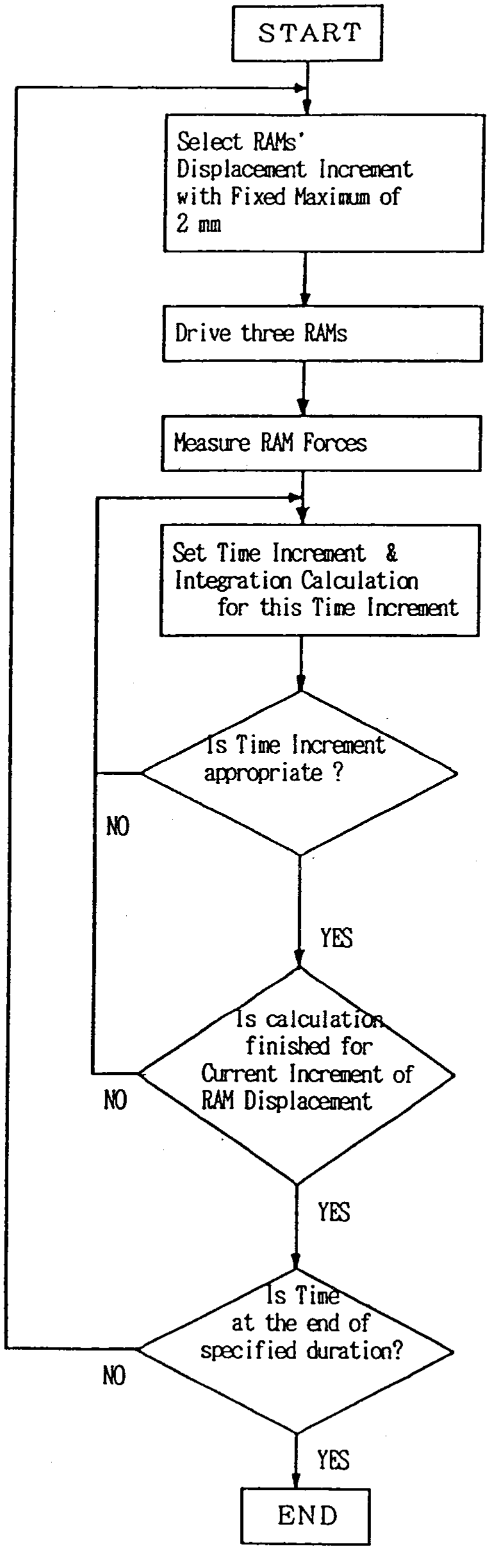


Figure 20. Flow of ACEA's CC-CTP Program

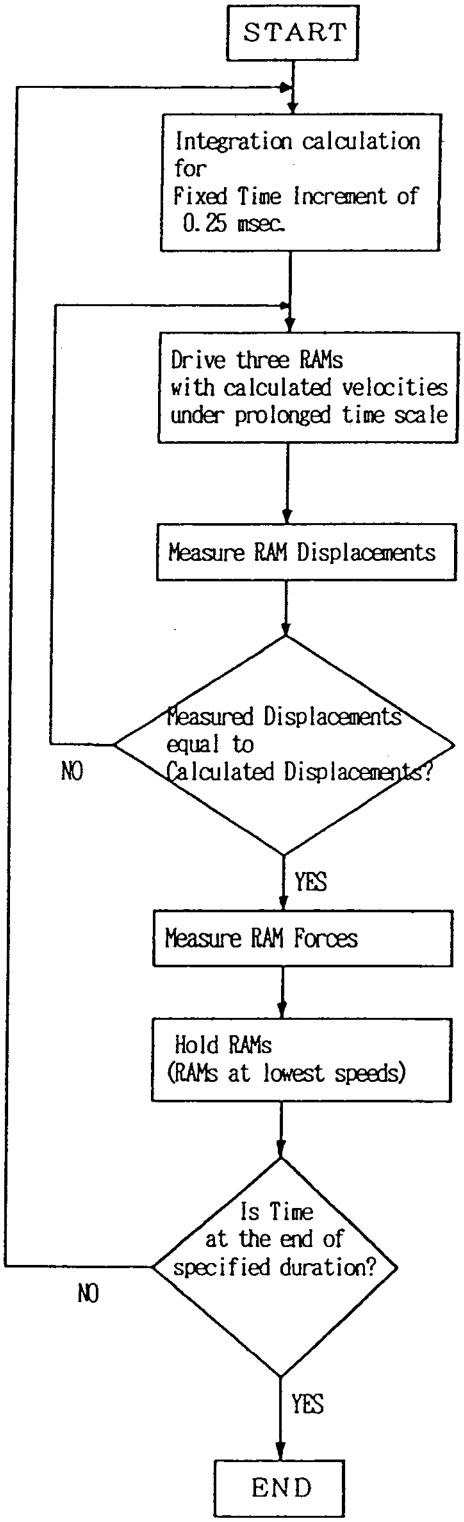


Figure 21. Flow of JAMA/JARI's CC-CTP Program

upper limit is checked for the device with fastest motion within the three.

The integration calculations are repeated within this stroke increment, with varying time increment, using the load-displacement data measured, to arrive at the optimum integrated results. If calculations are finished for the current stroke increment, then a new stroke increment is selected to start another cycle, and three devices are driven for this new stroke increment. The cycle is repeated until the end of the impact phenomenon is reached.

The time increment within a given stroke increment is not uniform, and is varied to follow a dynamic curve closely; a shorter time increment at a point of steep gradient, and a longer one at that of gentle gradient. Thus, a better accuracy is realized.

JAMA/JARI algorithm

With the JAMA/JARI system,a fixed time increment for calculation and a prolonged time scale of the device operation is adopted.

The time multiplying factor is set 12000, and the time interval is set 0.25 msec(in terms of the real time scale on FST). With this system, the integration is performed with the loading data at the beginning of the existing time interval, and the condition after 0.25 msec is calculated.

The CC-CTP equipment is driven in stages, the position measurement repeated, and when the target stroke increment is achieved, the value of the load on each device is measured to obtain data for the next-cycle integration calculation.

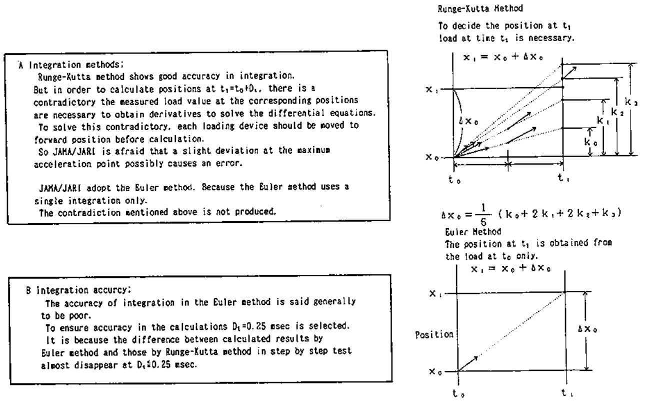
The whole cycle of integration and driving are repeated until the end of the impact phenomenon.

Because the integrations are performed at regular intervals irrelevant to the magnitude of the change, the accuracy of the calculations is poor by reason of the integration method, which is later outlined. However, because the equipment can be driven to the calculated target values, the position of each device closely follows the calculation results and the accuracy of the test is improved.

Interpretation of points of difference: 1) Integration calculation method. With the ACEA system, where the integration is performed in the obtained load-displacement range after the equipment is driven, the Runge-Kutta method, in which integration accuracy is high, has been adopted. Furthermore, the adoption of a varying time increment to follow varying gradient of the change provides improved accuracy of calculation.

The basic philosophy of the JAMA/JARI system is to determine the position and velocity for the next time interval from the current data only, therefore the Euler method is used for the integration calculations. Because this method integrates existing current data only, it is a very convenient method. However, poor accuracy is a drawback.

JAMA/JARI, in the SBS-CTP research stage, confirmed that, with the time interval of about 0.25 msec for the duration of the main phenomena in a range of 100 msec, data was obtained which was not inferior to that obtained by the Runge-Kutta method. This value of 0.25 msec was therefore used in the integration (Figure 22).



A Integration methods;
Runge-Kutta method shows good accuracy in integration.
But in order to calculate positions at $t_1=t_0+D_t$, there is a contradictory the measured load value at the corresponding positions are necessary to obtain derivatives to solve the differential equations.
To solve this contradictory. each loading device should be moved to forward position before calculation.
So JAMA/JARI is afraid that a slight deviation at the maximum acceleration point possibly causes an error.

JAMA/JARI adopt the Euler method. Because the Euler method uses a single integration only.
The contradiction mentioned above is not produced.

B Integration accurcy;
The accuracy of integration in the Euler method is said generally to be poor.
To ensure accuracy in the calculations $D_t=0.25$ msec is selected.
It is because the difference between calculated results by Euler method and those by Runge-Kutta method in step by step test almost disappear at $D_t \doteqdot 0.25$ msec.

Runge-Kutta Method
To decide the position at t_1 load at time t_1 is necessary.

$$x_1 = x_0 + \Delta x_0$$

$$\Delta x_0 = \frac{1}{6}(k_0 + 2k_1 + 2k_2 + k_3)$$

Euler Method
The position at t_1 is obtained from the load at t_0 only.

$$x_1 = x_0 + \Delta x_0$$

Figure 22. Comparison Between Euler and Runge-Kutta Integration

Interpretation of points of difference: 2) Interpretation of the door-mass position, etc. Because passenger injuries are produced from contact with the door during a side impact, the evaluation of the door intrusion greatly affects the judgment of the passenger injuries.

In the CC-CTP model the door is set a single lamp mass. However an actual door itself is a structural entity, and substituting a single mass point presents a difficult problem. Also, in the case of a side impact, consideration must be given to including the parts in the vicinity of the door when making the substitution.

The interpretation of the door-mass position, in particular, is an important factor when a position calculated (to simulate dynamic condition) is implemented (as static condition) on CTP equipment, because it affects the door intrusion speed, and hence affects occupant injury significantly.

The ACEA system assumes that the door mass is positioned in the outer wall of the door and the intrusion of the door is derived from an average of the deformations measured at several point on the inner surface of the door. In the JAMA/JARI system, the assumption is made that the door mass is positioned in the vicinity of the inner wall of the door. The method of measuring the door intrusion is as follows.

Paying attention to the fact that the resultant spring coefficient of a composite of EDLD padding material and the outer door does not vary much for each vehicle, the relative displacement between EDLD and the door is derived from EDLD load measured.

Then the relative displacement is subtracted from EDLD displacement to give the door intrusion. The resultant spring coefficient of the composite is determined by the static crush test prior to CTP test.

Interpretation of points of difference: 3) Presence or absence of ILD pad. In order to measure the impact force imparted to the passenger, consideration must be given to providing suitable absorbing characteristics at the arm portion between the door and the rib. Between the door and the pelvis, shock absorbing characteristics suitable for handling the deformation of the outer skin of the pelvic region and the pelvis itself must also be considered. These two sets of shock absorbing characteristics can be measured in advance because it is an inherent characteristics of the passenger (in practice, the dummy).

As a method of considering these characteristics, ACEA has adopted a method to combine the necessary characteristics at the stage of computer calculation on the inner-door characteristics measured. In the JAMA/JARI method the ILD is equipped with a pad with suitable shock-absorbing characteristics. A method has been adopted by which the combined door-rib,door-pelvis characteristics is obtained directly as the load measured at the ILD (Figure 23).

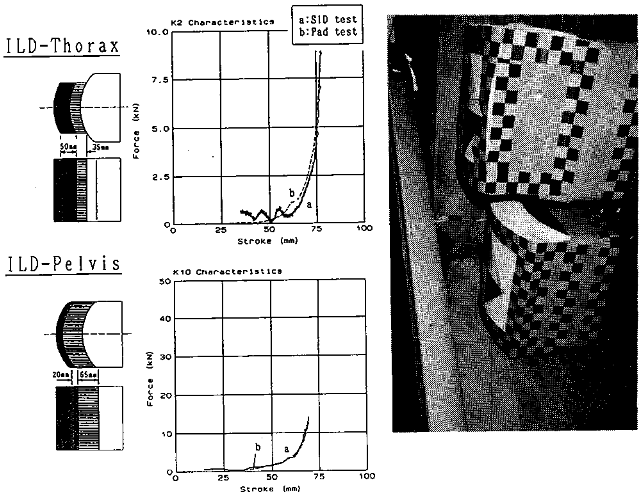


Figure 23. JAMA/JARI's ILDs with Pad

Correlation Between CTP and FST Dummy Response

Reference of judgement

Regardless of whether Full Scale Tests or Composite Test Procedures are used, dispersion of data is unavoidable. Accordingly, the correlation analysis must be judged on the basis of proper statistical treatment. These treatments have been studied as a part of the WP29/GRSP ad hoc program. Here, the waveforms are simply compared.

Prior to a comparison of the waveforms, repeatability of the waveforms in FST using the SID, implemented by JAMA/JARI up to the present time, are presented as reference. Figure 24 shows the smallest differences between maximum values, and between waveform shapes. And Figure 25, the largest differences between maximum values, and between wave form shapes, from among duplicate tests carried out under four conditions.

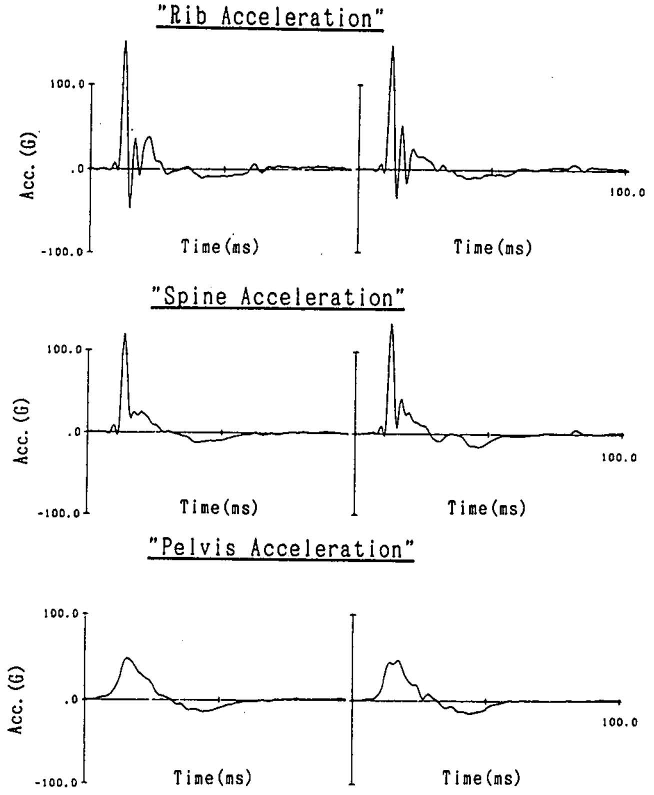


Figure 24. Example of Good Repeatability in FST Dummy Response (EEVC, 0° 85SID)

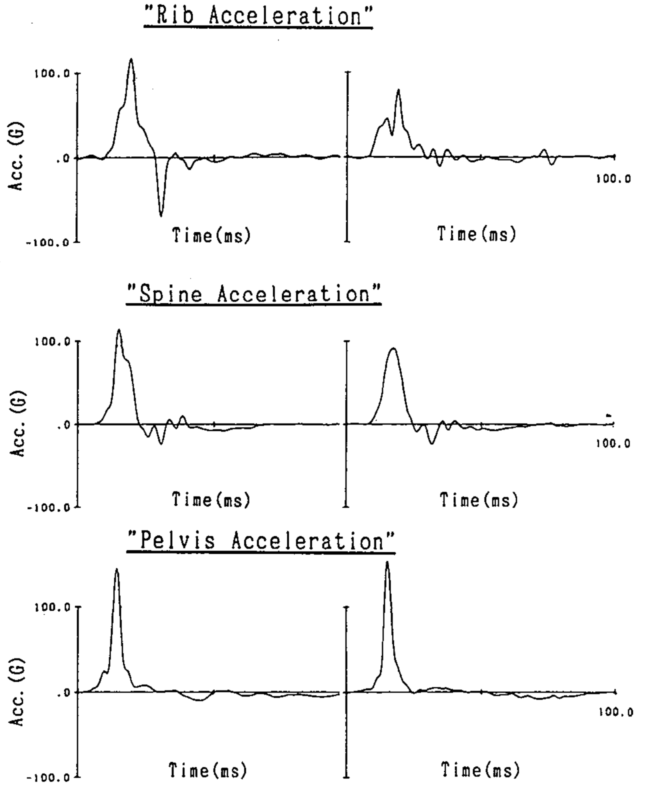


Figure 25. Example of Poor Repeatability in FST Dummy Response (EEVC, 2° 85SID)

The following discussion is proceeded admitting such amount of dispersion is existent.

ACEA examples. Results of tests of two different types of vehicles are shown. MVSS214 conditions apply to both types. Figure 26 shows the acceleration waveform in CTP, together with those in corresponding FST, for vehicle one. Figure 27 shows the results for vehicle two.

Viewed from commonly known judgements in the field of mathematical simulation, a high degree of correlation can be claimed, but some improvements might be desired to reduce the following types of differences.

- Difference of the first peak in the rib G, spine G and pelvis G for vehicle one.
- Difference in the timing of dummy responses in vehicle two.

Figure 28 and Figure 29 show the repeatability of the dummy responses from two CC-CTP tests. Repeatability is very good in both sets of results especially in vehicle 2.

JAMA/JARI examples. Results are shown in Figure 30 for the case where the seat position was 50 mm forward of the rearmost setting and where high correlation has already been obtained in SBS-CTP tests. Opposite case of low correlation are shown in Figure 31, where the seat position was at the frontmost setting. The tests were run in duplicate in each case.

The test conditions were completely identical in the two tests at the frontmost setting, while the characteristics of the pelvic-region ILD pad were modified in the test where the seat position was 50 mm forward of the rearmost setting, since the characteristics of the pelvic region is dependent on the impact position. This dependence is specifically due to the vertical nonuniformity of the dummy (SID) pelvis shape, and complexity in shapes of the rigid pelvic core and of the pelvic joints in the upper leg. The shape and characteristics of the ILD are scheduled to be redesigned, but the conventional ILD was used here tentatively, and only the pad characteristics were modified in accordance with the position of pelvic impact for FST (Figure 32).

It was possible to obtain high correlation for the dummy responses in all cases. The shapes of the acceleration waveforms gave very good agreement. In particular, the ribs can be said to be in almost equivalent condition. The curtailment of the difference in magnitude of the first peak for the spine, and the few differences in the wave form shapes for the pelvis will be taken up as future topics. We deem it necessary to redesign the mathematical dummy model to solve the first point, and to redesign the ILD shape and ILD pad characteristics to solve the latter.

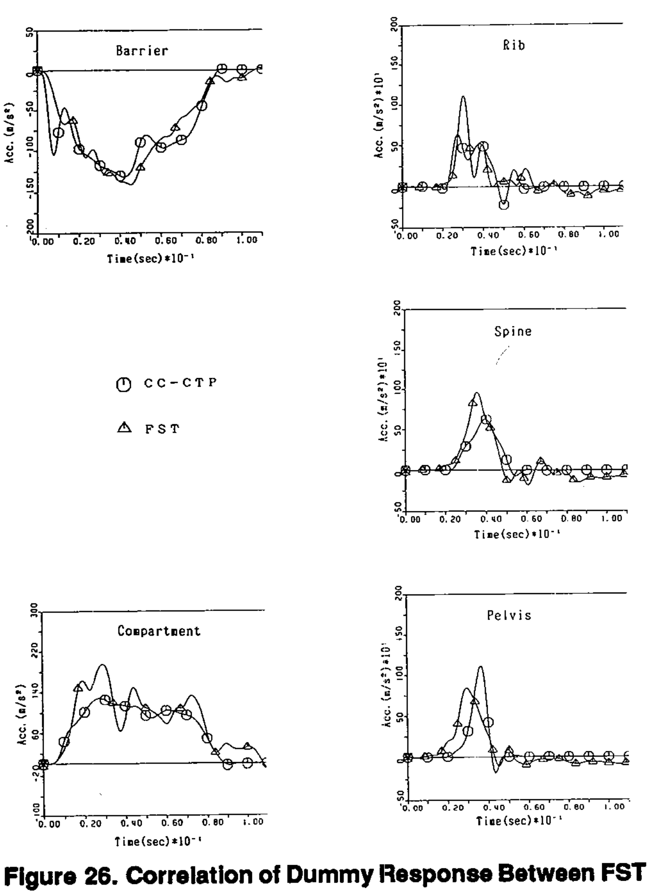


Figure 26. Correlation of Dummy Response Between FST and CC-CTP/ACEA Vehicle 1

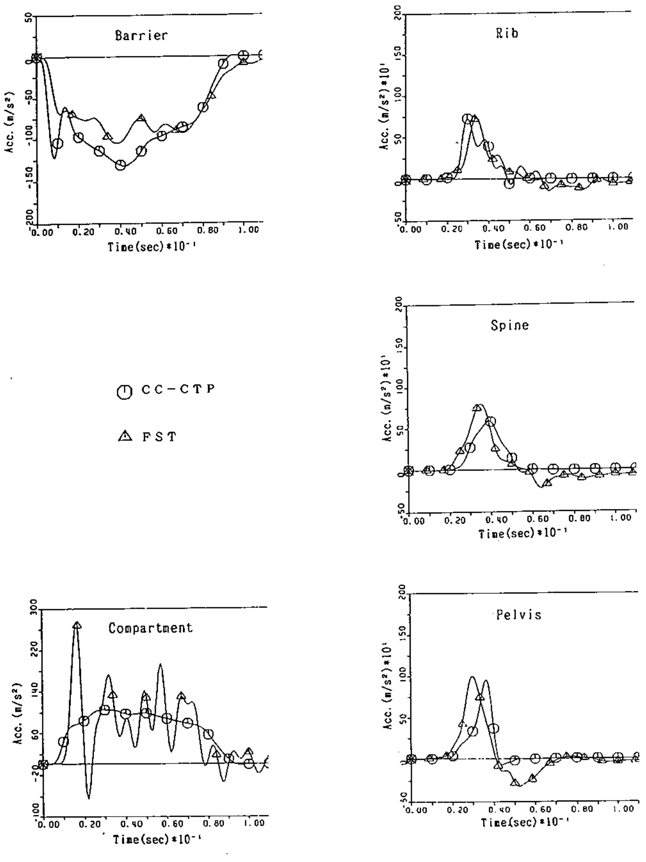


Figure 27. Correlation of Dummy Response Between FST and CC-CTP/ACEA Vehicle 2

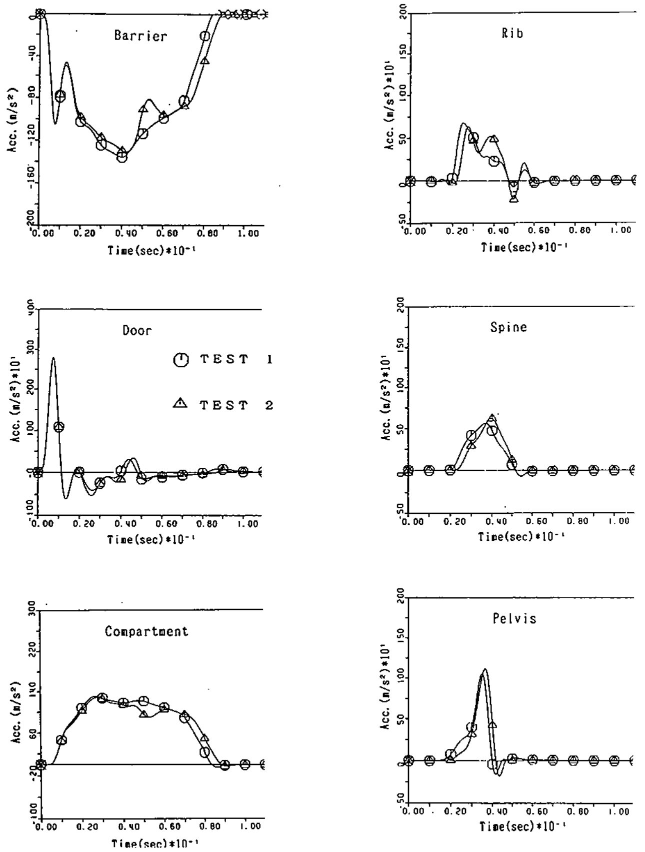


Figure 28. Repeatability of Dummy Response Between Two CC-CTP/ACEA Vehicle 1

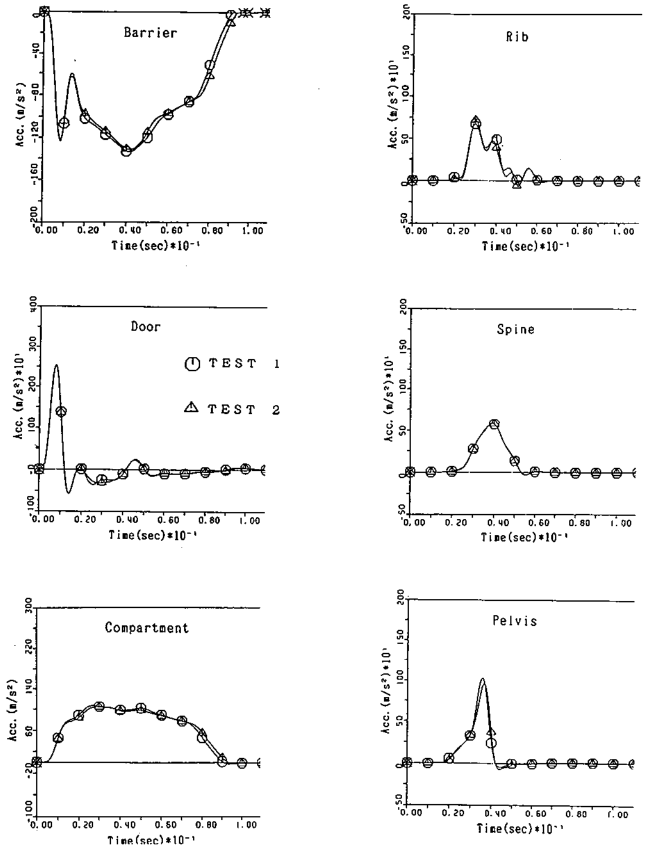


Figure 29. Repeatability of Dummy Response Between Two CC-CTP/ACEA Vehicle 2

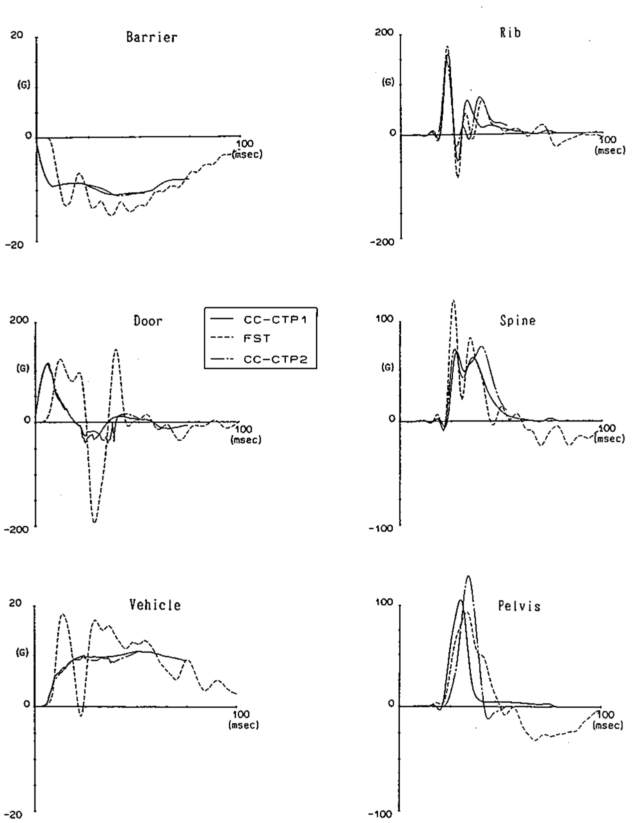


Figure 30. Correlation of Dummy Response Between FST and CC-CTP/JAMA/JARA in Condition of "RM-50mm" Seat Position

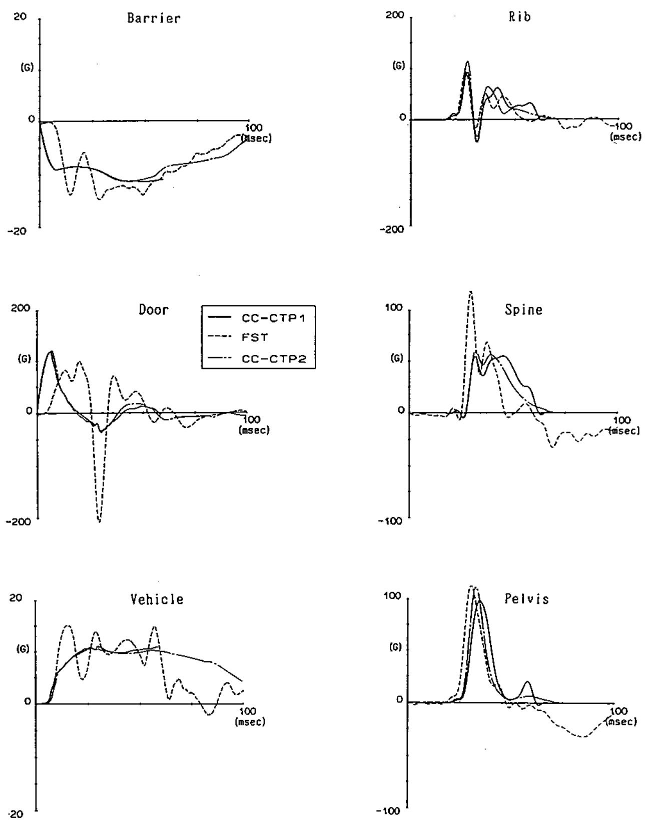


Figure 31. Correlation of Dummy Response Between FST and CC-CTP/JAMA/JARA in Condition of "FM" Seat Position

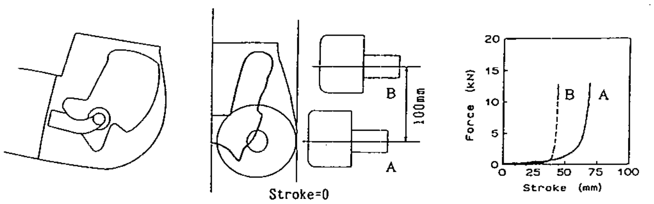


Figure 32. SID Pelvis Shape and Crush Characteristics

Conclusions

(1) As the history of the JAMA/JARI research shows, considerable improvement has been made in the correlation between CTP and FST dummy responses in a short time, with the cooperation of ACEA and MVMA.

(2) The CC-CTP equipment and software used by JAMA/JARI and those used by ACEA, differ in detail, but in both cases it can be said that the correlation between CTP and full scale test dummy responses has already reached a high level, judged from an average of achievements in the field of mathematical simulation.

(3) The results in both cases show low dispersion in comparison with full scale test results, and repeatability is very good. However, the results must finally be judged by means of proper statistical procedures.

(4) In the future, based on cooperation between ACEA, MVMA, and JAMA/JARI, an effort will be made to quickly solve the remaining problems, and to complete one CC-CTP so that full use can be made of the advantages of this system.

S5-O-24

Future Enhancements of the Computer Controlled Composite Test Procedure (CC-CTP)

Ronald J. Wasko
Motor Vehicle Manufacturers Association

Introduction

During the past four years of development, the Composite Test Procedure (CTP) has reached a state of maturity that qualifies it to be considered as an alternative to the full scale test (FST). The many advantages of the CTP are listed in the paper "Evolution and Current State of Development of the Computer Controlled Composite Test Procedure" appearing elsewhere in these proceedings. One of the advantages of CTP is the complete elimination of a mechanical dummy along with its variability, calibration and maintenance problems.

In spite of the progress that has been made to bring the CTP to its current state of equivalence with the FST, several improvements have been identified which can further enhance the performance of the CTP. The following paper describes these improvements that are already underway. Biomechanical Approach describes the weaknesses of the present FST method and gives a rationale for using subsystem tests such as CTP. Dynamic Effects describes work to date at Volvo to study the loading rate dependency of door padding materials and to develop corrections to CTP to deal with the rate dependency of door padding materials. Enhanced Dummy Model describes the work of MVMA at the MGA Corporation to develop a more detailed mathematical model of the dummy used in CTP and accompanying modifications to the test procedure. MVMA, like Volvo has also studied the loading rate dependency of door padding materials and is seeking a method for incorporating these effects into the CTP. JAMA lists several factors that it recommends for investigation to improve the correlation between CTP and FST. Among these are an improved estimate of the door mass, dynamic loading factors for both the vehicle interior and exterior, an improved representation of the mathematical dummy, improvements to the loading devices and alternative methods of controlling the crushing procedure. Simulation of Human Behavior describes the work of APR to go beyond the computer simulation of an existing dummy such as SID or EuroSID and directly simulate the human being using the latest biomechanical data. This method has the potential to model with the computer what may not be possible to model with a mechanical dummy.

Biomechanics Approach

Geometrical Approach to the Safety

Initially, the passive safety provided by a car was considered as the preservation of the integrity the interior compartment that had been designed to ensure a satisfactory standard of protection for passengers in collisions. This philosophy gave rise to a series of standards intended to observe certain geometrical characteristics in situations of established stress either dynamic or static. Today we know that car safety must be evaluated through biomechanical criteria; this means ensuring that in accident situations the stresses undergone by passengers are less than the limits of human tolerances.

Experimental Biomechanical Approach

The correctness of the biomechanical approach to safety has been universally recognized by both Government and Industry, for example, by the second memorandum of CCMC (Committee of Common Market Automobile Constructors) and the conclusions of the EEC Symposium of 1974. The main difficulty has been a lack of the necessary basic biomechanics knowledge. All the driven into comparable samples or assembled doors by means of hydraulic actuators.

In all test cases the force-deflection responses were recorded. The comparison of the dynamic and quasi static force deflection responses of material samples of the same kind gave the dynamic-static correlation of some of these materials assembled with doors.

This correlation should be incorporated into the composite test because of the fact that the CTP is a quasi static test procedure which is only able to measure the static characteristics of interior door constructions. The CTP computer model is only able to recalculate the dynamic occupant responses accurately if the interior static dynamic conversion is given as input information for the model.

The comparison of the static and dynamic responses of the separate material samples showed clearly that the correlation is material type dependent. A conversion formula can be designed but will be different for each type of material e.g. visco elastic material or full energy absorbing material. In case the material samples are assembled with a door it can be concluded that it is hardly possible to design a conversion formula. An additional test procedure can solve the problem. Also from the analysis of this test series it can be concluded that simply adding up dynamic stiffness characteristics of door padding and door itself does not give the dynamic assembly stiffness of the door, assembled with padding. The tests were conducted and analyzed under responsibility of Volvo Car B.V. in Holland by test engineer Mr. D. Landheer.

Introduction

The composite test procedure (CTP) is a test method which is able to calculate the occupant injury responses during a dynamic side impact between two passengers cars.

The calculation by means of a mass spring model however is based on quasi static responses. These responses are input information for the model which is coming from a simultaneously run test rig which is simulating a side impact quasi-staticly. To compensate for the lack of dynamic responses a conversion has to be take place. This static dynamic conversion is only concentrated on the impact between the interior side structure (door) and the impacted occupant.

This investigation is concentrated on the static dynamic correlation of some potential interior padding materials separately, and in combination with door structures. In conclusion of this investigation it should result into a validated method to solve the problem of the lack of dynamic response of the CTP.

Method

The dynamic impact tests. The dynamic impact tests were conducted on material samples and on door assemblies. Impactors were used for the thorax and pelvic ILD's of the CTP.

The impact speed used was approximately 12 m/s, which is also the initial contact speed between the interior door panel and the occupant in a Volvo 480 side impact. Both ILD's were positioned in relation to each other and the door in accordance with the US-SID position in a CTP. Both thorax and pelvis ILD's were loaded up to 31 kg and 24 kg, respectively, which were the mathematical masses of the thorax and pelvis of the US-SID at the time of test execution. Both ILD's were built into a drop frame in such a way that during the impact of the sample, both ILD's were able to respond to the material stiffness fully independent of each other but guided such that the impact occurred vertically true. The drop frame was dropped vertically from a certain height and guided by the guiding system of the drop rig. (See Figure 2.)

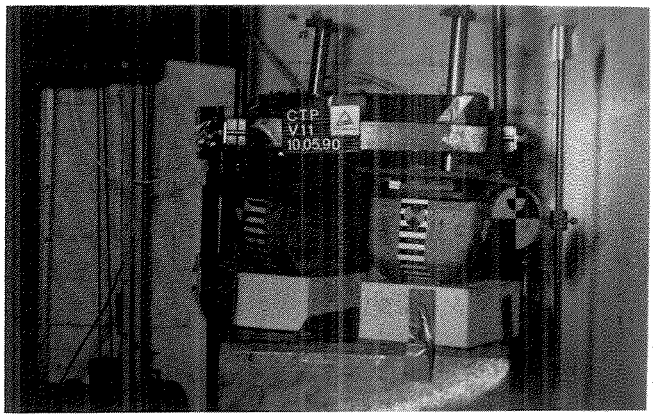


Figure 2. Dynamic Impact Test Rig with Thorax and Pelvis Materials

The material samples were supported by a flat solid bottom surface. The Volvo 480 doors assembled with various kinds of padding were supported by a wooden model of the honeycomb barrier face, prescribed in the latest FMVSS 214 standard. The door contour was fixated as realistic as possible to simulate the CTP test situation based on the procedure derived from the FMVSS 214 standard. (See Figure 3.)

The quasi-static crush tests. The quasi-static tests were performed by means of driving the thorax and pelvis ILD quasi-statically into the material samples or the door assemblies. The forces were supplied by using two hydraulic actuators. For the material sample testing, the thorax and pelvis ILD were actuated separately. (See Figure 4.)

For the door assembly tests, both ILD's were driven quasi-statically into the doors such that the movement of the ILD's in relation to each other and to the door were as close as possible to the movement of the same door assembly derived from film analysis of the previously conducted dynamic tests. (See Figure 5.)

The support of the material samples and the door assemblies were similar to the dynamic test cases.

Description of the material samples. The different material samples, which were separately subjected to the western world biomechanical studies received increased consideration in particular, the EEC began a program of studies on biomechanics that lasted several years, the results of which were presented at a Symposium in Brussels, Belgium, in March 1983. The biomechanical approach to car safety is clearly multidisciplinary and complex.

Figure 1 shows the logical steps leading to the formulation of standards based on biomechanics. In practice, it is possible to distinguish three groups of knowledge and activity that are necessary for the formulation of biomechanics standards:

- *accident analysis background,* which has to provide intervention priorities and check the effectiveness of standards;
- *test condition* definition to subject the interior compartment to identical stresses of accidents which are intended to be reproduced;
- *performance criteria* definition expressed in biomechanical terms.

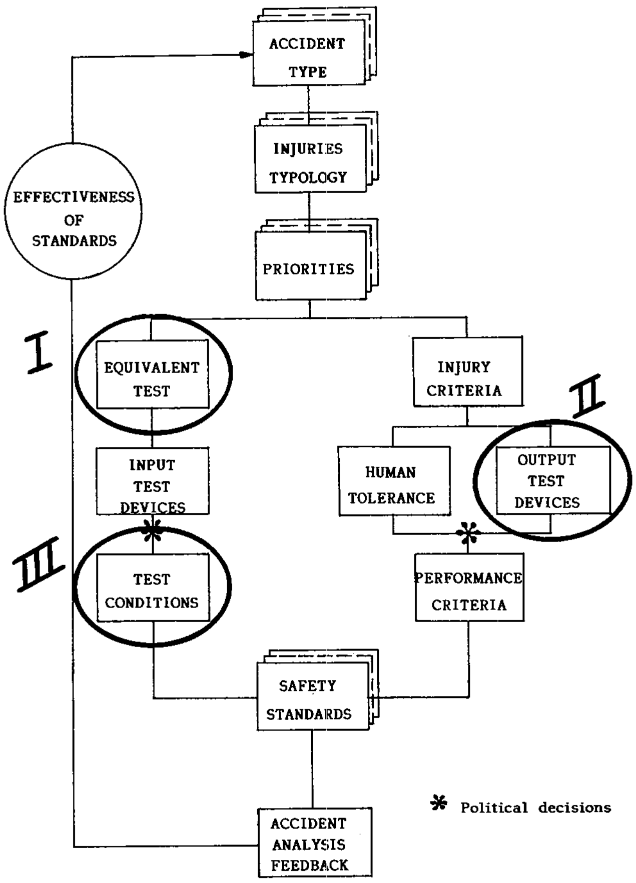


Figure 1. Biomechanical Approach

Composite Biomechanical Approach

The experimental biomechanical approach based on full-scale tests has already shown some shortcomings that, for some types of collisions, can affect the validity of this method. Three major weak points exist in the logical procedure to develop a safety standard based on the experimental biomechanical approach (see I, II, and II in Fig. 1). These are:

- *Representativeness of the equivalent test.* Recent studies based on accident analysis have shown the low representativeness of some equivalent tests that are now proposed in new standards.
- *Biofidelity of the dummies.* Development of mechanical output devices is inadequate because of engineering complexity. Even though the biomechanical response of the human body is known, mechanical surrogates that would reproduce responses in an acceptable manner have not been fully developed due to existing complexities.
- *Possibility of using the test for setting up the vehicle.* For fullscale testing a vehicle is required that, in some situations (e.g., side impact), must be complete in every final detail. Therefore, conformity assessments can only be made at a very advanced vehicle development phase in which any structural modifications would result in high costs and long lead time for changes. This test methodology is unsuitable in the development schedule of a new car model.

To overcome these difficulties, test methods based on subsystems are being developed and evaluated. In practice, the use of mathematical models, along with experimental tests on car subsystems, enables engineers to ascertain the safety characteristics of a car in the initial phases of model development and optimize such characteristics. A method of this kind also provides the vehicle stiffness characteristics that can be used to simulate several test conditions.

Moreover, when occupant mathematical models are used, this method has the potential to eliminate the problems of insufficient biofidelity of the current mechanical models.

The Computer Controlled-Composite Test Procedure (CC-CTP) is the first application, developed for side impact protection, of a "composite biomechanical approach."

Dynamic Effects

Twenty four tests have been conducted during 1990 to investigate the problems related to the comparison of quasi-static and dynamic impact response. The tests were executed by means of impacting several different kinds of potential vehicle door padding material and also the same material assembled on Volvo 480 doors.

The impactors used were both thorax and pelvic interior loading devices ILD's) of the composite test (CTP). In the case of the dynamic tests both ILD's were loaded up to the mathematical weights of respectively thorax and pelvis of the CTP model. The ILD's were dropped by means of a guiding system at approximately 12 m/s on the samples of the assembled doors. In the case of the quasi static tests both ILD's were slowly

Figure 3. Dynamic Impact Test Rig with a Production Volvo 480 Door Assembly

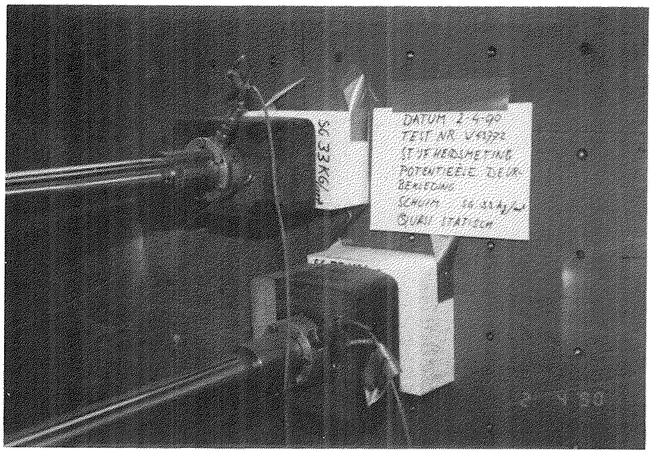


Figure 4. Quasi-Static Test Rig with Thorax and Pelvis Material Sample

dynamic, as well as the quasi-static tests were the following:

Polypropolyene foam 33 kg/m3 density
Polypropolyene foam 48 kg/m3 density

Both materials have a so called visco elastic impact behavior.

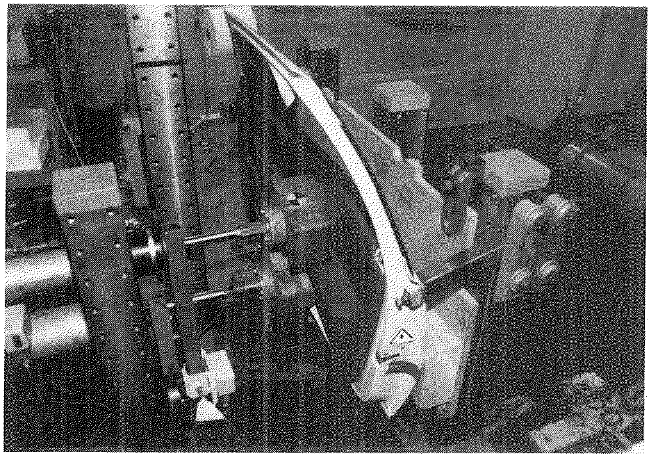


Figure 5. Quasi-Static Test Rig with a Production Volvo 480 Door Assembly

Furthermore, two other kinds of material, called material A and B, were tested which show an almost 100% plastic impact behavior. Generally, the visco elastic materials behave such that during impact (static and dynamic), a part of the energy is "stored" in the material as elastic energy which is released during the rebound phase. The materials A and B do not store elastic energy during impact. All impact energy is dissipated by the deformation. The visco elastic material samples, separately tested, had a thickness of 104 mm. The size of the samples were 200 x 180 mm. The samples of material A and B were 120 mm thick. Also, the production Volvo 480 interior door panel was tested separately.

Description of the door assemblies. The tested door assemblies were built up as follows:

- Production Volvo 480 left hand side and right hand side doors, equipped with:
  - side door intrusion beam minimum 32 mm diameter
  - side door intrusion beam maximum 22 mm diameter
  - electric window mechanism
  - side molding at bumper height 25 mm thick.
- The alternate assembled interior panels were made of the same materials which were separately tested. However, the materials were shaped to fit well against the door inner sheet metal panel and were, in principle, suitable to be used as an interior door panel without a coverage layer.

The doors used for the quasi-static tests were identical to the doors which were dynamically impacted, in order to compare the results. The left hand side doors are symmetric to the right hand side doors. A symmetric set of ICD's were used for this test series in order to impact the right hand and left hand side doors in a comparable manner.

Some additional impact tests on doors were carried out with pre-deformed doors. These doors were crushed with a FMVSS 214 honeycomb barrier face while they were mounted in a Volvo 480 vehicle. The necessary crash distance was derived from the step one phase of the step-by-step method of the CTP (120 mm).

Measurements

During the quasi-static tests both the force between the ILD's and the impacted surfaces (thorax and pelvis) and the deflection of these surfaces were recorded. The signals of the load transducers and the displacement transducers were amplified (not filtered), recorded by a computer, and the force-deflection curves were plotted.

For the dynamic tests, the forces between the ILD's and the impact surfaces were not directly recorded. The forces were derived by measuring the decelerations during impact of the ILD's. These decelerations were then multiplied by the mass of the ILD's to get the correct force.

The deflections during the dynamic impacts were measured by using the high speed film technique. Both the force and the deflection were recorded in relation to time in order to plot the dynamic force deflection curves.

Analysis of Results

Static - dynamic comparison of the different material samples. Comparison of the static and the dynamic force deflection curves of the visco elastic materials show a clear three-phase phenomenon. The first phase shows a steep rise of the force deflection. The second phase of the curve shows a rise which is not as steep, but occurs at a higher force level.

The last phase of the dynamic curve shows clearly that bottoming out is occurring at less deflection. Also clear is that the general shape and the amplitude of the curves is dependent on the material type and density. (See Figures 6 and 7.)

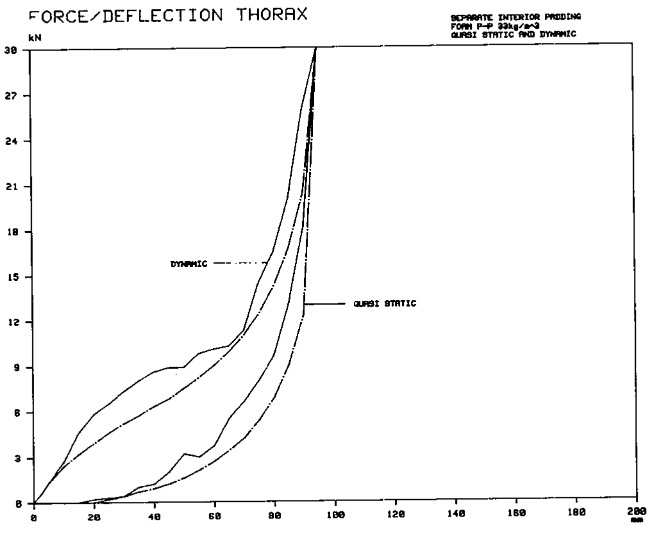


Figure 6

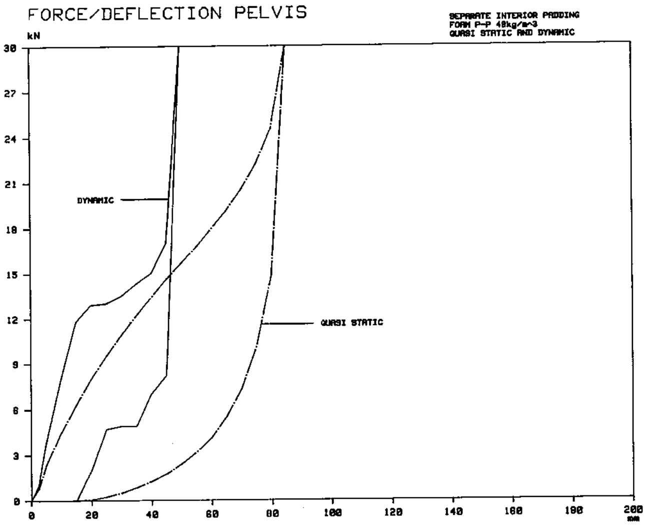


Figure 7

A comparison of the static and dynamic force deflection curves of material A and B (100% plastic deformation behavior) yields a different result. The curves do not show a progressive rise. The dynamic curve show a much steeper rise of the force deflection only initially, in comparison to the static curve. After this phase, the dynamic curve starts to follow the course of the static curve. A possible explanation of this phenomenon is that the velocity during dynamic impact becomes closer to the quasi-static "speed" at the end of the impact phase. (See Figure 8.)

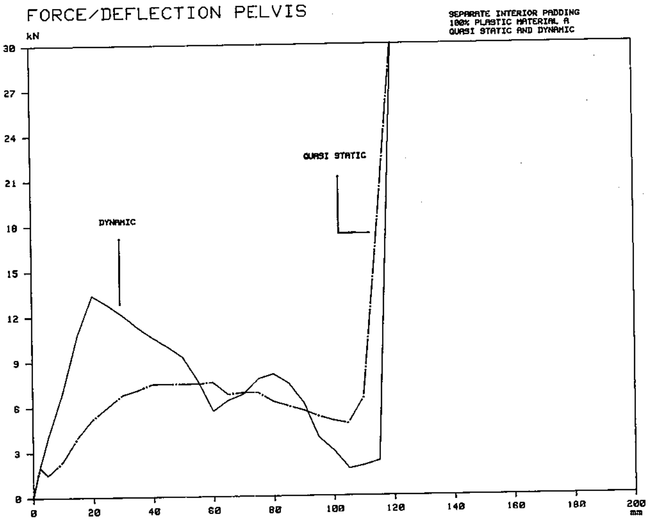


Figure 8

Static - dynamic comparison of the different Volvo 480 door assemblies. When the static and dynamic force deflection curves are compared to doors which are assembled with a visco elastic interior padding material, there is a very clear difference. The dynamic test result initially shows a much stiffer behavior. After the impact speed of the dynamic test becomes lower, the dynamic curve tends to follow the static curve. The stiffer behavior at the beginning is caused by the combination of the stiffer behavior of the padding material itself and the mass inertia effect (stiffer) of the door inner sheet metal panel. (See Figures 9 and 10.)

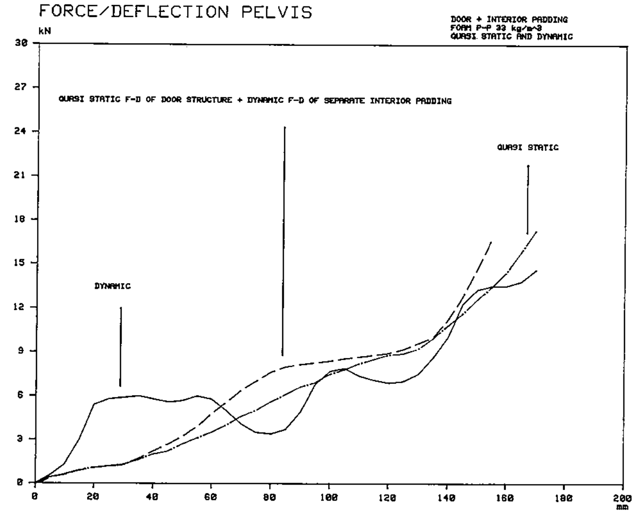


Figure 9

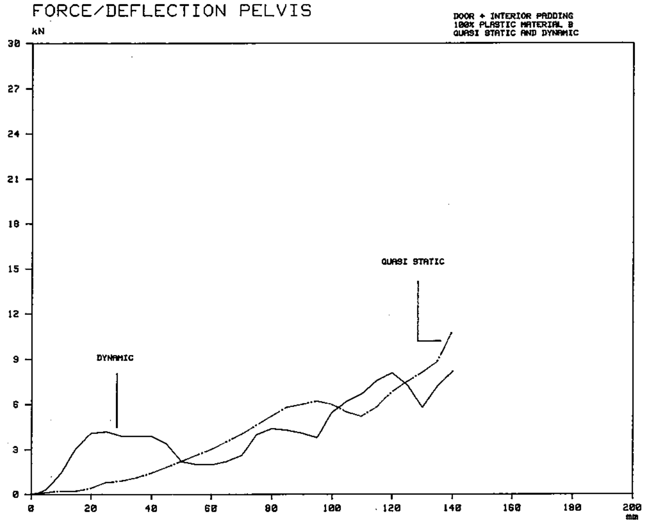


Figure 10

Another phenomenon becomes evident very clearly. The dynamic curve shows a regular wave form, or oscillation. This oscillation is caused by the mass inertia effects of the inner door sheet metal panel in combination with the stiffness of the total system. This conclusion is based on the high speed film analysis.

Comparison of the door assembled with material A and B (100% plastic) yields the same phenomena and is caused by the same effects described above.

Static - dynamic comparison of door assemblies which are pre-crushed. The phenomena which result when a static-dynamic comparison is made of assembled doors which are non-deformed and predeformed are similar to those described in the previous paragraph.

The difference, which is clearly shown, is that bottoming out of the padding material occurs much earlier for the predeformed doors. The time of bottoming out is, however, dependent on the energy absorbed during the first part of the impact. It is clear that in a dynamic impact the energy absorption is much greater than in a static impact. Consequently, whether a door is predeformed or not and which solid parts are designed in the door (e.g. the side door intrusion beam), can play a major role in the actual course of the quasi-static curve compared to the dynamic curve.

In general, it can be concluded that the initial force during a dynamic impact compared with the static crush of a similar door is caused by the dynamically stiffer behavior of the padding material; the mass inertia force of the padding material; and the mass inertia force of the door inner sheet metal panel. These parameters influence each other during the course of the impact. When the speed during impact is approaching the quasi-static "speed," the force deflection curve comes increasingly closer to the quasi-static level. The wave form is caused by the above described oscillating behavior of the door inner sheet metal panel. (See Figures 9 and 10.)

Discussion of the problem of adding up stiffness characteristics. In this test series, an additional investigation is conducted, if necessary, to determine the dynamic interior stiffness characteristic of a complete door during a CTP test by only adding up the static-dynamic stiffness increase of the separate interior padding parts of the door assembly. Figures 9 and 11 show the plot of such an exercise in comparison to the quasi-static and the dynamic force deflection of the complete door assembly.

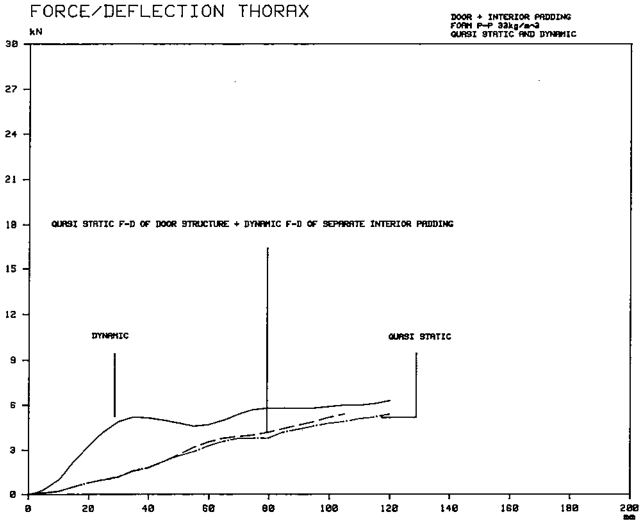


Figure 11

The curves show clearly that such a simplified method is not valid. The mass inertia effect of the door inner sheet metal panel is not incorporated, which plays a major role in the interior force deflection characteristic of the door assembly.

Conclusions

General. The static-dynamic conversion of a door impact from the interior, related to the CTP, is dependent on the construction of the door assembly and on the material properties of the interior padding.

Because of the described complexity of a quasi-static and a dynamic interior impact on a door assembly, it is not possible to design a mathematical static-dynamic conversion formula.

Separate padding materials. The tested material samples manufactured of polypropulene foam show a clear, progressive, increasing force deflection in the quasi-static compression as well as in the dynamic compression. However, the static-dynamic comparison shows considerably stiffer behavior in dynamic compression during the complete compression. The comparison shows that a conversion formula could be designed for this kind of material.

At the start of the dynamic impact, the tested material samples A and B (100% plastic deformation behavior) show considerably greater stiffness in comparison to the static compression.

Door assemblies. The results of the static-dynamic comparison tests of the door assemblies and the explanation of these results show clearly that the conversion is dependent both on the construction of the door and of the properties of the assembled interior padding material.

Proposal for Finalization

The described investigation should be seen as a first attempt to gain knowledge about the quasi-static and the dynamic behavior of complex door assemblies. ACEA has a second program in preparation to investigate this problem more extensively and accurately. This second program should result in improvement of the test results like repeatability, reproducibility, speed dependency, and role of the door support. This investigation should possibly result in an additional procedure which has to be integrated in the CTP. The final goal of this program is to improve the CTP to predict the side impact performance of a vehicle even more accurately.

Enhanced Dummy Model

Enhancement of Dummy Characteristics

MVMA undertook research to review, assess and enhance the composite test procedure. The original test procedure provided load paths for the pelvis and the thorax based on the National Highway Traffic Safety Administration (NHTSA) approach on side impact rulemaking. The Motor Vehicle Manufacturers Association of the United States, Inc. (MVMA) deemed it appropriate to investigate additional load paths to more represent the United States side impact regulatory philosophy currently in effect and to investigate additional load paths that might be adopted by the NHTSA and future side impact rulemaking.

MVMA undertook a project to enhance load paths in the composite test procedure using the computer controlled-composite test procedure to represent a real time simulation of the dynamic crash event using static force-deflection data generated incrementally by the test equipment. The computer controlled-composite test procedure directly controls the magnitude of the crushing which is applied to the exterior and interior of the test procedure. The CC-CTP represents a substantial improvement over the three step method. MVMA addressed the additional load paths by first extending the occupant mathematical model and then physically representing the new elements by including more load paths in the test rig as part of the development, a necessary control algorithm for equipment operation formed the part of this test. Elements included in the enhancement were:

Dynamic Padding Effects
Including a representation for seat/occupant interaction
Refining the occupant vehicle kinematics during the CC-CTP test
Enhancement of dummy characteristics.

Dynamic Padding Effects

Including a representation for seat/occupant interaction Refining the occupant vehicle kinematics during the CC-CTP test Enhancement of dummy characteristics.

The enhanced dummy characteristics will include a mathematical model dummy representation to anatomically upper and lower rib responses and upper and lower spine responses. Additionally, the mathematical model of the CC-CTP dummy was investigated to include the effects of load paths for the shoulder, abdomen, arm, pelvis, iliac wing, and pelvic pubic synthesis.

Dynamic Effects of Padding

MVMA investigated the dynamic effects of padding to determine the visco-elastic characteristics of interior door padding. There was a sense that the conventional CC-CTP, in which all the ram motions are quasi-static, it might be necessary to input dynamic material properties (e.g. a rate factor or a dynamic force-deflection curve appropriate to various paddings used in the door interior) prior to testing by including a visco-elastic effect of the interior, the computer would make an adjustment for the dynamic effects during the quasi-static CCCTP test.

A method to valid the quasi-static CC-CTP would combine aspects of the original three step CTP with the computer controlled CTP. When the CC-CTP simulation model indicated an initial motion of the dummy dynamic impactors rather than static cylinders were fired against the interior door panel to obtain dynamic effects in interior force-deflection characteristics. The results of the dynamic visco-elastic effects are shown in Table 1. The paddings used for this test series were representative of various paddings available at the time and do not constitute an endorsement of any paddings by the MVMA. Rather, the purpose of selecting the paddings was to determine if the CC-CTP test, as modified with the proper algorithm, could determine the existence and effects of the padding. As the data show, for completeness in the enhanced model, a factor is needed for visco-elastic effects of padding, if this aspect is to be considered by the CCCTP.

Table 1

Actual Foam Testing Conditions

MATERIAL	SIZE (IN)	STATIC (IN/MIN)	10 MPH	15 MPH	20 MPH
ETHAFOAM (1.6 PCF)	1	0.5	-	-	-
	2	1.0	9.96	-	-
	3	1.0	9.99	-	-
	4	1.0	-	15.01	-
	5	1.0	-	15.01	20.11
DYTHERM (2.8 PCF)	1	0.5	9.98 —	-	-
	2	1.0	10.10	15.01	-
	3	1.0	10.08	15.21	19.99
	4	1.0	-	14.95	20.05
	5	1.0	-	15.01	19.99
ARCEL (2.15 PCF)	1	0.5	10.01	-	-
	2	1.0	10.01	15.05	-
	3	1.0	-	15.05	-
	4	1.0	-	15.01	20.11
	5	1.0	-	14.88	20.17
ARPAK (2.2 PCF)	1	0.5	10.01	-	-
	2	1.0	10.01	-	-
	3	1.0	9.99	14.95	-
	4	1.0	-	14.81	19.81
	5	1.0	-	14.98	19.75

NOTE: All tests were conducted at ambient laboratory temperatures.

CC-CTP Test on Pontiac 6000

The enhanced dummy characteristics CC-CTP model developed by MVMA included three masses, one rib, one spine, and pelvis. Along with these masses representation for the shoulder, abdomen, and arms are also included in the model. The representation of the enhanced model is shown in Figure 12. Note that the shoulder, arm, and abdomen are all considered to be spring masses. Test results were obtained using the CC-CTP procedure for the enhanced CC-CTP model. However, MVMA did not have any full scale vehicle data on which to validate the CC-CTP model. MVMA had recently completed a series of twelve Pontiac 6000 side impact tests using the SAE developed BIOSID and NHTSA SID dummy. Since these full scale vehicle data were available and current, the enhanced CC-CTP test was conducted on a Pontiac 6000 vehicle. A brief comparison was made of the full scale data to the resultant CC-CTP data. Also, in conjunction with the Pontiac 6000 data, earlier full-vehicle and the three step CTP testing done on Ford LTDs were reviewed. From the data shown in Table 2, the Ford LTD three step CTP procedure more closely matched the enhanced dummy model CC-CTP test results. We are currently investigating possible reasons why the enhanced CC-CTP model did not provide results correlated to full scale testing as did the simplified CTP model.

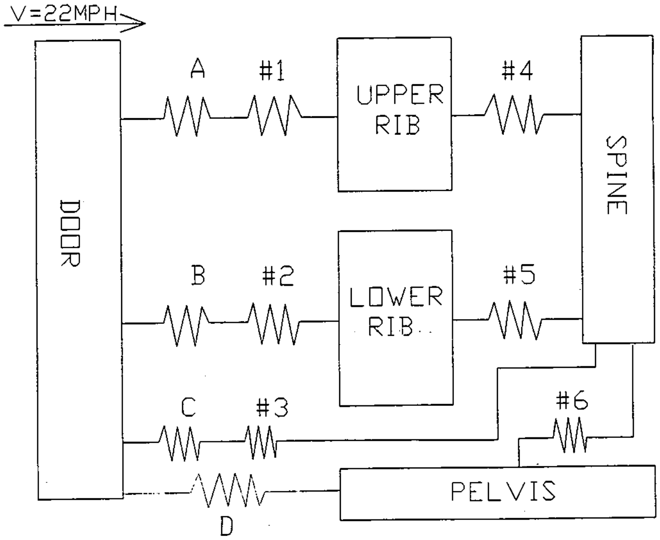


Figure 12. MVMA Developed Enhanced CC-CTP Model

Table 2

Comparison of 1985 LTD Injury Results

TEST CONDITION	RIB		SPINE		PELVIS		TTI
	PEAK G'S	TIME (MS)	PEAK G'S	TIME (MS)	PEAK G'S	TIME (MS)	G'S
LTD CRASH TEST	52.0	34	72.0	38	62.0	37	62.0
CONVENTIONAL CTP - LTD	48.5	35	73.7	39.8	64.9	34	61.1
MODIFIED CTP - LTD	49.5	33	75.2	38.6	68.9	35	62.3

Integrated, Enhanced CTP

MVMA is currently investigating the three-step CTP procedure and the computer controlled enhanced composite test procedure to determine the apparent anomaly in less reproducible results for the enhanced procedure as compared to the initial three-step procedure. Initially, it appears that the interior door velocity during a full-scale test is different at different heights of the door. Specifically, the pelvis may be interacted at an earlier time than the thorax. Conceivably, the pelvis would receive a higher load and the thorax being coupled to the pelvis would impact the upper part of the door with additional force as compared to a un-coupled dummy during a full-scale test. One of the possible reasons for the enhanced CC-CTP test procedure differences when compared to the earlier simplified three-step procedure is an algorithm needs to be placed in the CC-CTP procedure to account for coupling. MVMA is investigating this theory as well as several others and will report on them when data are available.

Further Enhancements

Analysis for Improvements Toward Better Correlation

Door mass. In the CTP simulation model, the door is considered as a lump mass joined to the vehicle body by a spring. Thus,the separate door mass value is necessary. In the FST, ELD crashes also into the periphery of the door. Therefore, the simulated door mass must be considered as including the door and the part of the vehicle body around the door. (hereafter "door-area mass") From this consideration, at JARI/JAMA, the door area was divided into seven blocks for Japanese cars, as shown in Figure 13, and the mass for each block was measured. The ratio of door-area mass to unoccupied vehicle mass in a 4-door vehicle has a minimum value of 0.04, a maximum value of 0.068, and an average value of 0.053.

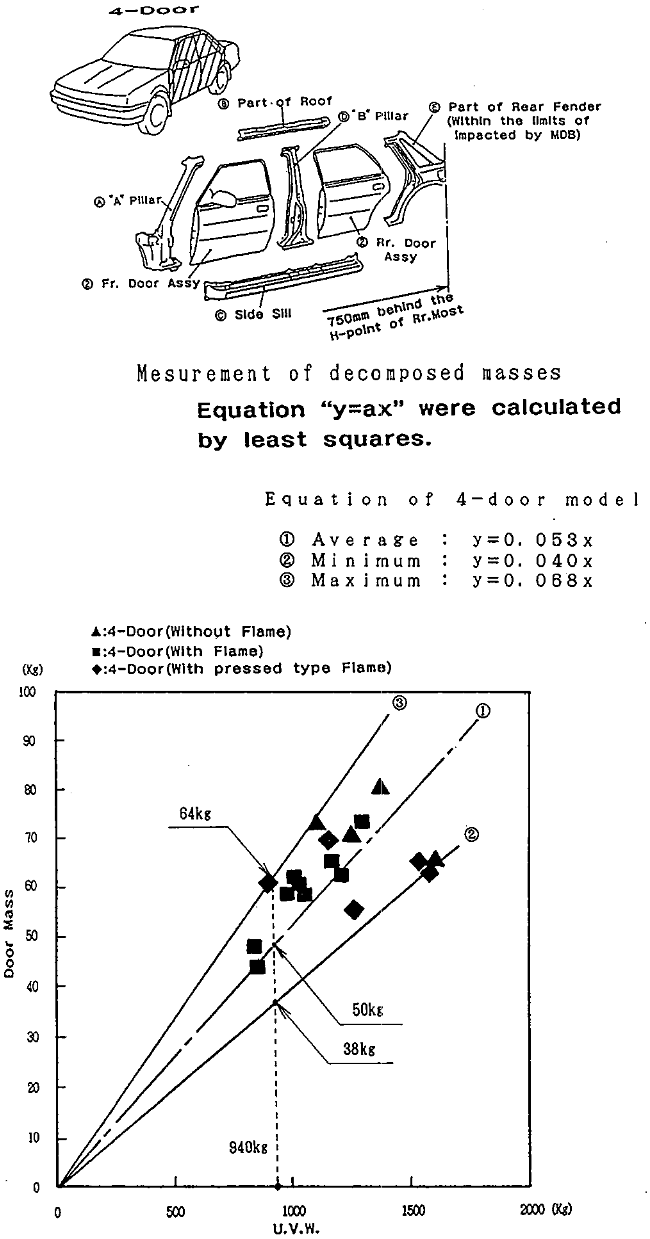


Figure 13. Correlation Between Door-Area Mass and Unoccupied Vehicle Mass

For a vehicle with an curb weight of 940 kg these values work out the door-area mass to 38 kg, 64 kg, and 50 kg respectively. The results obtained from the CTP simulation calculations with these values are shown in Figure 14. From Figure 14, it can be understood that the maximum acceleration on the ribs and pelvis of the dummy, where the impact is directly against the door, is almost unaffected by the mass of the door.

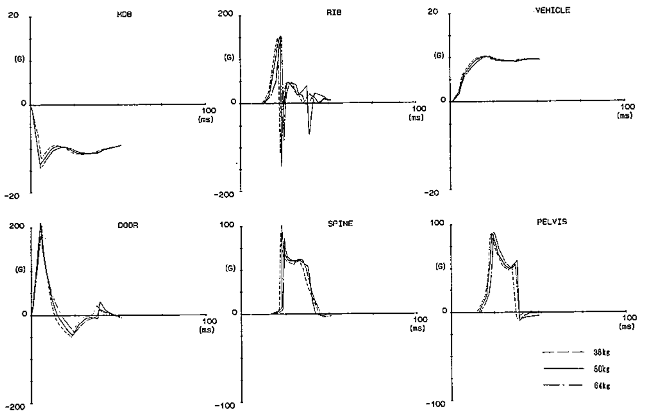


Figure 14. Effects of Door Area Mass on CTP Simulation

From this fact, the decision was made to use the median value of 0.053, i.e., 50 kg. The CTP results in Figure 15 was calculated by using 50kg as the door-area mass.

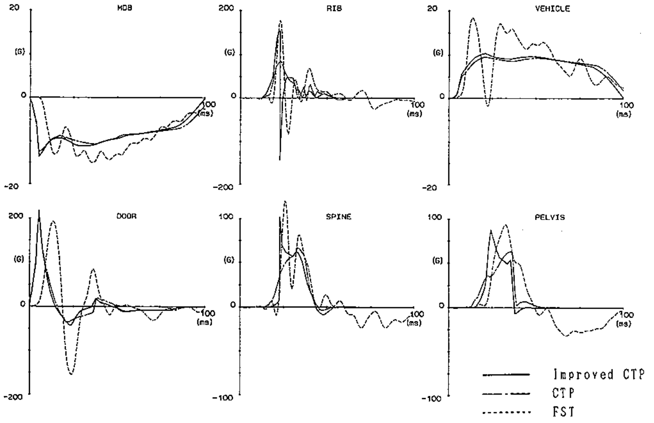


Figure 15. Findings on Correlation Between CTP and FST

Dynamic factor. Damper effect for the vehicle exterior and interior is not obtained from the CTP test. JAMA tried to resolve this by introducing a dynamic factor in the CTP simulation model. For studies of the dynamic factor, static tests and impact tests on door and padding material were carried out. The test layouts are shown in Figure 16.

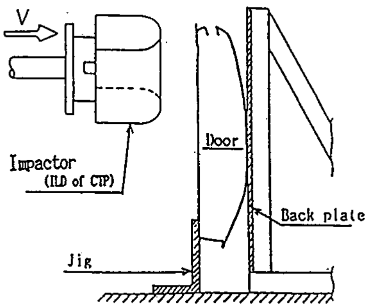
The following four equations to convert from static data to dynamic data were compared in fitting of conversion results and dynamic test results.

[1] Fd=Fs (1+r)
[2] Fd=Fs (1 +rIvI)) Fd = Force dynamic
[3] Fd=Fs +CIvI Fs = Force static
[4] Fd=Fs [1+(e/D)1/p]

Equation [4] is called Cowper and Symmonds equation, where r, C and D are dynamic factors, and the optimum values of these dynamic factors were determined by the least squares method.

FRONT DOOR TESTED

	Body Type	Frame	Note
Door 1	4 door ①	with frame	pressed type
Door 2	4 door ②	with frame	pressed type
Door 3	2 door	with frame	



	$\overline{X}$
eq. (1)	1.492
eq. (2)	0.084
eq. (3)	16.009

⟸ γ of eq. (2)

Figure 16. Static and Dynamic Crush Test for Door and Pad Material

The fitting was analysed in terms of "QSum of deviation/stroke" and "Dispersion of deviation." Sum of deviation/stroke shows the difference of total absorbed energy in a force-deflection curve, i.e., degree of general coincidence. The sum of deviation was divided by each stroke in order to normalize differences of stroke. Dispersion of Deviations shows the standard deviation, i.e., degree of local dispersion. For example, when the sum of deviation was close to zero and dispersion of deviation was large in comparison with two results, it means generally good coincidence but locally there were large differences.

The results of fitting of conversion equations are also shown in Figure 16. From the results of tests on the padding material, the Equation [2]: Fd = Fs (1 + r*IvI), (r = dynamic factor), gives comparatively good results. Therefore, Equation [2] was used with the CTP simulation results shown in Figure 15.

For the dynamic factor r, the value r = 0.084 obtained from the door test results was used. Table 3 gives the results of the CTP simulations carried out in the range r = 0.05 to 0.09. Except in the case of the spine and rib, the maximum acceleration tends to increase as r increases.

Table 3. CTP Simulation Results: Maximum Acceleration/Dynamic Factor

Gamma	MDB (G)	Door(G)	Rib (G)	Spine (G)	Vehicle(G)	Pelvis(G)
0.05	12	201	173	107	9	80
0.06	13	205	169	73	10	82
0.07	13	208	158	88	10	88
0.08	14	220	154	102	10	88
0.09	14	237	148	67	11	91

Spring and Damper in Mathematical SID Dummy

In the CTP simulation model,the dummy is connected through contact-2 on the arm form section, contact-3 on the rib-spine section, contact-9 on the spine-pelvis section, and contact-10 on the pelvis section.

Large differences can be produced in the results of the simulations according to the way the characteristics of the dummy are set.

In the JAMA/JARI studies, a SID dummy was used. Study of the spring constant and damper coefficient of each connection was made by applying static compression test and impact tests.

The impact tests were carried out in the 4.3 m/s to 10 m/s range, where the upper end is close to the velocity at which the door impacts the dummy.

Figure 17 is an example of analysis for the contact-2 on the armform section.

Figure 18 gives a comparison of the acceleration waveforms for the dummy from the CTP simulations using the values of the characteristics before and after studies into the spring and damper characteristics. The response of the dummy was improved as a result of these revision of the data. The effect in the case of the pelvis is seen to be particularly large.

Idle Stroke of Damper Between Rib and Spine

Figure 19 shows the results of the impact tests for the acceleration of the ribs and spine with respect to the thoracic displacement. The onset of the spine acceleration lags in comparison with the acceleration of the ribs by about 15 mm thoracic stroke.

Figure 20 shows the rib and spine behavior taken by a high speed camera during the impact tests. This shows that the movement of the spine bears no relation to the rib deformation.

Specifically, the rib deformation occurs prior to the action of the damper at time of impact and a discrepancy is produced in the onset of the acceleration.

The acceleration produced in the ribs is by the difference in force from the door and that from contact-3 which links the rib to the spine.

In the FST, as a result of this lag the damper force at contact-3 does not act at the initial impact when the

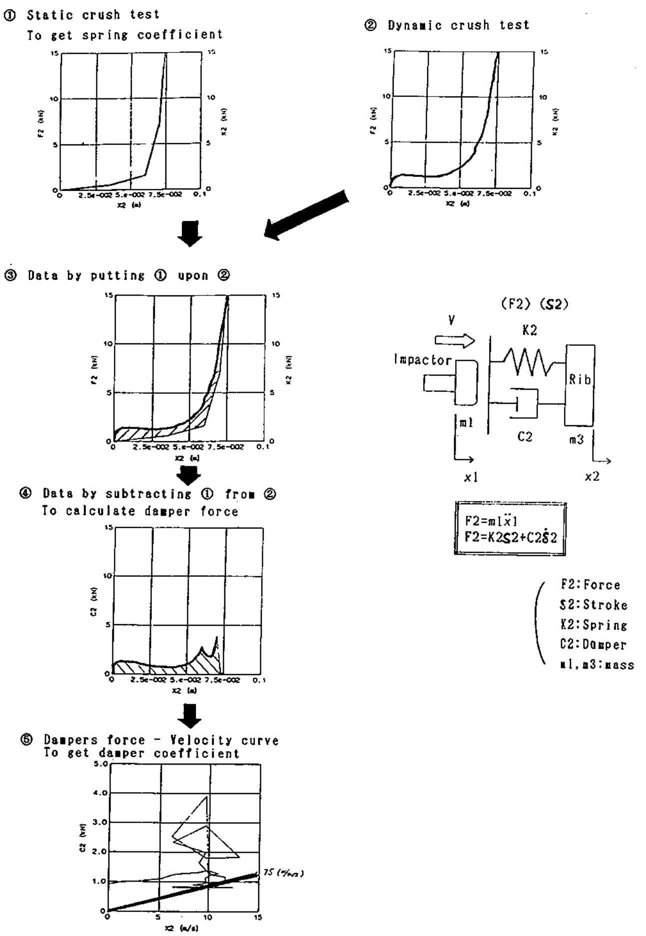


Figure 17. Calculation Process of Spring and Damper Coefficients (Example: contact2: Arm Form)

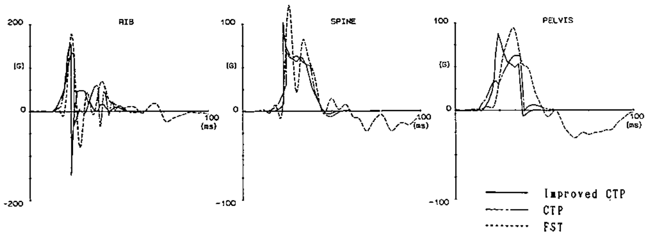


Figure 18. Comparison of Acceleration History in CTP and FST (Evaluation of Improved Spring and Damper Coefficients)

force from the door is applied to the ribs, so that the rib acceleration becomes high.

The effect tends to be large because of the mass of the rib being small. In the configuration of the SID thoracic section, the rib cage is connected to the spine through a spring and a damper, as shown in upper one of Figure 21.

We analyzed the lag between rib and spine strokes at the onset of accelerations in a various manner, and found that it cannot reasonably be reproduced by the conventional dummy model in CTP.

Accordingly, in order to reproduce this lag in the simulation a 15mm gap was provided between the ribs and the damper, as shown in Figure 22 and Figure 23, shows the maximum acceleration of each part in the simulation and in the impact test results with respect to the impact velocity. The correlation between the test results is seen to be improved by the provision of the gap between the ribs and the damper.

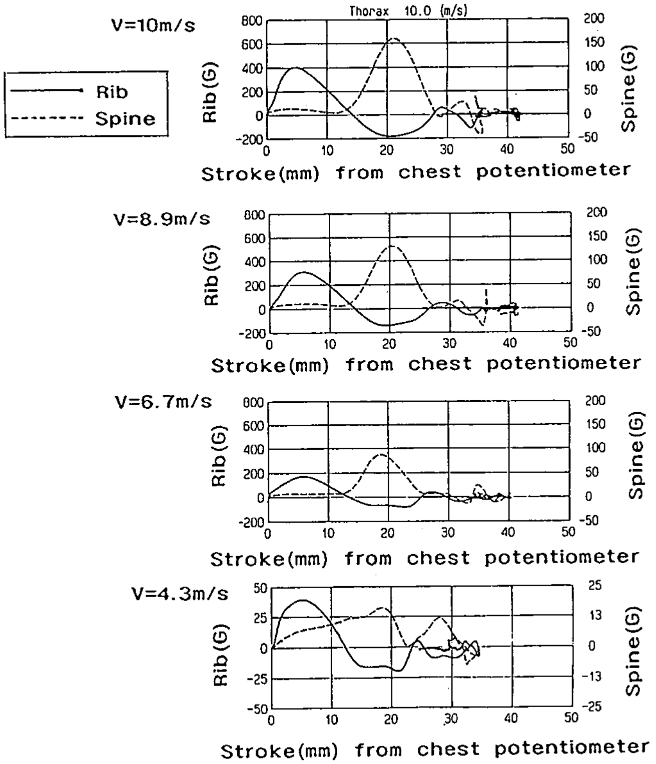


Figure 19. Delay of Spine Acceleration Response on Thorax Impact Test

Figure 24 is a comparison of the acceleration waveforms of each part of the FST dummy and the results of the CTP simulations, both with the gap present and with the gap absent. The correlation with the FST tests is seen to be improved by the introduction of the gap.

Further Study Items

As a result of step-by-step research,the correlation between FST and CTP was remarkably improved, but we still have several items to be studied. Some items are expected to be solved by using CC-CTP and other items should be studied individually. We will now consider future research concerning these items.

Loading method. In the step-by step tests the ELD loading and ILD loading are carried out separately so that the relative position between the two is not related to that in the case of FST.

The loading characteristics of complex structures such as a vehicle are thought to differ as relative position change.

With CC-CTP, the elementary test steps are:

(1) The ELD position is obtained from the results of the CTP simulation calculations.
(2) The ELD and ILD are moved to the positions obtained from the calculations.
(3) Data is collected for the forces at that position.

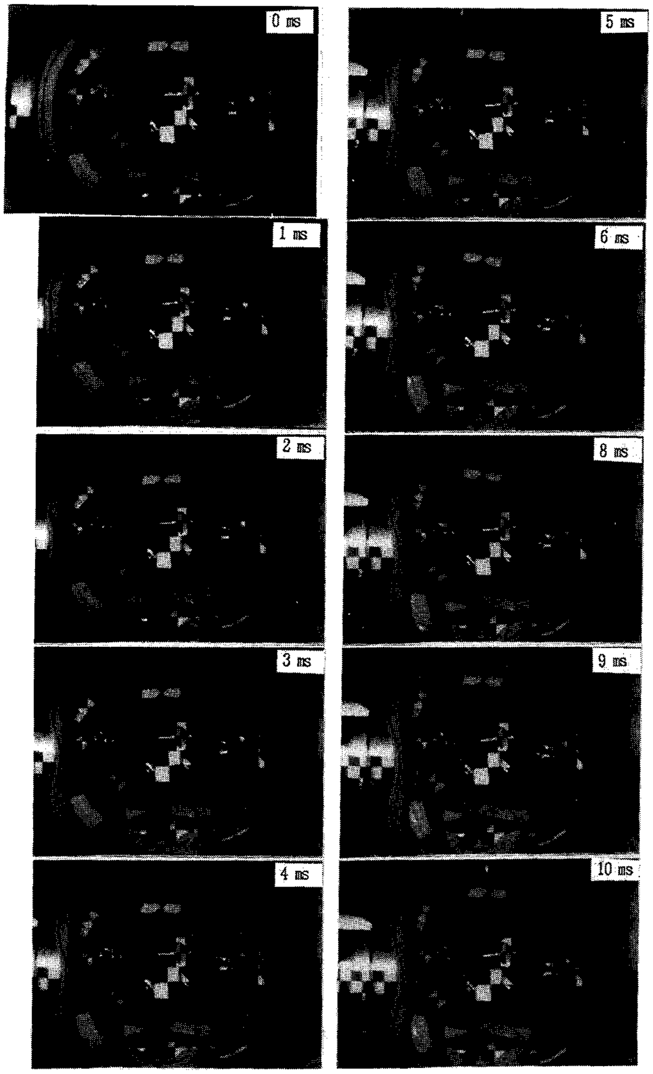


Figure 20. Rib and Spine Behavior on Impact Test

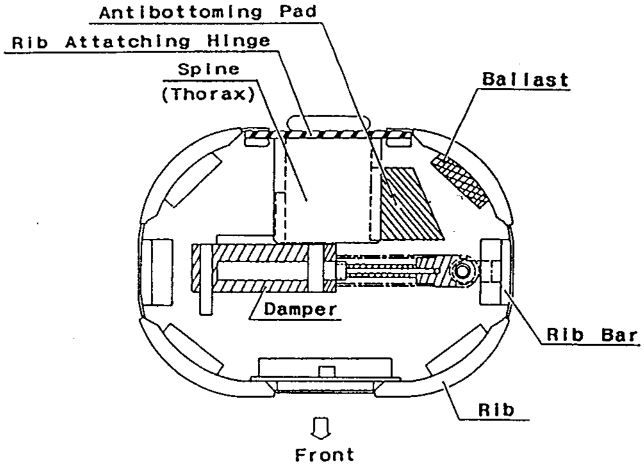


Figure 21. SID Thoracic Structure

(4) CTP simulation calculations are made from these results.

These steps are repeated cyclically to form a whole test. This is thought to produce a situation close to the behavior of the FST.

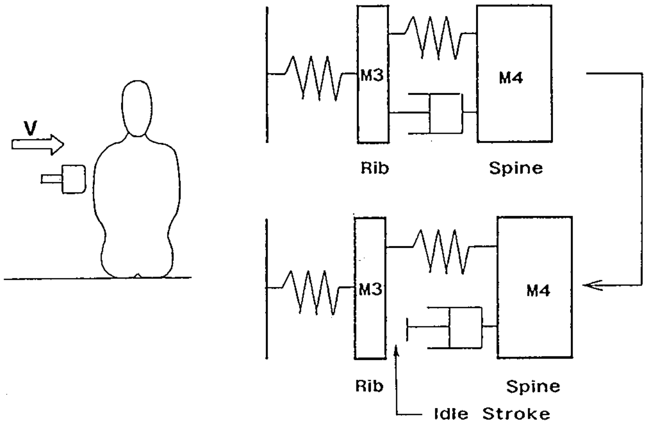


Figure 22. Simulation Model with 15 mm Idle Stroke of Damper

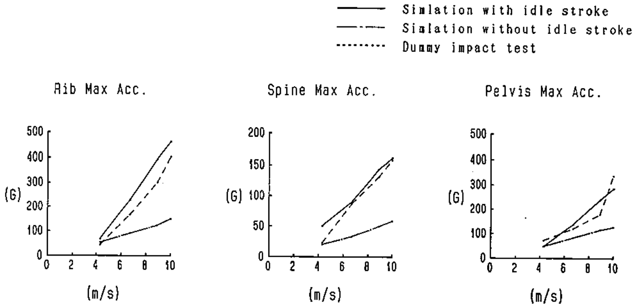


Figure 23. Comparison of Maximum Accelerations Between Similation and Dummy Impact Tests (Evaluation of Adopted Idle Stroke)

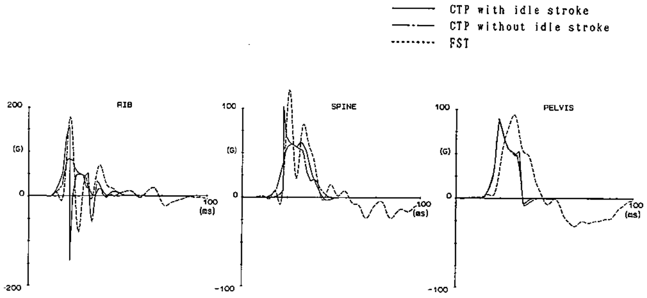


Figure 24. Comparison of Acceleration History in CTP and FST (Evaluation of Adopted Idle Stroke)

For example, when a difference is produced between the thorax ILD load and the pelvis ILD load, the positions of these respective ILDs can change into natural positions consistent with the dynamics. Thus we can avoid an unreal loading sometimes seen in the step by-step method, such as a large load acting on one ILD only.

Lump-mass identification. A CTP simulation model with seven lump mass points is a comparatively simple model. This allows easy comparison of the CTP simulation results obtained from the individual tests.

On the other hand, because both the dummy and the vehicle are constructed from a large number of parts, it is essential to determine which parts are actually included in each lump mass in the model. In the present studies, the door-area mass was investigated, but it will be necessary to study the other portions in the same manner.

Lump-mass distribution modeling. The acceleration waveforms for the CTP simulation results and the FST tests shows that they differ in detail for the vehicle acceleration shown in Figure 15. One reason for this is thought to be that the movement of point measured does not directly represent the movement of simulated portion in the model, therefore the results differ from the movement of the lump mass in the CTP simulations. This could be due to the effect of conditions that the vehicle body deforms at various points and that the engine, transmission and some other parts are flexibly joined to the body.

This indicates that studies must be made to determine the best location of measurements for the FST that represent each lump mass in the simulation model. Or, it might be considered that the correlation is not important in the vehicle acceleration waveform.

Dynamic factor. In the CTP simulation, the concept of the dynamic factor is introduced. The dynamic factor for the door and the padding considerably affect the response of the dummy.

Research into improving the precision of the static-to-dynamic conversion method when the door and the padding material are combined remains as a problem which must be solved by future research.

In addition, because of the differences in the CTP and FST results for the above mentioned vehicle acceleration and barrier acceleration, the deformation characteristics of the barrier and the door, and of the door and the vehicle, must be studied from the aspect of dynamic conversion.

ILD shape. The present ILD is a half-cylinder shaped rigid body, which roughly simulates the shape of the dummy, but differs in detail. As a result, there is the possibility that the reaction force differs in the case where the dummy impacts the door in FST from the case where the ILD is contacted by the door. For example, the pelvic ILD simulates the dummy surface shape, not the shape of the rigid part of the pelvis.

Figure 25 shows the positional relationship between the pelvic region and the arm rest. As can be understood from the drawing, a large reaction force is produced because the pelvis ILD contacts the arm rest, while no large reaction force with a dummy being more flexible under similar conditions. Therefore, it is necessary to study pelvic ILD shapes which give conditions closer to that with FST.

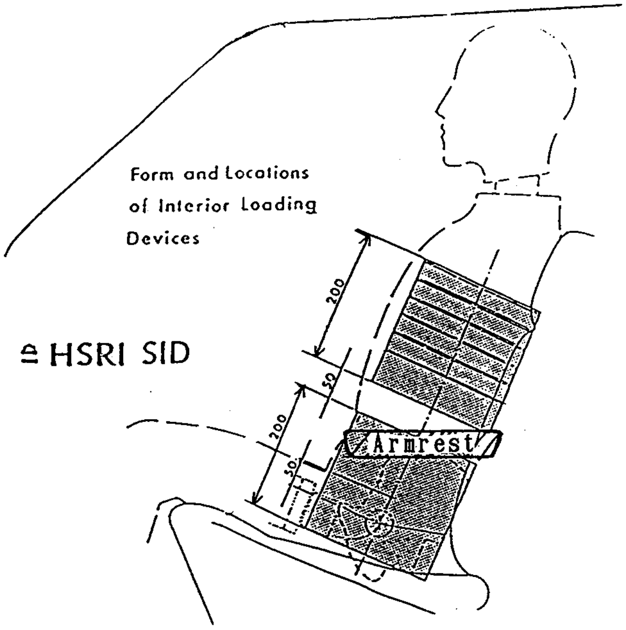


Figure 25. Armrest Location for ILD and SID

Simulation of Human Behavior

In order to evaluate lateral protection provided for the occupants of vehicles according to the Composite Test Procedure, it is necessary to have a mathematical modelization of the occupant. Due to the lack of a sufficiently human-like test dummy (1-2), this modelization must be made from data related to the dynamic behaviour of the human being under lateral impact.

In absence of sufficient data characterizing the stiffness and the viscous effect of each part of the body, CCMC has undertaken an important programme to acquire the data required for modelization of the human being, integrating the role of the arm and the shoulder. 5 static tests with 2 cadavers and 17 dynamic impactor tests with 5 cadavers have been carried out to characterize the lateral responses of the human being.

Two impact model responses were investigated and validated comparatively to the cadaver impactor tests:

- model with arm and shoulder interposed called "passenger arm position."
- model without arm and shoulder interposed called "driver arm position."

In addition, in order to design and make the rigid devices measuring the stiffness of the inner panel of the door, 2 static tests with cadaver were carried out to approach the shape of the compressed thorax and pelvis.

Experimental Materials and Methods

Static tests. In order to define the following parameters of the CTP model:

- the shape of compressed thorax and pelvis for the construction of the Impactor Loading Devices
- the cumulated stiffness of the rib cage and shoulder
- the stiffness of the thorax, of the arm, and pelvis

static tests on cadavers, whose anthropometric characteristics were close to 50th percentile male, were carried out. For these tests, the human being was compressed by means of a rigid flat impactor (240 x 240 mm). The deflection was measured with a linear potentiometer. The force applied by the impactor was measured with 3 piezo resistive sensors.

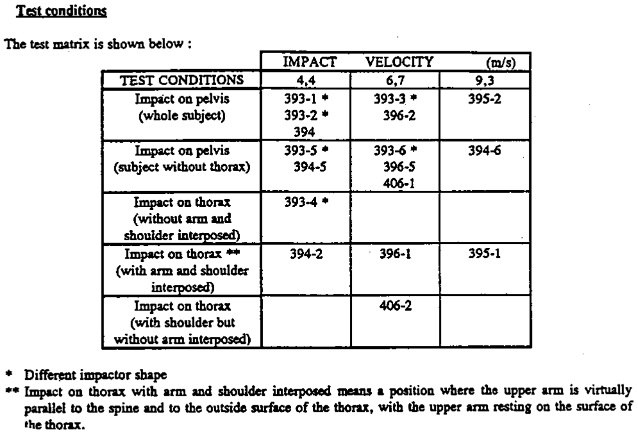
Dynamic tests. In order to approach:

- the dynamic stiffness of the arm and pelvis
- the visco-elastic component of the thorax
- the effective mass of the pelvis, the arm, the ribs and the thorax

17 dynamic impactor tests were carried out with 5 cadavers.

Test conditions. The test matrix is shown in Table 4. Each impact configuration has been performed for 3 values of impact velocity: 4.4 m/s, 6.7 m/s, and 9.3 m/s.

Table 4. Test Conditions



Test conditions

The test matrix is shown below :

	IMPACT	VELOCITY	(m/s)
TEST CONDITIONS	4,4	6,7	9,3
Impact on pelvis (whole subject)	393-1 * 393-2 * 394	393-3 * 396-2	395-2
Impact on pelvis (subject without thorax)	393-5 * 394-5	393-6 * 396-5 406-1	394-6
Impact on thorax (without arm and shoulder interposed)	393-4 *		
Impact on thorax ** (with arm and shoulder interposed)	394-2	396-1	395-1
Impact on thorax (with shoulder but without arm interposed)		406-2	

* Different impactor shape

** Impact on thorax with arm and shoulder interposed means a position where the upper arm is virtually parallel to the spine and to the outside surface of the thorax, with the upper arm resting on the surface of the thorax.

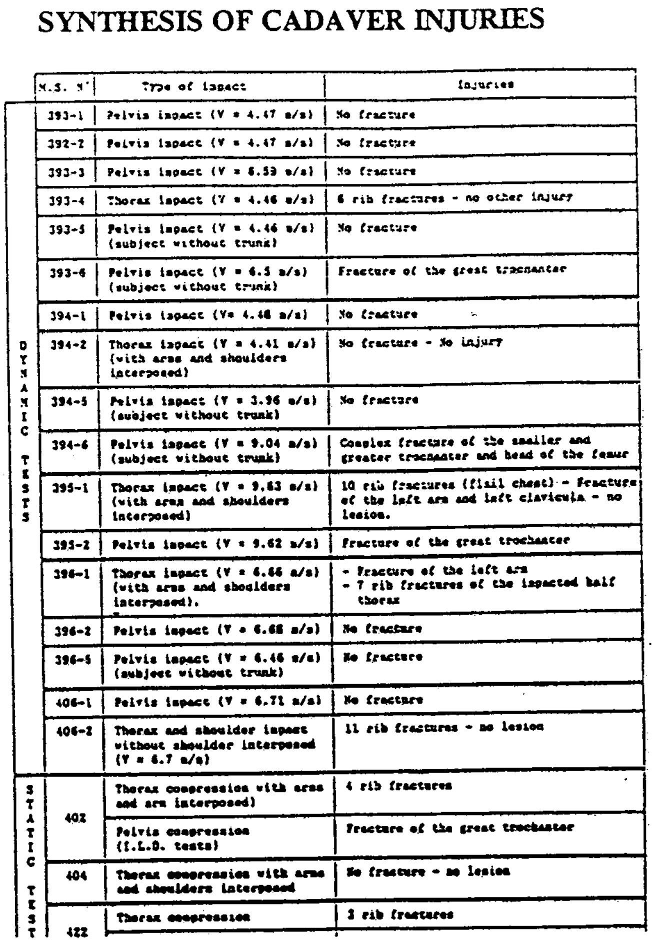
Necropsy. For the static and dynamic tests on cadavers, an autopsy was performed by a certified pathologist, and special attention was paid to injuries of the chest, abdomen and pelvis. The rib bone condition factor (3) was evaluated for each subject. A synthesis of the lesions observed at autopsy is given in Table 5.

Construction of the Model. In a previous study (4-5) APR had already presented an approach by mathematical modelization of the dynamic behaviour of a human being under lateral impact. The model of the thorax had been validated on the basis of ISO DP 9790 ↓ - reference data and Viano raw data (6). With respect to the Viano tests, the response of this model in terms of force, deflection and V*C was within the dispersion of the cadavers test results.

At this stage of development, the mass located at the periphery of the thorax was near 0. Moreover, the constant values of spring and damper were determined by a heuristic approach.

On the basis of the complementary test program presented in this paper, we have refined this model in order to take into account the role of the skin, the arm and the shoulder. Two possibilities of impact response model were investigated: Driver arm position "means a position of the upper arm that would result from placing the hands of a normally seated driver on the steering wheel rim," in a "ten to two" position, so as to completely expose the thorax. "Passenger arm position" means a position where the upper arm is virtually parallel to the spine and to the outside surface of the thorax, with the upper arm resting on the surface of the thorax; so in this configuration the upper arm and shoulder are interposed with the thorax.

Table 5. Synthesis of Cadaver Injuries



SYNTHESIS OF CADAVER INJURIES

	N.S. N°	Type of impact	Injuries
DYNAMIC TESTS	393-1	Pelvis impact (V = 4.47 m/s)	No fracture
	392-2	Pelvis impact (V = 4.47 m/s)	No fracture
	393-3	Pelvis impact (V = 6.59 m/s)	No fracture
	393-4	Thorax impact (V = 4.46 m/s)	6 rib fractures - no other injury
	393-5	Pelvis impact (V = 4.46 m/s) (subject without trunk)	No fracture
	393-6	Pelvis impact (V = 6.5 m/s) (subject without trunk)	Fracture of the great trochanter
	394-1	Pelvis impact (V= 4.48 m/s)	No fracture
	394-2	Thorax impact (V = 4.41 m/s) (with arms and shoulders interposed)	No fracture - No injury
	394-5	Pelvis impact (V = 3.96 m/s) (subject without trunk)	No fracture
	394-6	Pelvis impact (V = 9.04 m/s) (subject without trunk)	Complex fracture of the smaller and greater trochanter and head of the femur
	395-1	Thorax impact (V = 9.63 m/s) (with arms and shoulders interposed)	10 rib fractures (flail chest) - Fracture of the left arm and left clavicula - no lesion.
	395-2	Pelvis impact (V = 9.62 m/s)	Fracture of the great trochanter
	396-1	Thorax impact (V = 6.66 m/s) (with arms and shoulders interposed).	- Fracture of the left arm - 7 rib fractures of the impacted half thorax
	396-2	Pelvis impact (V = 6.68 m/s)	No fracture
	396-5	Pelvis impact (V = 6.46 m/s) (subject without trunk)	No fracture
	406-1	Pelvis impact (V = 6.71 m/s)	No fracture
	406-2	Thorax and shoulder impact without shoulder interposed (V = 6.7 m/s)	11 rib fractures - no lesion
STATIC TESTS	402	Thorax compression with arms and arm interposed)	4 rib fractures
		Pelvis compression (I.L.D. tests)	Fracture of the great trochanter
	404	Thorax compression with arms and shoulders interposed	No fracture - no lesion
	422	Thorax compression	3 rib fractures

In the current C.T.P. software, the static force displacement characteristics of the inner panel of the door are cumulated to the force displacement characteristics of the arm, the skin covering the ribs, the pelvis; so these behaviors cannot be modeled by spring damper systems.

Model Simulating the "Driver Arm Position"

The approach which seemed the most satisfactory is in accordance with the work of Hung Hsu Chen (7) and Langdon (8).

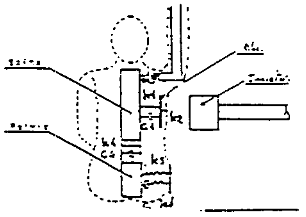
The characteristics of the "driver model" which was determined are given Table 6.

Model Simulating the "Passenger Arm Position"

In this configuration the upper arm and shoulder are interposed with the thorax. The simplified approach which seemed the most satisfactory and the characteristics of the model are given in Table 7.

Table 6. Characteristics of the "Driver Model"

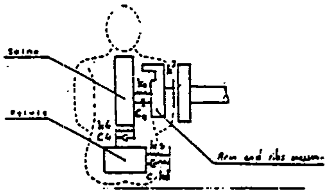
SEGMENT	MASS (kg)
Rib	0,45
Spine	24
Pelvis	14



SKIN COVERING THE RIBS (K2)	RIB CAGE (K1)	DASHPOOT CONSTANT OF RIBS CAGE (C1)
Loading phase (m) (N) 0 0 0,01 1000 0.015 5200 0,02 15100 If displacement > 0,02 m then K = 2 000 000 N/m Unloading phase K = 2 000 000 N/m	Loading or unloading (m) (N) 0 0 2250 0,09 If displacement > 0,09 m then K = 100 000 N/m	Loading or unloading phase C = 250 N.s/m
	Characteristics of Pelvis : Loading or unloading phase KS = 35 000 N/m Kd = 300 000 N/m C = 1 800 N/m/s	Coupling between thorax and pelvis (loading or unloading phase) K = 25 000 N/m C = 200 N.s/m

Table 7. Characteristics of the Model Simulating the Passenger Arm Position

SEGMENT	MASS (kg)
Rib + Arm	4,45
Spine	20
Pelvis	14

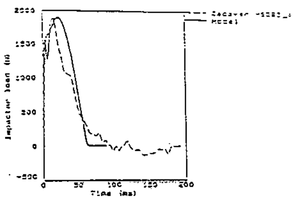


CHARACTERISTICS OF THE ARM AND SKIN COVERING THE RIBS (K3)	RIB CAGE (K0)	DASHPOT CONSTANT OF THE RIB CAGE (C0)
Loading or unloading phase K = 160 000 N/m If displacement > .06 m then K = 320 000 N/m	loading or unloading phase (m) (N/m) 0 37500 .025 88500 .09 400000	Loading or unloading phase C = 500 N.s/m
Coupling between thorax and pelvis (loading or unloading phase) K = 25 000 N/m C = 200	Characteristics of Pelvis : loading or unloading phase KS = 35 000 N/m Kd = 300 000 N/m C = 1 800 N/m/s	

Validation of the Model

Validation of the driver thorax model. By analogy with the cadaver test results, the step of calculation for the model was .666 ms and the data were filtered by FIR 100 Hz. The comparison between cadaver impactor test ms 393-4 and model results is shown below in Figure 26.

Impactor test on thorax (m = 23.4 kg). The force deflection response is a biomechanical key and defines the compliance of the thorax under a lateral impact. The response area under the curve represents the energy absorbed by body deformation. The comparison between the energy absorbed in the cadaver test and the simulation is given in Figure 27.



MODEL RESPONSE COMPARED TO CADAVER TEST DATA

Impactor test on thorax (m= 23.4 kg)

	impactor velocity (m/s)	max. impactor force (N)	Total deflection (mm)
Cadaver MS 393-4	4.4	1870	71
Model	4.4	1879	79

Figure 26. Model Response Compared to Cadaver Test Data

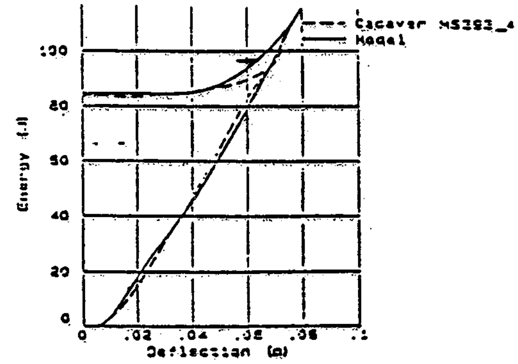


Figure 27. Energy Absorbed by the Thorax: Comparison Between Cadaver and Model Responses

Simulation of Viano cadaver tests (6). In the 33rd Stapp Car Crash Conference, Viano presented the results of fourteen unembalmed cadavers who were subjected to forty-four blunt lateral impacts on the thorax, abdomen and pelvis with a 15 cm flat 23.4 kg pendulum in range of 3.6 m/s to 10.2 m/s impact velocity.

The specimen, impacted on the left or right side, was rotated 30 degrees and the center of pendulum impact on the thorax was aligned with the xiphoid process. Abdominal impact was aligned 7.5 cm below the xiphoid.

Figure 28 shows the original force/impact velocity response (filtered FIR 100) for each impact on the thorax compared with the response given by mathematical model.

Using a linear regression between force and impactor velocity as shown in Figure 28, the Viano data were reanalyzed in order to rescale the cadaver raw response to a common impact speed. The best relationship is obtained by dividing the Viano test sample in two subsamples: the first one corresponds to tests with impactor velocity from 3.6 m/s to 6.73 m/s, the second one to tests with impactor velocity from 6.71 m/s to 10.2 m/s.

Acceleration data generated in side impact on cadavers are used in the analysis as input to satisfy impulse-momentum requirements.

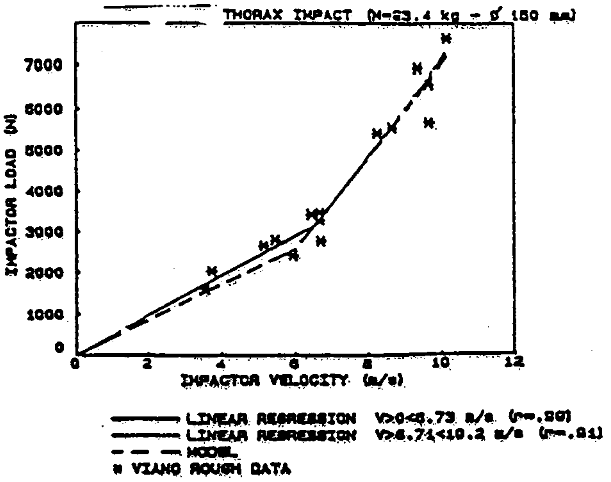
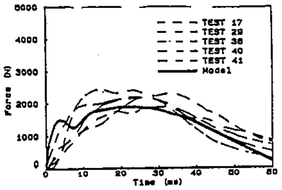


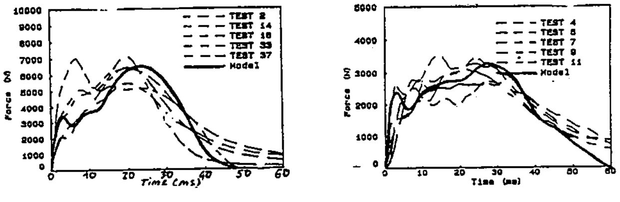
Figure 28. Force vs Impact Velocity in Viano Cadaver Tests Compared With Model Responses

The procedure scales responses to an arbitrarily chosen standard subject which is the 50th percentile male.

The comparison between the Viano Corridors (6) defined on the basis of the normalized cadavers results and the model response is given in Figure 29. As shown by the corridors (Figure 29) and the results of the simulation, these impactor cadaver tests on the thorax {from 4.4 m/s to 9.6 m/s) cannot be simulated with the actual dummies which have a mechanical thorax deflection less than 80 mm. The minimum value required for the test at 4.4 m/s is 80 mm. In order to simulate these tests, a mechanical thorax deflection device operating from 0 to 150 mm would be necessary.



Tests between 3.6 m/s and 5.5 m/s



Tests between 8.3 m/s and 10.2 m/s

Tests between 5.99 m/s and 6.73 m/s

Comparison between the response given by the model and those given by the Viano cadaver tests (6) rescaled to a standard impact speed

Figure 29. Comparison Between the Response Given by the Model and Those Given by the Viano Cadaver Tests (6) Rescaled to a Standard Impact Speed

Validation of the passenger thorax model. Validation against the requirements of documents ISO/DTR 9790-3 (17).

The biofidelity of the thorax model can be evaluated against the requirements of documents ISO/DTR 9790-3 based on 3 data sources: APR drop tests on rigid or padded surfaces; Heidelberg sled tests: impacts on rigid or padded surfaces; and H.S.R.I. impactor tests.

Only the lateral impact test configuration of the University of Heidelberg for rigid impact can be simulated with the "passenger model." The comparison with ISO corridors (17) is given in Figures 30 and 31, respectively.

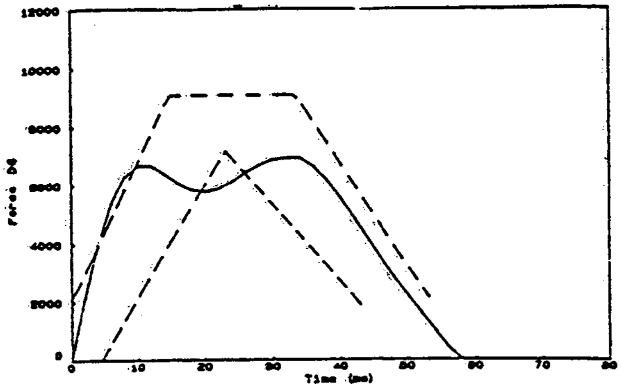


Figure 30. Force-Time History (Comparison of ISO Requirements with the Model Response)

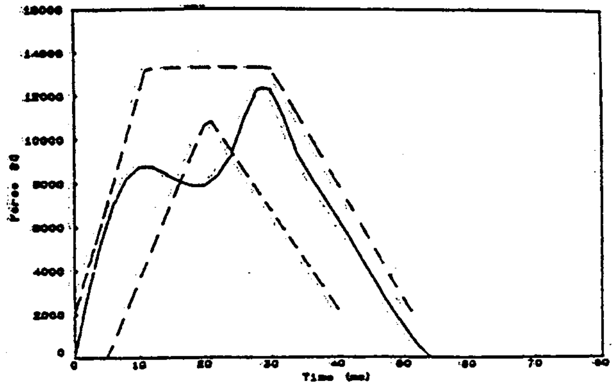


Figure 31. Passenger Model Response Compared with ISO Reference Data

Simulation of cadaver tests MS 394 - 395 - 396. On the basis of impactor test conditions described here, the comparison of maximum values between the response given by the "passenger model" with those of the cadavers is shown in Table 5.

The mathematical model response seems to be qualitatively satisfactory. Nevertheless, a complementary test program with cadavers would be necessary to improve the mathematical model response.

Validation of the pelvis model. By analogy with the human being tests results, filtered with the FIR 100 filter, the step of calculation in CTP procedure was 0.625 ms. The results of the modelization are not post-filtered.

On the basis of 10 dynamic impactor tests presented in this paper, cumulated with 13 dynamic impactor tests presented by VIANO (6), a linear regression between maximum impactor load (rough data) and impactor velocity has been performed (r=0,93):

$$\text{Force} = 126.704 \times \text{velocity} - 85.5514$$

The three-dimensional frequency histogram in Figure 32 shows the relationship and the distribution between impactor velocity (M=23.4 kg) and maximum force applied on the pelvis for our data mixed with Viano data (6). These test conditions are producing a distributed load on pelvis. Figure 33 shows that the results given by the model are in the 95 % confident limits for the mean response at a given value of velocity.

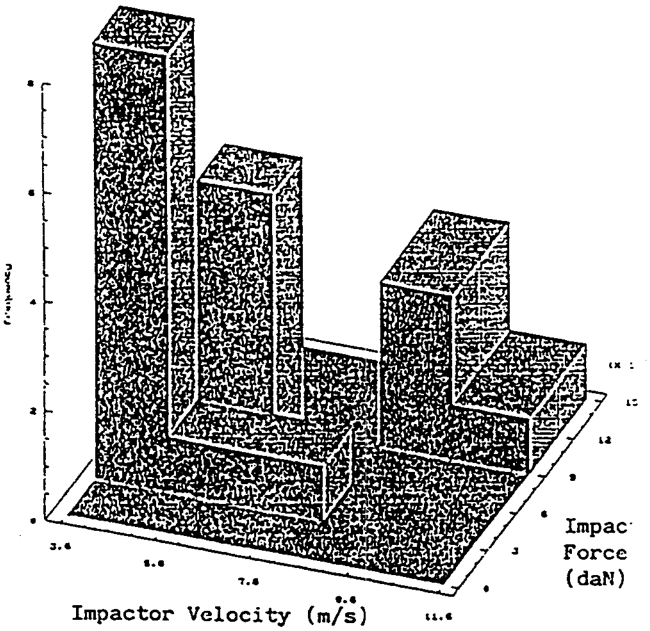


Figure 32. Distribution of Impactor Force and Velocity in Viano (1) and APR (16) Pelvis Test Data

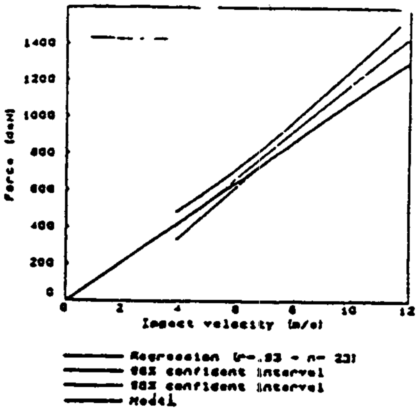


Figure 33. Force-Velocity Cooridor Response Based on Viano (1) and APR Data (16) Compared to the Model

The comparison between the maximum values predicted by the model and those observed in the tests presented in this paper is given in Table 8 and Table 9.

Table 8

Pelvis alone

TEST N°	IMPACT VELOCITY (m/s)	FORCE (daN)	PELVIS ACC. (g)	PELVIS DEFLECTION (m)
394/5	4.0	360	27.3	0.033
model	4.0	429	31.2	0.024
396/5	6.5	719	73.1	0.057
model	6.5	698	50.8	0.039
394/6	9.0	1210	85.7	0.059
model	9.0	966	70.3	0.054

Table 9

Pelvis + Thorax

TEST N°	IMPACT VELOCITY (m/s)	FORCE (daN)	PELVIS ACC. (g)	THORAX ACC.	PELVIS DEFLECTION (m)
394/1	4.5	600	41.4	8.0	0.035
model	4.5	487	31.7	6.3	0.028
396/2	6.7	1136	58.9	6.1	0.045
model	6.7	724	48.6	9.4	0.052
395/2	9.6	1192	73.9	14.0	0.060
model	9.6	1038	69.7	13.5	0.060

Validation of the pelvis model according to ISO/ DP9750-4. INRETS has investigated the responses of 22 unembalmed cadavers submitted to lateral impact on the great trochanter. An accelerometer placed at the rear of the sacrum measured the transverse acceleration at the pelvis.

The unbelted cadavers were seated on a seat and received shocks at various speeds (6 m/s < V < 14 m/s) transmitted by a rigid or soft impactor device. The forces applied by the device were measured. These data were normalized to give the response characteristics of a 50th percentile adult male.

A relationship between the impact speed and the maximum standardized force is determined on the basis of rigid impactor tests (M = 17.3 kg). When the shock applied occurs at a speed of between 6 and 10 m/s, the response is considered correct if the maximum force of the impacting device is within the corridor. The model response is inside the corridor response, as shown in Figure 34.

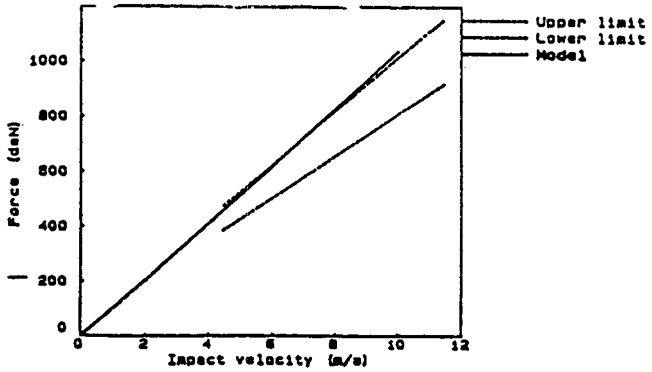


Figure 34. Pelvic Model Response Compared to ISO Reference Data

Conclusions

On the basis of static and dynamic cadavers tests on the lateral parts of the body, a mathematical human being impact model, with or without arm and shoulder interposed, was developed and was shown to be capable of simulating the impact response given in the literature. Nevertheless, a complementary test program with cadavers is necessary to improve the mathematical model response included in the C.T.P. procedure. Concerning the coupling between thorax and pelvis, and taking into account the spine rotation, a better modeling approach could be obtained by using a two-dimensional approach. The model and the cadaver data given in this report could be used as a tool in the design of an impact dummy.

S5-O-25

Simulation Model for Vehicle Performance Improvement in Lateral Collisions

P.J.A. de Coo, E.G. Janssen,
A.P. Goudswaard, J. Wismans
TNO Crash-Safety Research Centre
M. Rashidy
Ford Motor Company

Abstract

Crash tests have been conducted on a baseline vehicle in accordance with the proposed European side-impact regulation. With MADYMO, a model of the vehicle including the EUROSID-1 dummy and the barrier was developed and validated against the test results. The model was used to evaluate the effect of vehicle modifications on injury assessed by the dummy. Based on the results of the simulations and analysis of the tests, simple modifications were introduced in the vehicle and a test was carried out on the modified vehicle. The baseline vehicle met the regulation on head and lower body criteria, but failed on all chest criteria. The modified vehicle satisfied the regulation on all criteria, except for the lower rib Soft Tissue Criterion. It is shown that vehicle improvement does not necessarily lead to stiffening or strengthening of the structure. Improvement was achieved by tuning the side-structure deformation so that it takes place over a wider area.

Introduction

In the USA side-impact regulation has been finalized. In Europe it will be introduced in 1995. The proposed European Regulation [1] principally requires a full-scale test (FST), but the possibility of a composite test (CTP) is being considered. Only complete vehicles can be submitted for type approval. This means that with respect to this regulation the status of a vehicle can only be determined in a last stage of the development. The manufacturer, however, wants to know the status of his vehicle much earlier. During the development, the manufacturer is interested in economical ways to predict the influence of certain measures which could improve safety performance. Simulation models are the easiest way to check the effect of design changes at an early stage. The CTP applied to a body in white can possibly also fulfil this goal.

In the past, lumped mass models, space frame models and finite element models have been used to simulate certain aspects of a lateral collision. The objective of this paper is twofold: first, to demonstrate the applicability of a multi-body program, which can be considered a special class of lumped mass and space frame models, in vehicle and occupant modelling of a side-impact collision, and second, to test the sensitivity of EUROSID-1 in detecting vehicle design changes.

The study as presented here was originally set up as a comparison between the FST and the CTP, both followed by computer simulation to obtain measures for vehicle improvement. The FST would be followed by parametric studies by modelling the event with the crash victim simulation program MADYMO [2], and the CTP would be followed by a parameteric study using the CTP software. The results of these simulations, together with a structural analysis of the deformed vehicle, would serve to define a number of modifications on the baseline vehicle. A second series of tests according to both methods would evaluate the sensitivity of both methods in predicting vehicle performance and the influence of certain measures in the design of the vehicle.

The above-mentioned research program had to be split up because the CTP software was until recently available only to CCMC members. This paper describes the development, validation and use as a computer aided design tool which provides a vehicle side-structure and dummy model for studying occupant safety in side-impact collisions. The model has been validated against the results of a full-scale side-impact test on a baseline vehicle in accordance with the European test procedure. To fulfil the requirements of the regulation, recommendations for design changes have been made based on a parameter study. The baseline vehicle was modified according to the model predictions, and a full-scale side-impact test was conducted for verification of the design changes.

Model Philosophy

Designing a vehicle is a process which covers a number of stages. In the early design stage, there is insufficient available data for detailed modelling of structural components. Lumped parameter models for predicting vehicle response using static crush data have been in use for several years. These one-dimensional models are useful in studying the effect of mass and stiffness changes on structural responses. One-dimensional side-impact models of vehicle structure and occupant have been reported, like the computer simulation of the CTP, which test method is proposed as an alternative for the Full-Scale Test Procedure [1]. Two- and three-dimensional models may be useful if rotation of the dummy as a whole or rotation of lower torso relative to upper torso is significant. In [3] a two part 3-D model consisting of a structural part and an occupant part, is described. The structural part consists of three rigid masses, representing the striking vehicle and the struck vehicle, where the masses are connected by non-linear springs. The occupant part is represented by a tree structure, simulating the occupant.

Another way of modelling the side-impact event is by considering the structure as an assembly of a number of individual beams connected at nodal points [4]. Structural properties are incorporated in the beam stiffness matrix, and collapse properties of the beams and joints, measured in quasi-static tests, are specified in the beam ends. Loading is applied incrementally, and after each load increment the status of internal forces is evaluated with respect to collapse properties and successively updated. This procedure allows the (static) analysis to proceed well beyond the onset of collapse. The static analysis results are then used in a lumped mass model to predict side-impact dynamics as well as the deformation speed of the target vehicle. Finally, these results could be used in a Crash Victim Simulation program to predict occupant injury.

A comprehensive approach of modelling a side-impact crash is by using finite elements [5]. In this case, detailed information about the structural components must be available. A complete and accurate description of both vehicle stiffness and mass distribution is essential for the analysis. Areas directly involved in the deformation have to be meshed in fine detail, while the other part, where an accurate stiffness is less important to the analysis, can be meshed more coarsely. A disadvantage of this kind of modelling is the great amount of time involved in preparing the model and the computer time required for simulation, even on a super computer. Systematic parameter optimization studies involving only a few candidate design parameters are not practical yet with the current computer hardware available.

Model Set-Up

When many design alternatives have to be investigated, a fast simulation model is desirable, one which also takes occupant injury assessment directly into account. Combination of the lumped mass approach and space frame modelling can be realized using a multi-body approach, where the structure as well as the occupant are represented by rigid bodies interconnected by arbitrary kinematic joints. Recently, TNO developed a new multi-body module for the MADYMO multi-body program which is based on a recursive algorithm. It allows modelling of kinematic joints with arbitrary degrees of freedom. Examples are translational joints, hinges and spherical joints. In fact, any user defined joint can now simply be included in MADYMO. Using this option, a model of a baseline vehicle was developed to describe its behaviour during a side-impact collision. The moving deformable barrier and the side-impact dummy were also modelled using the new module.

Based on the philosophy of [4], the method of the 'hybrid' approach is adopted here for a side-impact simulation model including bullet and target vehicles and the occupant (Figure 1). The quasi-static collapse characteristics of the energy absorbing components (beams and joints) are obtained experimentally.

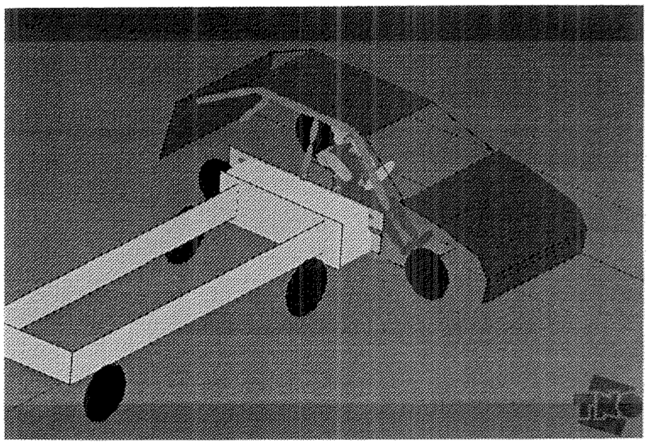


Figure 1. MADYMO Representation of a Side-Impact Collision

The vehicle model consists of a deformable side structure, defined by a tree structure of rigid bodies (Figure 2), and a mass representing the non-deforming body shell. The side structure is connected to the body shell by means of non-linear springs. The side-structure stiffness is condensed in the joints between each pair of elements. Spring and joint characteristics were obtained from quasi-static tests on the separate elements. The joints in the rocker are 3-D joints, which have two bending degrees of freedom and one torsional degrees of freedom. The B-pillar elements are connected by 1-D joints, which only allow inward or outward bending.

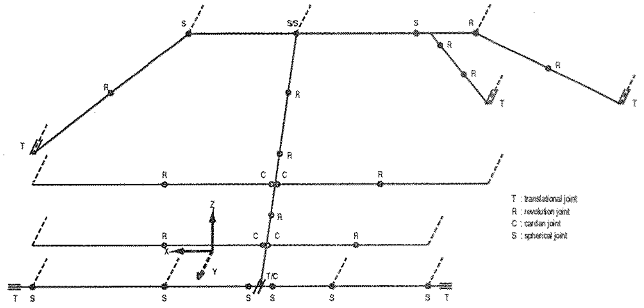


Figure 2. MADYMO Representation of Side Structure

Torsion of the B-pillar has been accounted for in the joints with the rocker and the cantrail.

Cantrail, A-, C- and D-pillar elements are interconnected by appropriate joints, allowing for a deformation normally observed in side-impact tests. The front door and rear door are modelled by means of an upper door beam and a lower door beam, coupled by spring elements. The door stiffness has been divided on a 40/60 basis over upper and lower beams and is concentrated in the beams mid-joints, which allows for inward bending.

The barrier is modelled as a rigid body with a deformable front structure which consists of six ellipsoids. The force/deflection characteristics of these ellipsoids are derived from [1]. The dummy model represents the EUROSID-1 and is an updated version of the MADYMO EUROSID database [6], where the latest certification tests were used for validation. Contacts have been defined to describe vehicle/floor, barrier/floor, barrier/vehicle and dummy/vehicle interactions. A friction coefficient of 1. was used for the contact between floor and tyres. Barrier/vehicle interaction is realized by defining contact between barrier ellipsoids and planes which are connected to the door beam elements on the outside. On the inside, planes have been connected to the elements of the front door to describe the dummy/door interaction. In this way a thorax plate, a pelvis plate and a leg plate have been defined together with contact functions to account for the inner door padding.

Correlation with Baseline Vehicle Crash Test

Full-scale side-impact tests were conducted with a baseline and a modified 5-door, medium-sized passenger car in accordance with the proposed European Side Impact Procedure [1]. The stationary target vehicle was impacted perpendicularly by an EEVC deformable barrier directed at the driver's side at a nominal impact speed of 50 km/h. The symmetrical plane of the barrier was aligned to impact the target vehicle at its "R-point." As defined in [1], the R-point denotes the location of the driver's H-point when the seat is in its most rearward position. The barrier face (Kenmont Ltd.) ground clearance was set at 300 mm, and the barrier had a nominal mass of 950 kilograms.

A European Side-Impact Dummy (EUROSID-1) was installed as specified in the seating procedure in the driver's seat to assess crash severity. The EUROSID-1 was equipped with accelerometers, displacement and force transducers [7]. The dummy was constrained by a three point safety belt. To detect dummy contacts, copper foil was fixed to the vehicle's inside padding and the dummy's head, chest and pelvis. Accelerometers were placed in the vehicle on the front and rear rockers, the inside front and rear doors, and the A- and B-pillars on the impacted side.

Dummy-related results are summarized in Table 1. It appears that the baseline vehicle satisfies the regulation on head and lower body criteria. Head, abdomen and pelvis responses seem well below the proposed criteria. The vehicle exceeds the proposed EEVC Rib Deflection Criteria (42 mm) and Soft Tissue Criterion (1.0 m/s) for all three ribs. Figures 3 to 6 show responses versus time of the barrier, the vehicle and the dummy (dotted lines). Simulation results obtained with the model as described in the previous section are also presented in these figures. It appears that the amplitude, shape and timing in general are in close agreement with the experimental results.

Table 1. Dummy Test Results

Body part		Baseline vehicle	Modified vehicle	Performance Criteria
Head				
HPC	[s]	345	311	≤ 1000
Chest				
Upper rib defl.	[mm]	44	35	≤ 42
Middle rib defl.	[mm]	45	38	≤ 42
Lower rib defl.	[mm]	47	42	≤ 42
Upper rib V*C	[m/s]	1.6	0.9	≤ 1.0
Middle rib V*C	[m/s]	1.6	1.0	≤ 1.0
Lower rib V*C	[m/s]	1.7	1.2	≤ 1.0
Abdomen				
Total peak force	[kN]	1.7	1.6	≤ 2.5
Pelvis				
Pubic symph. force	[kN]	3.2	3.3	≤ 10

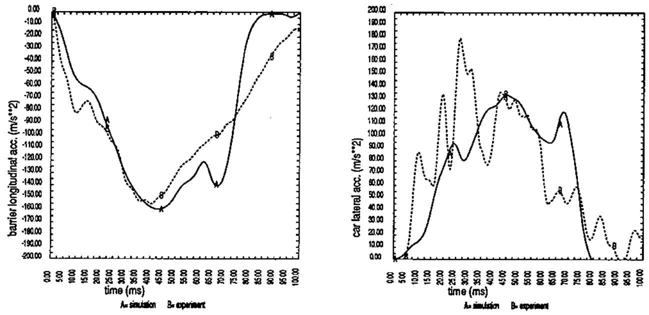


Figure 3. Barrier Longitudinal Acceleration (left) and Vehicle Lateral Acceleration (right)

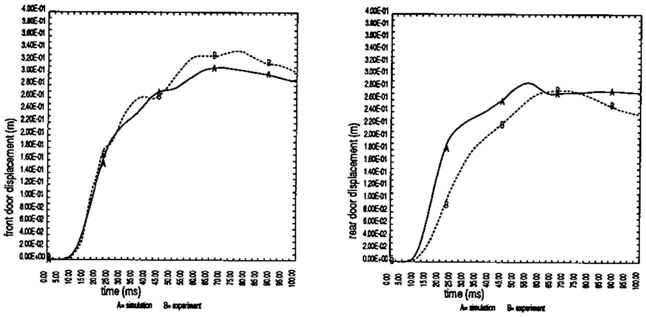


Figure 4. Vehicle Front Door (left) and Rear Door (right) Intrusion

The barrier hits the side of the vehicle just above the rocker. First the B-pillar buckles at waistline level, then the rocker deforms and after that there is a slight deformation of floor and roof. The severe impact on the chest is caused by the high door velocity and the large B-pillar intrusion at shoulder level. Peak intrusion is found at the B-pillar waistline level (=dummy thorax level). The difference in velocity between the B-pillar and dummy is great at the time of contact (at approx. 20 ms): up to 11 m/s (Figure 7).

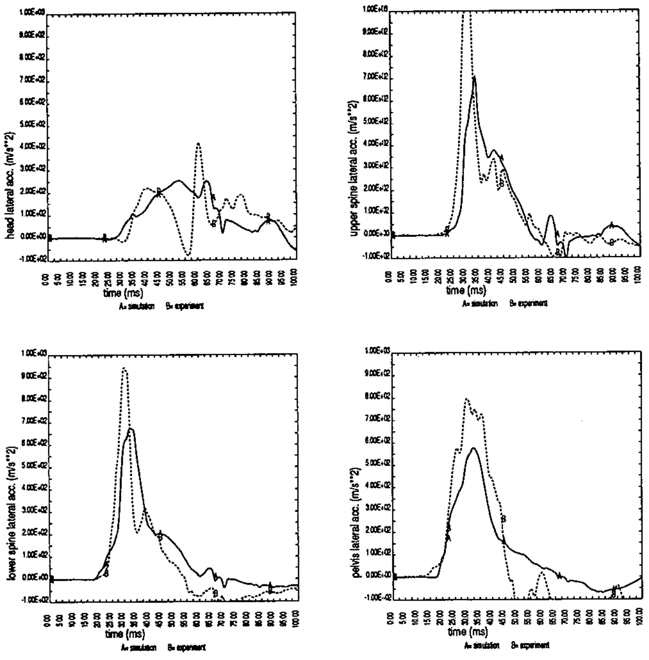


Figure 5. Dummy-Related Lateral Accelerations of Head (upper left), Upper Spine (upper right), Lower Spine (lower left) and Pelvis (lower right)

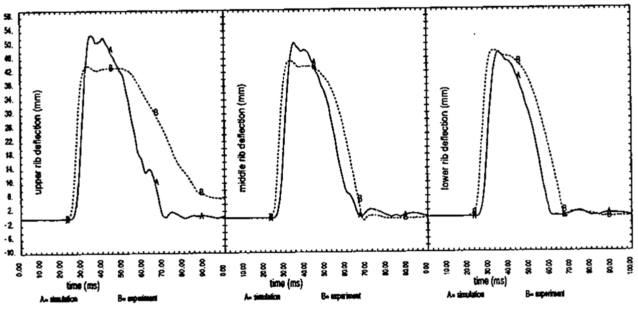


Figure 6. Dummy Upper, Middle, and Lower Rib Deflections

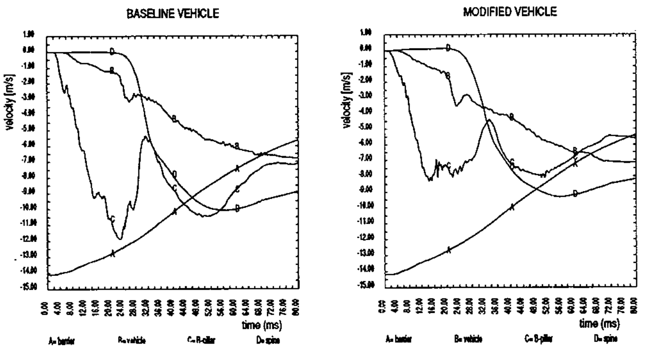


Figure 7. Time Histories of Barrier, Vehicle, Intruding B-pillar and for Spine for the Baseline Vehicle (left) and the Modified Vehicle (right)

Design Optimization and Vehicle Modifications

The main factors influencing the magnitude of impact on the occupant are the velocity of door intrusion, the stiffness of the door interior, the occupant to door clearance and the deformation mode of the side structure. These four parameters are, in a way, related to each other. Structural reinforcement reduces wall speed on impact with the occupant. Door trim absorbs the energy of the impact of the occupant in the vehicle. By reducing the gap between occupant and door by increasing the padding thickness, peak forces will be reduced and the period over which the change in velocity of the dummy occurs is longer [8]. The vertical intrusion profile appears to be of greater importance than the prevention of intrusion. The degree of door tilt will especially influence the way loads are transferred to the occupant. By guiding the way the door tilts inward it is possible to emphasize loading on one area in favour of another [9].

To modify the vehicle for better performance in a side-impact collision, the main load paths should be influenced and attuned to each other [10]. The side-structure stiffness and the profile of the intruding structure are controlled by the performance of the B-pillar and the rocker. The influence can be studied by varying the joint stiffnesses of the B-pillar and by changing the energy absorbing capacity of the floor. A door beam at lower level may account for lower door intrusion velocity. Padding is applied to absorb energy and to reduce the clearance between occupant and door. A parameter optimization study has been conducted using the MADYMO model as described earlier. In Table 2 the parameters that were varied are summarized.

Table 2. Parameter Variations

Simulation number	Parameter and degree of variation
#0	Baseline simulation
#1	Reinforcement of side structure by increasing front door and rear door stiffnesses
#2	Decrease of floor stiffness
#3a	Decrease of rocker bending stiffness by 25%
#3b	Decrease of rocker bending stiffness by 50%
#4	Increase of B-pillar stiffness at waistline level and mid upper level
#5	Increase of B-pillar stiffness at mid lower level
#6	Increase of B-pillar stiffness at rocker level
#7a	Combination of #2 and #3a
#7b	Combination of #2 and #3b
#8	Combination of #4 and #5
#9	Combination of #5 and #6
#10	Combination of #2 and #4
#11a	Combination of #2, #3a and #4
#11b	Combination of #2, #3b and #4
#12a	Reduced dummy-door clearance by installing 50 mm padding on doorplate at thorax level
#12b	Reduced dummy-door clearance by installing 100 mm padding on doorplate at thorax level

The effect of the modifications should be judged on the basis of the dummy's performance. The criteria are: upper spinal lateral acceleration, rib deflections, soft tissue criteria, lower spinal lateral acceleration, abdominal force and pelvic lateral acceleration. Simulation results are summarized in Table 3. The last column shows the results of the test on the baseline vehicle, relative to the allowed injury criteria (the value between brackets is not really an injury parameter as mentioned in the regulation).

Table 3. Simulation Results of Parameter Variations, Expressed as a Percentage of the Baseline Simulation (+ = higher than baseline result; - = lower than baseline result)

Simulation	#1	#2	#3a	#3b	#4	#5	#6	#7a	#7b	#8	#9	#10	#11a	#11b	#12a	#12b	test
T1 acc.	-8	-17	-11	-27	-33	-22	+19	-17	-26	-37	-3	-32	-35	-30	+113	+35	-
Rib1 defl	0	0	0	-2	-5	-1	+1	0	-2	-10	0	-8	-5	-3	+2	+1	+5
Rib2 defl	-1	-1	-1	-6	-9	-3	+5	-2	-6	-13	+3	-12	-9	-9	+6	+7	+7
Rib3 defl	-1	-3	-5	-10	-11	-3	+7	-6	-10	-12	+4	-13	-13	-16	+14	+14	+12
Rib1 vc	-4	0	-13	-33	-17	0	+17	-13	-33	-21	+13	-17	-21	-46	+4	+4	+60
Rib2 vc	-10	-5	-10	-33	-19	-5	+14	-14	-33	-24	+10	-19	-24	-48	+10	+19	+60
Rib3 vc	-6	-6	-6	-35	-24	0	+24	-12	-35	-24	+12	-18	-24	-47	+29	+47	+70
T12 acc	-6	-5	-5	-13	-8	-4	+14	-6	-14	-11	-2	-8	-7	-21	+61	+5	-
Abdomen frc	0	-1	-12	-4	-19	-12	+24	-14	-9	-24	+21	-25	-28	-39	+19	+82	-32
Pelvis acc	-1	-1	+2	+2	+1	-1	+7	+1	-1	-2	+3	+1	+20	+17	+15	-3	(-27)

The influence of the different parameters can be observed directly. It appears that decreasing the floor stiffness benefits the velocity of door intrusion (lower VC). Also stiffening of the upper part of the B-pillar leads to reduction of rib deflection, because the intrusion profile is more vertical. Installing door beams may have only minor influence. This conclusion is based on the way the doorbeams are simulated in this model. This conclusion is also valid for the door padding, which effect is very much dependent on the way it is modelled.

The following relatively simple modifications were introduced in the baseline vehicle, based on the analysis of the test and the results of the simulations. The B-pillar was reinforced by installing a u-shaped profile on the outside between roof rail and upper door hinge. The doors were provided with door beams at pelvis level and the cross member in the floor of the vehicle was partly removed, thus allowing more local rocker intrusion.

Crash Test on Modified Vehicle

Due to the reinforced B-pillar the door remains upright and the load on the dummy is more uniformly distributed. The maximum interior deformation now takes place at the B-pillar at pelvis level. However, the pubic symphysis load is increased only slightly. Figure 7 shows that the velocity difference between the B-pillar and dummy at the time of contact (at approx. 20 ms) has been reduced to 8 m/s.

The dummy-related test results of the full-scale test with the modified vehicle are summarized in Table 1. It appears that the maximum Rib Deflection Criterion and the maximum Soft Tissue Criterion are reduced considerably: 10-20% and 30-45%, respectively. However, the proposed Soft Tissue Criterion is still exceeded for the lower rib.

Discussion and Conclusions

Crash tests have been conducted on a baseline vehicle in accordance with the proposed European side-impact regulation. With MADYMO, a model of the vehicle including the EUROSID-1 dummy and the barrier was developed and validated against the test results. The model was used to evaluate the effect of vehicle modifications on injury assessed by the dummy. Based on the results of the simulations and the analysis of the test, simple modifications were introduced and a test was carried out on the modified vehicle.

The baseline vehicle satisfied the regulation on head and lower body criteria, but failed on all chest criteria. The Rib Deflection Criterion as well as the Soft Tissue Criterion were exceeded. The modified vehicle satisfied the regulation on all criteria, except for the lower rib Soft Tissue Criterion which was exceeded only slightly. As shown, vehicle improvement does not necessarily lead to structural stiffening or strengthening. Here, the improvement was achieved by tuning the side-structure deformation so that it takes place over a wider area. Further improvements can be assessed by adjusting the door and/or B-pillar strength so that the highest intrusion occurs behind the B-pillar, so behind the occupant. This can be achieved by changing the stiffness of the rear door beam. To reduce the difference in velocity between the B-pillar and dummy, it is desirable to start the dummy moving as soon as possible on the impact. This can be done by incorporating padding which reduces the gap between the dummy and the door and reduces the time duration of the impact.

Using quasi-static collapse characteristics of the most important parts of the side structure of the vehicle, the MADYMO model including dummy model and moving deformable barrier showed very realistic gross motion of the side-impact collision. Close agreement between parameters measured during the test and those obtained in the simulation was achieved. Although only a rough model of the side structure was developed, the influence of vehicle modifications could be distinguished quite well. However, the method needs more experience and applications with different types of vehicles.

The advantage of the current modelling approach is that it provides a quick and economical means of analysis of the global effect (trends) of a large number of design changes. For example, the total set of variations described in Table 3 requires about 20 hours calculation time on a standard engineering work station. This type of analysis guides the design engineer in understanding the effect of changes in the vehicle structure and to select promising design directions. In this selection process aspects like feasibility, practicability, producibility etc. already can be taken into account. It should be noted, however, that the actual vehicle structure is only roughly described in such a model. After selecting global design changes, finite element techniques can be used to describe critical components, which are subject to redesign, in detail. This can be done either independently from the multi-body approach or, if interactions are important, by performing integrated analysis where the multi-body model and the detailed finite element model are combined in one simulation. Current couplings between MADYMO and finite element codes like PAM-CRASH and LS-DYNA3D can be used for this purpose.

It shows that the combination of engineering judgement and computer analysis may lead to well-defined ways of improving the vehicle performance in a side-impact collision. In a verification test, relatively simple modifications may indicate the way the design should be adapted.

In [11] it was already demonstrated that EUROSID-1 is sensitive to car design and is considered an appropriate anthropomorphic test device for approval. In this paper it is demonstrated that EUROSID-1 can also be used as a research and development tool, where the effect of modifications is to be examined. In the tests mentioned in this paper the EUROSID-1 performed without failures and distinguished the difference in side-structure behaviour of the baseline vehicle and the modified vehicle very well.

Acknowledgements

Joint and section tests on the vehicle body shell were carried out by Cranfield Impact Centre Ltd. CIC Ltd. is also acknowledged for their contribution in translating the suggested modifications into structural modifications.

References

[1] Working Party on the Construction of Vehicles; Group of Experts on Passive Safety. Proposal for Draft Regulation: Uniform Provisions concerning the Approval of Vehicles with regard to the Protection of the Occupants in the event of a Lateral Collision. TRANS/SCI/WP29/GRSP/R.48/Rev.1, January 1991, Geneva.

[2] Lupker, H.A., De Coo, P.J.A., Nieboer, J.J. and Wismans, J. Advances in MADYMO Crash Simulations. SAE Technical Paper Series 910879.

[3] Prasad, P., Low, T.C., Chou, C.C. Lim, G.G. and Sundararajan, S. Side Impact Modeling using Quasi-Static Crush Data. SAE Technical Paper Series 910601.

[4] Rashidy, M. Developments in the Mathematical Modelling of Vehicle Crashworthiness. Automotive Design Engineering, 1991.

[5] Stanger, J., Ng, P. and Hatch, T. A Numerical Simulation of the Proposed European Side Impact Test Procedure. Proceedings of the Second International Conference on Supercomputing Applications in the Automotive Industry. Seville, Spain, October 1988.

[6] De Coo, P.J.A., Wismans, J. and Janssen, E.G. Computer Simulation and Biofidelity Considerations of EUROSID. 1990 International IRCOBI Conference on the Biomechanics of Impacts. Lyon, France, 1990.

[7] EUROSID-1 User's Manual. TNO Road-Vehicles Research Institute, Crash-Safety Research Centre. Delft, The Netherlands, November 1990.

[8] Hobbs, C.A. The influence of Car Structures and Padding on Side Impact Injuries. 12th ESV Conference, Göteborg, 1989.

[9] Mellander, H., Ivarsson, J., Korner, J., Nilsson, S. Side Impact Protection System—A Description of the Technical Solutions and the Statistical and Experimental Tools. 12th ESV Conference, Göteborg, 1989.

[10] Hobbs, C.A., Langdon, M.G., Lowne, R.W., Penoyre, S. Development of the European Side Impact Test Procedure and Related Vehicle Improvements. 11th ESV Conference, Washington, 1987.

[11] Experience of Using EUROSID-1 in Car Side Impacts. Beusenberg, M.C., Janssen, E.G., Lowne, R., Roberts, A., Glaeser, K.-P., Cesari, D. To be presented at the 13th ESV Conference, Paris, 1991.

S5-O-26

The Development of a Method for Dynamic Simulation of Side Impacts Using a HyGe Accelerator-The S.I.D.E. Procedure

V.M. Stephens, D.G.C. Bacon
Motor Industry Research Association

Abstract

A novel method of simulating side impact has been developed, resulting in a representative and economical dynamic test, which can be performed various stages in vehicle development programmes. The technique utilizes a conventional HyGe sled test facility, with a set of two purpose built sleds. The first of these, the striking sled, represents a mobile barrier which can be ballasted and carry a deformable face to either the Federal or European specifications. This sled is propelled rapidly and accurately to speed by the HyGe accelerator. The second (struck) sled carries a vehicle bodyshell or representative side structure with trimmed doors, seats and dummies installed. Mounting of the bodyshell is important in ensuring a high degree of correlation with full vehicle crash tests. The sled complete with bodyshell and payload is ballasted to vehicle curb weight, and moves away after impact by the striking sled under simulated tyre friction. The first part of a series of tests being conducted in the development of the S.I.D.E. Procedure is described and comparison made between the results and those of full vehicle crash tests conducted on nominally identical vehicles.

Introduction

Full scale side impact test procedures have been developed in the USA and Europe over the last 10 years. The Industry has been searching for a representative component test to reduce the development time and cost. The dynamic structural intrusion of the vehicle, stress rate effects and the dynamic interaction of occupants and vehicle are the most difficult to emulate in a test or analysis procedure.

An array of tools for use in structural development and occupant protection in side impact is available, but is perhaps incomplete without a cost-effective means of dynamic evaluation prior to full vehicle testing in the sign-off stages. The advantages and drawbacks of the techniques used presently are discussed in the following sections. A novel form of dynamic component test is examined, which has been developed by MIRA, called the Side Impact Dynamic Emulation (S.I.D.E) Procedure.

Component Testing

Component tests can be used to establish the performance of particular sub-assemblies in a variety of loading conditions. For impact tests, this would normally mean various velocities, impactors and points of impact, to establish the limits of performance. What a component test does not provide however, is an indication of how the other components will interact, and hence the overall level of protection that the vehicle will provide to the occupants.

A further set of limitations are placed on the usefulness of component tests when quasi-static methods are used to predict dynamic performance. The pattern of structural deformation produced by quasi-static methods can differ from that produced when the same component is tested dynamically. Material and structural properties are known to show velocity-dependency, and occupant injury predictions cannot reliably be predicted from quasi-static tests.

Mathematical Modelling and Computer Simulation

Mathematical modelling of vehicle structural behaviour in side impact is of increasing importance. Non-linear finite element analysis can be used to model the vehicle body structure and hence provide data on the likely collapse mode and intrusion pattern during side impact. Lumped mass/spring models can also be used to generate vehicle velocity and acceleration profiles, and can include vehicle occupants. Use of programs such as MADYMO in this way also enables prediction of dummy injury levels.

It is of course necessary to use analytical techniques judiciously, since that which appears to be achievable in theory often differs from that which is achieved in reality. Furthermore, it is essential that modellers and analysts fully appreciate the assumptions and limitations which apply to their software and hence to their solutions.

Full Vehicle Crash Tests

Full crash tests are the only established way of assessing the crashworthiness that a particular vehicle provides in the particular impact scenario that the test is aiming to reproduce. This makes the full crash test particularly attractive as a legislative tool, since it can provide the highest fidelity to real accident situations, within the limitations of testing methodology (such as dummy and barrier face design and repeatability).

However, if used as a development tool, the full crash test is not an economic proposition. The development programme would ideally include tests to both EEVC and NHTSA specifications, NCAP and low speed tests, plus other configurations identified as product liability issues. Furthermore, the wider the technical gap between the development methods used and the specification of the legislative test, the higher the probability of failure.

Composite and Hybrid Methods

As a consequence of the limitations of each type of test and analysis methods, Engineers have used combinations of these techniques. Detailed study of the role of each method has led to a number of integrated "methodologies" being developed and proposed. The majority of these techniques involve combinations of quasi-static component testing and mathematical modelling, such as the Composite Test Procedure (1). Whilst offering a sophisticated means of evaluation, the process is less cost-effective than many of the alternatives, and suffers from the limitations which have been cited for the constituent techniques.

Other hybrid methods use combinations of data collected from full crash tests to generate input data for mathematical models, such as that employed by Ford Motor Company (2). This has the benefit of using dynamic input data, but does of course require that a complex and hence costly full crash test is conducted during the vehicle development phase.

Sled Test Methods

The role of the sled test has traditionally been to bridge the gap between the development techniques (component tests, modelling) and the full crash test, particularly in the field of frontal impact. This has been because it can offer a cost-effective method of evaluating the level of occupant protection, with results that can be correlated to both mathematical modelling and to full crash testing.

In developing a sled test method for side impact development, it is desirable to provide a system flexible enough to perform a range of tests from evaluation of the pattern of structural deformation, to prediction of dummy injury levels in a legislative crash test. It should also be compatible with the range of dummy types (SID, BIOSID, EUROSID), barrier faces (NHTSA, EEVC, rigid) and test methods (mass of impacting sled, direction of impact, velocity), and be capable of evaluating the limits of performance and nonstandard impact conditions.

A number of methods have been used to evaluate the performance of interior padding by sled testing, the most sophisticated of which was perhaps that pioneered by NHTSA (3), using energy absorbers to reproduce the vehicle side-structure velocity profile. However, such methods do not produce data on structural performance of the vehicle, and hence cannot be used to evaluate proposed modifications.

Outline proposals have been made by MVMA (4) for a sled test concept which is similar to the technique described in this paper, with two principal differences. Firstly, the S.I.D.E Procedure is based around use of existing HyGe facilities. Secondly, the main role of this test is seen as bridging the gap between the development process and vehicle certification, rather than proposing yet another legislative test procedure.

The Concept of Side Impact Dynamic Emulation

The objective in developing a sled-based test concept is to provide a representative and cost-effective test during structural and interior development, and also immediately prior to full vehicle crash testing. This then enables reliable results to be obtained that guide the side impact development programme in the right direction, and provide valuable validation data to the modelling and analysis activities.

Test Methodology

The system utilizes an existing HyGe Laboratory, of which many exist around the world. The existing lighting, camera and data acquisition systems are retained and employed. Two purpose-built sleds, which can be mounted and removed very rapidly, are used in the test, and are referred to as the "striking" and "struck" sleds.

The striking sled, carrying a barrier face and ballasted to the required test weight, is accelerated over a distance of approximately 1 metre to the test velocity (usually 30 mph) by the Hyge gun, leaving the sled travelling freely. The struck sled carries a vehicle bodyshell with interior trim and anthropomorphic Side Impact Dummies (SIDs). On impact of the deformable barrier-face with the vehicle side, representative deformation takes place and the dummy is subjected to the correct loading and dynamic effects. The struck sled with bodyshell then moves off with tyre friction simulated by sled braking forces, and the striking sled is decelerated rapidly to prevent secondary contact. The sleds were designed and manufactured at MIRA, and are configured to limit the reaction forces at the Hyge track to less than 60% of those produced in frontal impact sled tests.

Striking Sled

The striking sled can be configured to mount any type of barrier face, including the foam EEVC or aluminum honeycomb US deformable barrier-face. It is possible to ballast the sled to give a total mass as low as 500 kg or as high as 2000 kg, but would normally be configured to either 950 kg for European tests, or 1364 kg (3000 lb) for Federal regulations.

The barrier front end of the sled has a width of approximately 1.7m and is detachable, allowing easy maintenance or the use of alternative barrier designs. At present, a deformable barrier face is rigidly mounted to the sled, upright and perpendicular to the direction of impact. A wide range of mounting height adjustment is provided, and the front face can also accept several types of load cell matrices.

Other, more complex barrier-face mounting systems have also been considered, and hence the system has been designed to be versatile enough to allow for incorporation of particular additional features, as or when necessary. These include vertical compliance, rotational compliance about a vertical axis, and angled mounting of the barrier. The latter is discussed in more detail, with the "crab effect" in the discussion of the perpendicular test configuration.

Struck Sled

The basic mass of the struck sled is low, with provision to increase it by means of ballast weights. The total mass of the struck sled, trimmed vehicle body, onboard instrumentation and ballast should be equal to the vehicle curb weight. It is therefore possible to representatively test a wide range of vehicles, from small cars to light vans, at the correct weight. A system of adjustable vehicle mountings is provided, which are designed to restrain the vehicle relative to the sled, whilst still allowing representative deformation to take place in the vehicle body. In particular, it is important that the mounting system allows dynamic foreshortening of the vehicle body. The system uses simple brackets, manufactured specifically for each bodyshell, and bolted quickly and easily to the mountings on the sled. Provision has also been made for use of adjustable B-pillar or cant rail supports to restrain the non-impacted side of the bodyshell, but testing to date indicates that such supports would be superfluous.

The sled has both primary and secondary braking systems. The primary system is adjustable to simulate equivalent tyre friction of between 0.25 and 2g. The secondary braking system brings the sled to rest after the impact. The sled has an emergency energy-absorber system in the event of brake failure. This sled is also easily detachable from the Hyge track, to allow quick set-up times.

Perpendicular Impact Configuration

A perpendicular test configuration has the advantage of simplicity in terms of vehicle and barrier-face mounting, sled design and propulsion, and has been adopted for most of the proposed legislative tests, but Federal Regulations (5) call for a "crabbed" impact with the striking sled approaching at 27 degrees from perpendicular. It is therefore important to consider the differences which may exist between these two configurations.

Although the barrier-face approaches at 27 degrees from perpendicular, test results have shown that both the mean angle at which the barrier intrudes the vehicle and the angle from perpendicular at which the vehicle moves away are both approximately 20 degrees ±2 degrees. It would therefore be possible to mount both vehicle and barrier-face on the S.I.D.E. sleds at such an angle, to obtain the greatest possible fidelity to the Federal full-vehicle crash test. Whilst provision has been made in the design of the sleds to allow for this type of mounting method, it will not be adopted unless it proves to be necessary.

A wide-ranging study conducted by Transport Canada (6) concluded that damage profiles and dummy responses in crabbed tests were "virtually identical" to those obtained in perpendicular tests. Research has also shown that rotational effects only come into play late in the impact sequence, and have no significant effect on dummy injury results. The dummy is struck by the door a very short time after impact, typically 20ms. Even the US "crabbed" impact can be viewed as a perpendicular collision with respect to dummy injury measurements (a fact which allows use of the SIDE procedure for this scenario).

During the "crabbed" impact, the barrier-face translates rearward by 150mm or more as it intrudes the struck vehicle. One possibility being considered is to choose an impact point other than that specified in FMVSS 214 for S.I.D.E tests, for example 75mm rearwards.

S.I.D.E. Development Programme

A programme of research is currently being conducted to evaluate and develop the procedure, jointly supported by MIRA, Ford Motor Company, Jaguar Cars and Rover Group. The progress made to date is described and the results discussed.

A number of trials were conducted initially, to enable systems calibration and to check the operational status of mechanical, hydraulic and electronic systems. Having completed these checks, a programme of tests and analyses was agreed, to include several vehicle types, and two test configurations. The majority of tests will use the NHTSA barrier-face, enabling comparison with tests conducted to FMVSS 214, with additional testing to the EEVC configuration. One reason for placing greater emphasis on the Federal test, was the hypothesis that there may be more effort required to replicate the crabbed-barrier test, than the simpler perpendicular impact specified in European test proposals.

To date, several tests in this programme have been completed, including two with full instrumentation. In order that the confidential nature of the results obtained is maintained, only anonymous sample data and normalized results are presented in this paper. However, the following conclusions have been drawn from the data available at the present time.

Post-Test Vehicle Damage

It was found that representative post-test damage was achieved, given the correct choice of vehicle-to-sled mounting points. It has proved necessary to exercise care in choice of mounting location, to avoid excessive stiffening of the vehicle underside.

Correlation of interior crush measurements has been very encouraging. In the first test conducted, the mean crush of the vehicle at the driver door location was 97.7% of that in the equivalent full vehicle crash test. The maximum difference in the intrusion obtained at any particular point on the door was only 16%. Rear passenger door crush values were generally slightly lower than in the equivalent crash test. This was expected, since the crabbed barrier has a tendency to yaw during the latter part of the full crash test, and hence increase the amount of rear door deformation. However, this occurs well after the critical period of occupant loading, and hence can be treated as a secondary effect.

Structural Dynamics and Dummy Loading

Of particular importance are the velocity profile of the intruding door structure, the resulting velocity of the dummy body regions (pelvis, ribs and spine) and the occupant injury criteria (peak accelerations and Thoracic Trauma Index).

Figure 1 shows typical correlation of dummy rib velocity results in a S.I.D.E. test with the equivalent crash test, with peak velocity 98.7% of that in the crash test. Figure 2 gives an example of struck door velocity profiles, which indicate a satisfactory match, especially when the questions of test-to-test repeatability are considered. These apply to both the vehicle and the barrier-face stiffnesses.

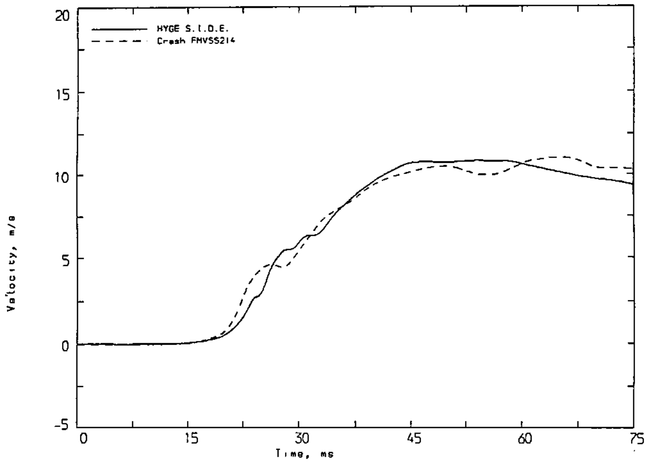


Figure 1. Correlation of Dummy Rib Velocity

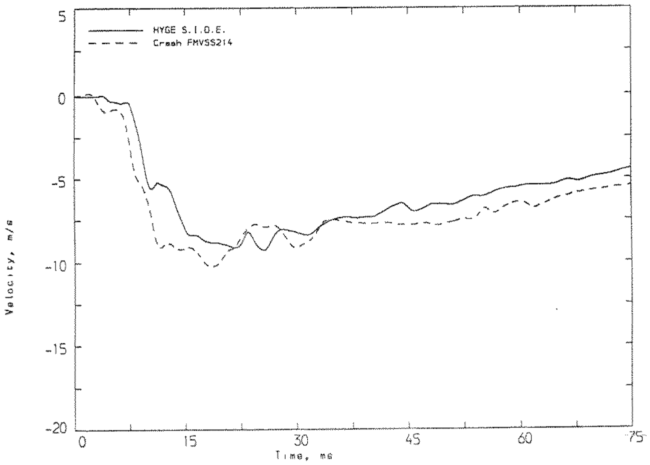


Figure 2. Correlation of Struck Door Velocity

Table 1 illustrates the degree of correlation relating to dummy injury criteria. Whilst it is not possible to publish the absolute values obtained from the tests, normalized results are presented. Good agreement is indicated, with TTI and lower rib peak accelerations within 4%, and the other criteria within typical limits of experimental error for Side Impact Dummy results.

Table 1. A Normalized Comparison of Driver Dummy Injury Criteria Between a S.I.D.E. Test and Equivalent FMVSS214 Crash Test

Criterion	Difference in Magnitude	Difference in Timing
Thoracic Trauma Index (TTI)	-4%	-
Pelvis Peak Acceleration	-12%	+1ms
Upper Rib Peak Acceleration	+16%	+10ms
Lower Rib Peak Acceleration	+4%	+1ms
Lower Spine Acceleration	-6%	+4ms

Discussion of the S.I.D.E. Procedure

The S.I.D.E. system has been developed to provide an accurate and repeatable evaluation of vehicle side impact performance. Thus it can be used to develop both the vehicle structural crashworthiness and occupant protection. Precision control of test parameters is particularly important in development studies. Typically, the HyGe sled system is capable of controlling the impact velocity to within ±0.1 mph, with the point of impact to within ±2mm.

The test is representative of full vehicle impact. Using either a full body-in-white or even just the side structure, together with the correct deformable barrier-face and correct impacting masses, both the US and European specification tests can be reproduced. Tyre friction of the struck vehicle is also simulated. Typical test configurations are illustrated in Figures 3 and 4.

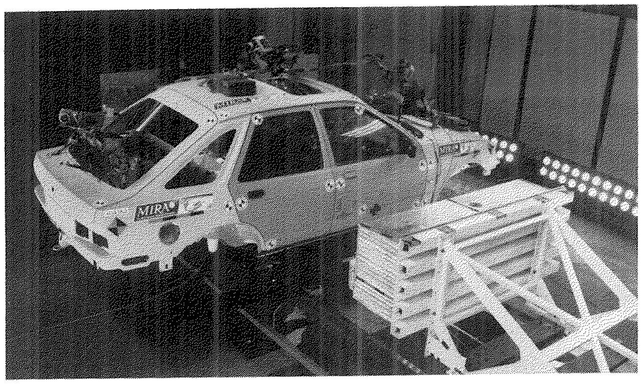


Figure 3. S.I.D.E. Procedure Test Configuration

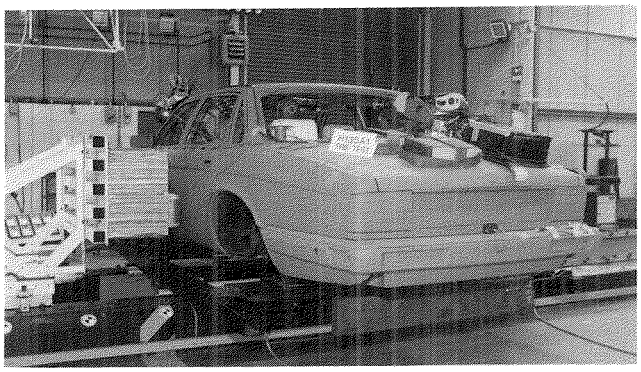


Figure 4. Trackside View of S.I.D.E. Test

Use of the HyGe facility allows rapid test turnaround. Quickly-detachable sled mounting systems are used, and barrier faces can also be changed very rapidly. Separate sub-frame mountings for each vehicle type allow quick changeover, and hence high test throughput. The system can be used for development purposes in a variety of ways. The system is flexible enough to allow a full range of impact speeds and locations. Impact energy can be input in discrete steps, by a series of low speed impacts. This enables dynamic collapse characteristics to be closely studied.

Conclusion

MIRA has developed a new concept in vehicle side impact evaluation. This system, based on a HyGe sled facility, allows accurate, repeatable and representative dynamic tests to be conducted cost-effectively and efficiently. This will enable vehicle manufacturers to improve the structural performance and occupant protection afforded by their cars, in conjunction with established component test and modelling techniques.

A wide range of configurations can be evaluated, including US or European legislative-type tests, or non-standard development tests at different impact speeds and orientations. This is particularly important at a time when manufacturers are faced with developing "World Cars" which may be required to pass a number of different legislative side impact tests.

Acknowledgements

The authors of this paper gratefully acknowledge the invaluable assistance, cooperation and contribution of the following companies: Ford Motor Company, Jaguar Cars, Rover Group.

References

1. Composite Test Procedure for Side Impact Protection. R.Richter et al. SAE 871117,1987.
2. Side Impact Research. G.G. Lim, A. Paluszny, Ford Motor Company. SAE 885055, 1988.
3. Side Impact Restraint Development and Evaluation Techniques. L.M. Shaw, C. Clark, NHTSA. Proc. 8th ESV Conference, 1980.
4. In-Laboratory Side Impact Test Proposal. MVMA Committee. ISO/TC22/SC10/WG1. TEC/795/1990.
5. Federal Motor Vehicle Safety Standard No.214: Side Impact Protection. NHTSA, 1990.
6. Transport Canada's Side Impact Test Programme. Preliminary Findings. ISO/TC22/SC10/WG1. TEC/795/1990.

S5-O-27

Light Truck Side Impacts with Serious Occupant Injury

Susan C. Partyka
National Highway Traffic Safety
Administration

Abstract

The National Highway Traffic Safety Administration specified a dynamic side impact test for passenger cars in 1990 and has proposed extending this test to other light passenger vehicles. The test involves an instrumented test dummy in a vehicle that is struck in the side by a moving barrier that simulates a striking passenger car, and the test includes a requirement that the doors of the side-impacted vehicle remain closed during the test. However, there are differences between the crash circumstances surrounding passenger car occupant fatalities and fatalities in other light passenger vehicles that need to be considered in extending the test requirement to other light passenger vehicles. For example, a larger fraction of light truck occupant fatalities were completely or partially ejected from their vehicles during the crash and a smaller fraction were occupants of vehicles struck in the side by another light passenger vehicle, compared to passenger car occupant fatalities. This paper summarizes the available damage and injury data for passenger vehicle side impacts to compare the experience of passenger cars with that of other light passenger vehicles.

Introduction

The moving barrier side impact test for passenger cars specified by the National Highway Traffic Safety Administration in the 1990 amendment to Federal Motor Vehicle Safety Standard (FMVSS) 214, "Side Door Strength," represents crashes in which car occupants receive serious thoracic injury. The test measures the effect on the torso of a belted test dummy in the front seat of a passenger car struck in the side by a moving barrier that simulates a striking passenger car. The agency is now considering an amendment to FMVSS 214, placing additional dynamic requirements (corresponding to those that have already been specified for passenger cars) on other light passenger vehicles. One option the agency has is to extend the standard as it applies to passenger cars to other light vehicles. However, the test conditions used for cars may be less severe than typical serious injury crashes for occupants of light trucks and multipurpose vehicles (referred to collectively as "light trucks" here) because of differences in vehicle size, vehicle design, vehicle use, and occupant characteristics.

The purpose of the effort reported here was to determine the weight and speed of the test barrier and the impact angle and impact point on the side-impacted vehicle that would represent the side impact crashes that produce serious torso injury in light trucks. The relevant collisions were defined as those involving unejected occupants who received serious torso injury from side surface, hardware, and armrest contact in a side impact with another light passenger vehicle. Side-impacted vehicles that also rolled over (either before or after the vehicle impact) were not excluded from the analysis on this basis alone. Information on the relevant accidents was extracted from the National Accident Sampling System (NASS) and extrapolated to an annual estimate using data from the 1989 Fatal Accident Reporting System (FARS).

Unfortunately, the primary goal of this effort could not be met because there were insufficient data: from 1982 to 1989, NASS investigated only 13 cases that satisfied this definition of a relevant collision. A review of the fatality data suggests why so few relevant NASS cases were found. Compared to passenger cars, light truck fatalities were less likely to involve a side-impact with another light passenger vehicle. And those light truck occupants who were killed in a side impact with another light passenger vehicle were more likely to have been ejected (either completely or partially) than were car occupants. The effects of the definition are summarized in Figure 1 as seven successively more-restrictive filters on the light vehicle occupant fatality data. The numbers shown are the percentage of all light truck (and, separately, all passenger car) occupant fatalities in 1989 that remained after each filter was applied to the FARS data, where:

Filter 1 = The fatality was attributed to a side impact.
Filter 2 = The side impact was with another vehicle.

Filter 3 = The other vehicle was a light passenger vehicle.
Filter 4 = The fatality was a retained occupant.
Filter 5 = The retained occupant was seated on the same side as the impact.
Filter 6 = The near-side occupant was in the front seat of the vehicle.
Filter 7 = The occupant suffered serious torso injuries from contact with interior side components.

The percentages shown are based on 8,619 light truck occupant fatalities and 24,927 passenger car occupant fatalities that occurred in 1989 (based on FARS data).

The fatalities that remain after Filter 7 has been applied represent 1.0 percent of light truck fatalities (an estimated 79 fatalities) and 6.3 percent of passenger car fatalities (an estimated 1,504 fatalities), estimated for 1989 (based on FARS and NASS data).

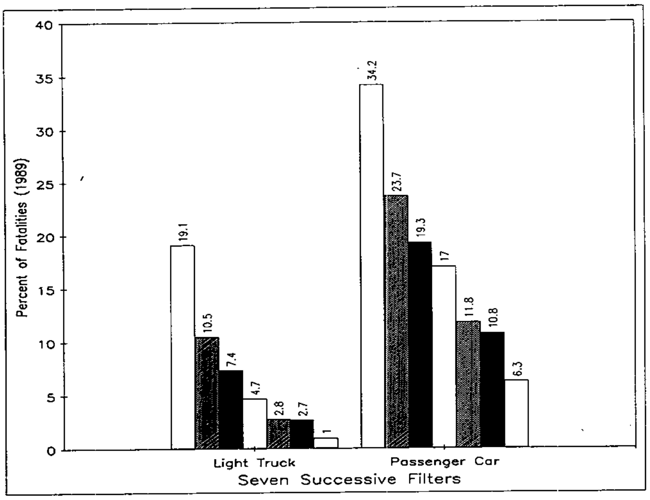


Figure 1. Light Vehicle Occupant Fatalities in 1989, Showing the Effects of Successively More-Stringent Filters

The combined NASS and FARS data produce an estimate of 86 unejected fatalities with serious torso injury from side contact in the front seat of a light truck that was side-impacted by another light passenger vehicle in 1989. Crash severity and impacting vehicle weight were available for many of these 13 cases, but there are too few data for more-detailed generalizations. The most that can be said is that some cases occurred under conditions that might be simulated by the current passenger car test, but more would be covered by a test that was more serious, in terms of the barrier weight and speed and possibly in terms of the impact angle and point on the side-impacted vehicle.

There were nine other NASS cases involving serious torso injury from side contacts received by unejected front-seat occupants of light trucks in other side impact collisions: three investigated cases with a striking medium or heavy truck and six cases of side collisions with an object such as a pole or tree. These cases, combined with the FARS data, produce an estimate of 130 such fatalities in 1989. Crash severity was not estimated for any of the nine NASS cases and, in general, the conditions of such cases tend to be outside the scope of the speed reconstruction method.

Another important aspect of the passenger car dynamic test is the requirement that the doors remain closed during the test. This requirement seems to be even more important for light trucks. There were 592 ejected light truck occupant fatalities in side impact crashes of all types identified in 1989. Of these, 486 were completely-ejected and 106 were partially-ejected from the vehicle. Preventing ejection from light trucks in side impacts would improve safety in side impacts, and would have additional benefits in preventing ejection and fatality in rollovers and other crashes.

These historical fatality estimates are not estimates of the benefits that might be realized from extending the dynamic side impact test procedure to light trucks. Other factors would need to be considered to project the potential benefits of extending the test (with or without modification) to light trucks. These factors include the specific test configuration chosen, trends in vehicle use, the effects of other safety standards and related changes (such as in belt use), the potential benefits in all crash situations, and the benefits of other aspects of the side impact test. These considerations are beyond the scope of the current problem identification, but they are critical to projecting the effects of any countermeasures.

Data

The descriptions provided in this paper are based on the 1982 through 1989 NASS and the 1989 FARS automated files for occupants of light passenger vehicles. Both data systems are maintained by the National Center for Statistics and Analysis, an office of the National Highway Traffic Safety Administration. NASS includes details on crash configuration and injury mechanisms, and these allow precise identification of cases that resemble the passenger car moving barrier side impact test. Parallel distinctions were made from the FARS data to the extent allowed by the data, but differences in the coding schemes means definitions differ slightly from those used in NASS. In general, these definitional differences appear to have little effect on the analysis and do not appear to limit the interpretation of the results.

The factors used to describe these crashes include the body type, damage area, direction of force, vehicle weight, and crash severity of the striking and struck vehicles; the damage location on the struck vehicle; occupant seating position, ejection, age, height, weight, and belt use; and injury type, severity, and contact point.

The nationally-weighted NASS data were used to estimate the relative frequency of torso injuries from side contacts, and these rates were applied to FARS fatality counts to estimate the number of fatalities that resembled the passenger car side impact test.

The term "passenger car" does not include automobile derivatives, for purposes of this analysis. This makes the term consistent with designations made by vehicle manufacturers to determine the applicability of Federal Motor Vehicle Safety Standards. Passenger cars were defined as those with Body Types coded 1 through 9 (in all years of NASS and FARS). The term "light truck" includes all other light passenger vehicles, which are those that do not exceed a gross vehicle weight rating of 10,000 pounds. Light trucks were defined as those with Body Types coded 10 through 49 in the 1988 and 1989 NASS (and as the corresponding values in other years of NASS and in FARS).

Side-impacted vehicles were defined for the NASS analysis as those that received the most severe damage to the side, whether the side was damaged in a planar or a rollover crash; rollover was considered to be simply one way of receiving side damage. The definition had to be modified slightly for use with FARS. Side-impacted vehicles were defined for the FARS analysis as those in which planar damage to the side was believed to have contributed most to the occupant fatality (as determined by the FARS analyst in each state), whether or not a rollover also occurred. The distinction between the NASS and FARS definitions can be an important one, but comparing the results suggests that the effects on this analysis were small.

The contact that caused the most severe vehicle damage is explicitly recorded for NASS cases. The damage contact was classified as a vehicle (either a light passenger vehicle, another vehicle type, or an unknown vehicle type) or an object based on unambiguous information. Classifying the damage contact for FARS cases was a little more complicated because the impacting object or vehicle is not explicitly coded. Instead, the damage contact was inferred from the number and types of the other vehicles involved in the accident. The most severe vehicle contact was defined as another vehicle for all FARS multi-vehicle accidents. If the other vehicle type could be determined unambiguously (if there were only two vehicles in the accident, if all other vehicles were known to be light passenger vehicles, or if all other vehicles were known to be other vehicle types), then the side-impacting vehicle was defined as a light passenger vehicle or as another vehicle type, as appropriate. The most severe vehicle contact was defined as an object for all FARS single-vehicle crashes. Despite their apparent differences, the NASS and FARS definitions produce similar results when the classification can be made. However, the classification frequently could not be made for FARS cases with three or more involved vehicles.

The NASS data were restricted to light passenger vehicle occupants who received a serious injury (with an Abbreviated Injury Scale, AIS, rating of three or greater) or were killed as a result of injuries received in the crash. The most-recent seven years of NASS data were combined as a better basis for estimation and interpretation than could be obtained from the limited data in a single year's file. There is no NASS statistical file for 1987, so the weighted data represent seven-year totals. The FARS data were restricted to fatally-injured occupants of light passenger vehicles. It was not necessary to combine multiple years of FARS data because each year includes a large number of fatalities in side impacts. FARS does not include the detailed injury and damage information available in NASS, but contains many more accidents than can be investigated by on-site teams. Comparing percentage estimates from seven years of NASS serious injuries with those from a single year of FARS fatalities suggests that these differences were not critical to this analysis.

A more important limitation of this analysis is that trends cannot be identified from the combined data of so many years. For example, it would be useful to understand the effect of trends in vehicle use and design (including the increasing popularity of compact pickup trucks, minivans, and small utility vehicles, increases in safety belt use following the enactment of state belt use laws, and the choice between two-door and four-door vehicle designs) and the effects of extending other safety standards to light trucks. This analysis is a side-impact problem identification for the light trucks of the 1980s.

Another limitation of the estimates reported here results from the uncertainty inherent in any sample. The NASS cases were selected based on a complex sample of police-reported accidents that were then investigated in depth using well-defined procedures and later statistically weighted to reflect the population from which the cases were selected. The resulting estimates include both sampling and nonsampling errors, but there is no simple statistical description of these errors because of the complexity of the sampling scheme. The percentage estimates provided from the weighted NASS data are the best available for the detailed injury and damage information needed for this analysis, but the actual precision is suggested by the number of investigated cases on which the estimates are based. For this reason, the number of investigated cases is provided for each NASS estimate reported here.

Side-Impact Fatalities

There were 8,619 light truck occupants killed in 1989, as shown in Tables 1, 2, and 3. The principal impact area was identified as the side of the light truck for 1,601 of these fatalities, which is 19 percent of the known data. Side impact fatalities accounted for a larger fraction of car occupant fatalities that year (34 percent of the 24,927 fatalities).

Table 1. Seriously-Injured Light Vehicle Occupants in Crashes with Other Light Passenger Vehicles (Occupant-Level Data)

	NASS Serious Injury Cases				NASS Serious Injury Estimates				Occupant Fatalities in 1989			
	Light Trucks		Cars		Light Trucks		Cars		Light Trucks		Cars	
	Number	%Total	Number	%Total	Number	%Total	Number	%Total	Number	%Total	Number	%Total
All impacts												
Side	304	21.7	1,800	36.3	33,984	22.2	194,161	35.4	1,601	19.1	8,390	34.2
Other	1,099	78.3	3,161	63.7	119,133	77.8	353,626	64.6	6,773	80.9	16,151	65.8
Unknown	152		450		17,878		40,978		245		386	
Total	1,555	100.0	5,411	100.0	170,995	100.0	588,765	100.0	8,619	100.0	24,927	100.0
Side only												
Vehicle	144	10.3	1,184	23.9	16,589	10.8	130,465	23.8	877	10.5	5,827	23.7
Object	159	11.4	616	12.4	17,369	11.4	63,696	11.6	724	8.6	2,563	10.4
Unknown	1		0		26		0		0		0	
Subtotal	304		1,800		33,984		194,161		1,601		8,390	
With vehicle												
Light	104	7.4	1,031	20.8	12,976	8.5	112,806	20.6	588	7.4	4,562	19.3
Other	40	2.9	153	3.1	3,613	2.4	17,659	3.2	243	3.1	1,045	4.4
Unknown	0		0		0		0		46		220	
Subtotal	144		1,184		16,589		130,465		877		5,827	
With light vehicle												
Retained	80	5.8	873	18.1	11,108	7.3	98,898	18.7	365	4.7	3,984	17.0
Ejected	23	1.7	128	2.7	1,853	1.2	10,032	1.9	216	2.8	553	2.4
Unknown	1		30		15		3,876		7		25	
Subtotal	104		1,031		12,976		112,806		588		4,562	
Occupant retained												
Near-side	46	3.3	554	11.5	6,341	4.1	63,385	12.0	219	2.8	2,771	11.8
Far-side	33	2.4	318	6.6	4,691	3.1	35,255	6.7	134	1.7	1,195	5.1
Other	1	0.1	1	0.0	76	0.0	258	0.0	8	0.1	2	0.0
Unknown	0		0		0		0		4		16	
Subtotal	80		873		11,108		98,898		365		3,984	
Near-side												
Front seat	45	3.2	500	10.4	6,190	4.1	56,557	10.7	210	2.7	2,526	10.8
Back seat	1	0.1	54	1.1	151	0.1	6,828	1.3	9	0.1	245	1.0
Subtotal	46		554		6,341		63,385		219		2,771	
Near, Front seat												
Torso/side	13	1.2	210	5.9	1,732	1.4	25,614	6.0	79 *		1,504 *	
No torso/side	23	2.1	162	4.5	3,373	2.7	20,241	4.7				
Unknown	9		128		1,085		10,702					
Subtotal	45		500		6,190		56,557					
Far-side												
Front seat	29	2.1	284	5.9	4,014	2.6	31,556	6.0	126	1.6	1,065	4.6
Back seat	4	0.3	33	0.7	677	0.4	3,536	0.7	8	0.1	130	0.6
Subtotal	33		317		4,691		35,092		134		1,195	
Far, Front seat												
Torso/side	2	0.2	21	0.6	165	0.1	1,415	0.3	7 *		63 *	
No torso/side	21	1.9	182	5.3	3,006	2.5	23,986	5.7				
Unknown	6		81		843		6,155					
Subtotal	29		284		4,014		31,556					

* Estimated by applying the percentages from the NASS weighted data to the FARS counts, adjusted for missing FARS classification data

Table 2. Seriously-Injured Light Vehicle Occupants in Crashes with Heavier Vehicles (Occupant-Level Data)

	NASS Serious Injury Cases				NASS Serious Injury Estimates				Occupant Fatalities in 1989			
	Light Trucks		Cars		Light Trucks		Cars		Light Trucks		Cars	
	Number	%Total	Number	%Total	Number	%Total	Number	%Total	Number	%Total	Number	%Total
All impacts												
Side	304	21.7	1,800	36.3	33,984	22.2	194,161	35.4	1,601	19.1	8,390	34.2
Other	1,099	78.3	3,161	63.7	119,133	77.8	353,626	64.6	6,773	80.9	16,151	65.8
Unknown	152		450		17,878		40,978		245		386	
Total	1,555	100.0	5,411	100.0	170,995	100.0	588,765	100.0	8,619	100.0	24,927	100.0
Side only												
Vehicle	144	10.3	1,184	23.9	16,589	10.8	130,465	23.8	877	10.5	5,827	23.7
Object	159	11.4	616	12.4	17,369	11.4	63,696	11.6	724	8.6	2,563	10.4
Unknown	1		0		26		0		0		0	
Subtotal	304		1,800		33,984		194,161		1,601		8,390	
With vehicle												
Light	104	7.4	1,031	20.8	12,976	8.5	112,806	20.6	588	7.4	4,562	19.3
Other	40	2.9	153	3.1	3,613	2.4	17,659	3.2	243	3.1	1,045	4.4
Unknown	0		0		0		0		46		220	
Subtotal	144		1,184		16,589		130,465		877		5,827	
With other vehicle												
Retained	32	2.3	119	2.5	3,113	2.1	14,744	2.8	180	2.3	924	3.9
Ejected	7	0.5	25	0.5	433	0.3	2,234	0.4	63	0.8	118	0.5
Unknown	1		9		67		681		0		3	
Subtotal	40		153		3,613		17,659		243		1,045	
Occupant retained												
Near-side	16	1.2	77	1.6	1,294	0.9	11,588	2.2	118	1.5	592	2.5
Far-side	16	1.2	42	0.9	1,819	1.2	3,156	0.6	57	0.7	326	1.4
Other	0	0.0	0	0.0	0	0.0	0	0.0	1	0.0	1	0.0
Unknown	0		0		0		0		4		5	
Subtotal	32		119		3,113		14,744		180		924	
Near-side												
Front seat	16	1.2	72	1.5	1,294	0.9	10,834	2.1	117	1.5	547	2.3
Back seat	0	0.0	5	0.1	0	0.0	754	0.1	1	0.0	45	0.2
Subtotal	16		77		1,294		11,588		118		592	
Near, Front seat												
Torso/side	3	0.4	26	0.9	403	0.4	3,627	0.8	62 *		229 *	
No torso/side	6	0.8	21	0.7	444	0.5	5,610	1.2				
Unknown	7		25		447		1,597					
Subtotal	16		72		1,294		10,834					
Far-side												
Front seat	15	1.1	38	0.8	1,712	1.1	2,880	0.5	56	0.7	290	1.2
Back seat	1	0.1	4	0.1	107	0.1	276	0.1	1	0.0	36	0.2
Subtotal	16		42		1,819		3,156		57		326	
Far, Front seat												
Torso/side	1	0.1	5	0.2	193	0.2	355	0.1	12 *		63 *	
No torso/side	10	1.0	19	0.6	785	0.9	1,398	0.4				
Unknown	4		14		734		1,127					
Subtotal	15		38		1,712		2,880					

* Estimated by applying the percentages from the NASS weighted data to the FARS counts, adjusted for missing FARS classification data

Table 3. Seriously-Injury Light Vehicle Occupants in Crashes with Objects (Occupant-Level Data)

	NASS Serious Injury Cases				NASS Serious Injury Estimates				Occupant Fatalities in 1989			
	Light Trucks		Cars		Light Trucks		Cars		Light Trucks		Cars	
	Number	%Total	Number	%Total	Number	%Total	Number	%Total	Number	%Total	Number	%Total
All impacts												
Side	304	21.7	1,800	36.3	33,984	22.2	194,161	35.4	1,601	19.1	8,390	34.2
Other	1,099	78.3	3,161	63.7	119,133	77.8	353,626	64.6	6,773	80.9	16,151	65.8
Unknown	152		450		17,878		40,978		245		386	
Total	1,555	100.0	5,411	100.0	170,995	100.0	588,765	100.0	8,619	100.0	24,927	100.0
Side only												
Vehicle	144	10.3	1,184	23.9	16,589	10.8	130,465	23.8	877	10.5	5,827	23.7
Object	159	11.4	616	12.4	17,369	11.4	63,696	11.6	724	8.6	2,563	10.4
Unknown	1		0		26		0		0		0	
Subtotal	304		1,800		33,984		194,161		1,601		8,390	
With object												
Retained	76	5.6	423	8.7	8,634	5.8	47,842	8.8	418	5.0	1,766	7.2
Ejected	79	5.8	178	3.7	8,269	5.6	15,180	2.8	299	3.6	782	3.2
Unknown	4		15		466		674		7		15	
Subtotal	159		616		17,369		63,696		724		2,563	
Occupant retained												
Near-side	41	3.0	244	5.0	4,519	3.0	25,620	4.7	235	2.9	1,080	4.4
Far-side	35	2.6	179	3.7	4,115	2.8	22,222	4.1	169	2.1	675	2.8
Other	0	0.0	0	0.0	0	0.0	0	0.0	9	0.1	2	0.0
Unknown	0		0		0		0		5		9	
Subtotal	76		423		8,634		47,842		418		1,766	
Near-side												
Front seat	39	2.9	266	4.7	4,393	3.0	23,663	4.4	230	2.8	972	4.0
Back seat	2	0.1	18	0.4	126	0.1	1,957	0.4	5	0.1	108	0.4
Subtotal	41		244		4,519		25,620		235		1,080	
Near, Front seat												
Torso/side	6	0.6	48	1.4	800	0.6	4,457	1.0	51 *		237 *	
No torso/side	22	2.2	114	3.3	2,993	2.3	14,303	3.3				
Unknown	11		64		600		4,903					
Subtotal	39		266		4,393		23,663					
Far-side												
Front seat	34	2.5	163	3.4	3,771	2.5	20,085	6.0	166	2.0	607	2.5
Back seat	1	0.1	16	0.3	344	0.2	2,137	0.7	3	0.0	68	0.3
Subtotal	35		179		4,115		22,222		169		675	
Far, Front seat												
Torso/side	1	0.1	14	0.4	80	0.1	1,700	0.4	5 *		71 *	
No torso/side	20	2.4	107	3.0	2,838	2.5	13,296	3.3				
Unknown	13		42		853		5,089					
Subtotal	34		163		3,771		20,085					

* Estimated by applying the percentages from the NASS weighted data to the FARS counts, adjusted for missing FARS classification data

Fatalities in side-impacted light trucks were less likely to have been struck by another light passenger vehicle than were fatalities in side-impacted cars:

- 39 percent of light truck side impact fatalities were struck by another light passenger vehicle, compared to
- 56 percent of passenger car side impact fatalities.

Fatalities in side-impacted light trucks were slightly more likely to involve a vehicle other than a light passenger vehicle (generally, a heavier truck) than was the case for fatalities in side-impacted passenger cars:

- 16 percent of light truck side impact fatalities were struck by a heavier vehicle, compared to
- 13 percent of passenger car side impact fatalities.

Fatalities in side-impacted light trucks were much more likely to involve an object (rather than another vehicle) than were fatalities in side-impacted passenger cars:

- 45 percent of light truck side impact fatalities involved collisions with an object (such as a pole or tree), compared to
- 31 percent of passenger car side impact fatalities.

When light passenger vehicle occupants were killed in side impacts, the light truck occupants were more likely than the passenger car occupants to have been ejected to some degree (37 percent and 12 percent, respectively). The difference may reflect, in part, the greater protection provided by light trucks if the occupant can be retained.

The difference does not necessarily imply that light trucks have higher ejection rates in crashes of comparable damage severity. However, it does suggest that preventing light truck ejection may be even more important for reducing fatalities among light truck occupants than it is for passenger car occupants. Overall, unejected occupants in side impacts with another light passenger vehicle were 5 percent of all light truck occupant fatalities, compared to 17 percent of car occupant fatalities. These rates should increase as safety belt use continues to improve.

Some portion of the fatalities attributed to side damage might be helped by other efforts to reduce the likelihood of rollover or the severity of the injuries in rollovers. Table 4 shows that about half the ejections in light trucks in side impacts with another passenger vehicle involved a subsequent rollover, compared to a quarter of those in passenger cars. There may be some difficulties in attributing these fatalities to the side-impact, rather than to the rollover. The FARS analysts may not always have the experience or information needed to determine the cause of death. It seems likely that the rollover was frequently an important factor in causing the ejection, if not in causing the death.

Table 4. Light Vehicle Occupant Fatalities with Some Degree of Ejection from Side-Impact Crashes with Another Light Passenger Vehicle (1989 FARS Occupant-Level Data)

Side-Impacted Vehicle	Ejection Degree	Rollover Occurrence	Fatalities
Passenger car	Complete	No rollover	372
"	"	First event	3
"	"	Subsequent event	79
"	Partial	No rollover	74
"	"	First event	0
"	"	Subsequent event	25
Light truck	Complete	No rollover	96
"	"	First event	3
"	"	Subsequent event	81
"	Partial	No rollover	15
"	"	First event	3
"	"	Subsequent event	18

Light truck occupant fatalities who were retained in crashes with another light passenger vehicle were more likely to have been sitting on the same side as the impact (drivers in left-side impacts and right-front passengers in right-side impacts, and similarly for back seat occupants) rather than on the side away from the impact (which was defined to include those sitting in the middle of a bench seat). However, the ratio of near-side to far-side fatalities in light trucks was less than the ratio for car occupant fatalities. Overall, unejected near-side occupants in these crashes accounted for 3 percent of all light truck occupant fatalities, compared to 12 percent for passenger cars.

Most of these near-side occupant fatalities were in the front seat, for both light trucks and passenger cars. However, light truck front-seat occupant fatalities accounted for a larger proportion of near-side fatalities than was the case for passenger cars, largely because many light trucks do not have a back seat. Overall, there were 210 light truck occupant fatalities identified in 1989 as being unejected from the front seat after a near-side crash with another light vehicle—an estimated 2.7 percent of all light truck occupant fatalities that year (after prorating unknown data at each stage, as shown in Table 1). In comparison, 2,526 (10.8 percent) of all passenger car occupant fatalities in 1989 were identified as involved in crashes of this type. These fatalities were in crashes that most-closely resembled the moving barrier side impact test conditions, based on the data currently available in FARS for making this determination. NASS includes information that allows further discrimination, to more-precisely identify those whose injuries are simulated by the test dummy.

Unejected far-side occupants in similar crashes represented about 1.6 percent of all light truck fatalities and 4.6 percent of passenger car fatalities. As with near-side fatalities, the overwhelming majority of these were in the front seat.

Ejection was noted to be more frequent among light truck than among passenger car occupants involved in side impacts with other light passenger vehicles. This same pattern was found for those involved in collisions with heavier vehicles and with objects. In collisions with heavier vehicles, 26 percent of light truck fatalities, compared to 11 percent of passenger car fatalities, were ejected (as shown in Table 2). This may imply that light truck occupants are more protected by the design and size of their vehicle, if they can be retained in it.

There were 724 light truck occupant fatalities in side-impact collisions with objects (such as poles and trees) in 1989, and 299 of these were ejected from the vehicle (Table 3). The ejection rate among fatally-injured occupants of light trucks was higher (41 percent) than for passenger cars (31 percent). A larger number of unejected light truck occupant fatalities were involved in side impacts with objects (418 fatalities) than with other light passenger vehicles (365 fatalities) in 1989.

Crashes that Resemble the Moving Barrier Test

The FARS data were used to count the number of unejected passenger vehicle occupant fatalities that occurred in side impacts in 1989, but FARS does not contain the information on injury type and contact point needed to identify fatalities with torso injuries from side surface, hardware, and armrest contact. These injuries are an important focus of the passenger car moving barrier test, so it is useful to estimate how many light truck occupant fatalities received injuries of this kind. The NASS data include detailed data on injury mechanisms, but several years of data had to be combined (1982 through 1989) because of the limited number of relevant investigations performed each year. Even then, the data were insufficient to adequately describe typical damage patterns and crash severity.

The NASS light passenger vehicle occupant data for those seriously-injured or killed was subjected to a series of filters like those used on the FARS data so that the comparability of the approaches used with the two data systems could be determined. The NASS results, weighted by the national inflation factor to account for the sampling scheme, are very similar to the FARS results for the gross comparisons shown in Tables 1, 2, and 3. There are probably important differences between the 1989 FARS and the combined 1982 through 1989 NASS data because of changes in vehicles and vehicle use (for example, the shift to smaller light trucks and to greater use of safety belts), and these could be considered in subsequent analysis.

The passenger car dynamic side impact test uses a barrier that mimics the frontal impact of an average passenger car, with belted instrumented dummies to measure the likely accelerations on the occupants in a similar crash. Thus, the crash test looks like what is experienced by a belted passenger car occupant in a side impact with another passenger vehicle. There are few (if any) investigated cases involving belted occupants of light trucks who were seriously-injured in side impacts with other passenger vehicles. For this reason, all unejected occupants (rather than all belted occupants) in side impacts involving two light passenger vehicles were used to define accidents that "resemble" the moving barrier test. This characterization was made without regard to the similarity of the crash severity and damage in actual crashes to those produced in the moving barrier test. These details were considered to be within the realm of changes to the moving barrier test that could make it more representative of injuries in light truck side impacts. If there were enough NASS cases, they could be used to describe the specific circumstances of crashes that resembled the moving barrier test, to guide exploration of possible changes of the test for light trucks.

Some occupants who were completely ejected and many occupants who were partially ejected received injuries from the vehicle interior before ejection. Preventing these injuries could reduce the overall injury severity and the risk of fatality for some of these occupants, and should be considered in projecting benefits from an extension of the moving barrier test to light trucks. However, including ejected occupants would complicate this discussion, especially given the large number of unknown injury contact points for ejected occupants. The aim here was more modest: simply to identify a group of NASS light truck serious injury cases that most closely resembled the passenger car moving barrier test and to describe the typical impact direction, speed, and severity and the typical damage to the side-impacted vehicle. This description could be helpful in specifying an appropriate test angle and barrier speed, weight, and height for an extension of the dynamic side impact test requirement to light trucks. As it turned out, even this more modest goal was too ambitious.

Near-Side Light Truck Occupants. Front-seat, near-side light truck occupants retained in vehicles struck in the side by another light vehicle represent:

- 2.7 percent of 1989 FARS fatalities and
- 4.1 percent of 1982 through 1989 estimated serious injuries.

These are less than the rates for car occupants in similar situations:

- 10.8 percent of 1989 FARS fatalities and
- 10.7 percent of 1982 through 1989 estimated serious injuries.

The NASS results (using a serious injury threshold) are similar enough to the FARS results (for fatalities only) to suggest that accident configuration, vehicle damage, injury mechanism, and victim size data available only in NASS could be used to estimate fatality-producing situations.

There were 45 unejected near-side, front-seat light truck occupants in side impacts with another light passenger vehicle investigated from 1982 to 1989 with serious or more severe injury (including fatalities, and referred to as "serious" here, for simplicity). Four of these were fatalities with incomplete injury data (such as occurs when a person dies before receiving medical treatment and is not autopsied). The other 41 occupants had at least one coded serious injury, and there were a total of 69 serious injuries coded for them. The injury contact was unknown for 20 of the 69 coded injuries. The injury counts (including multiple injuries for people who received more than one torso injury) by body region and injury source are shown in Table 5. "Torso," as used here, includes the five Occupant Injury Classification body regions: shoulder, chest, abdomen, back, and pelvis. All known injury sources except the A- and B-pillars, the side surface, hardware, armrest, window, and the category for other (unspecified) side contact have been collapsed into the category "not side" in this table.

Of the 69 coded serious injuries, 39 involved the torso (56.5 percent). Of the 39 coded torso injuries, 23 were caused by contact with the side surface, hardware, or armrest. This is 71.9 percent of 32 torso injuries with known injury contact data. The product of these two rates (40.6 percent) is the estimated proportion of the investigated serious injuries that involved a torso injury from the side surface, hardware, or armrest in the side-impact situations represented by these 45 occupants. This is less than the 51.2 percent estimated for the same group of injuries for car occupants in similar crashes. No further use is made of these injury-level estimates: they are presented here simply to provide an intuitive foundation for an occupant-level discussion.

Some occupants had more than one serious injury, and some even had more than one serious torso injury from side surface, hardware, or armrest contact. Thirteen investigated front-seat, near-side unejected occupants of light trucks struck in the side by another light passenger

Table 5. Serious Injuries to Near-Side, Front-Seat Retained Occupants in Side Impacts Involving Two Light Passenger Vehicles (Injury-Level Data from NASS Investigated Cases)

Light trucks	Torso	Head/ Face	Neck	Arm	Leg	Total
Side surface	21				2	23
Side hardware or armrest	2					2
Side window		2				2
Side, other	1					1
A-pillar		5				5
B-pillar		1				1
Not side	8	1	1	1	4	15
Unknown	7	4	2	1	6	20
Total	39	13	3	2	12	69
Percent of Total:						
Side surface, hardware, or armrests	71.9	0.0	0.0	0.0	33.3	51.0
Torso injury	56.5					
Torso-side	40.6					

Light truck occupants investigated = 45 (41 with data)

Passenger cars	Torso	Head/ Face	Neck	Arm	Leg	Total
Side surface	301	9	1	17	26	354
Side hardware or armrest	64	1		2	7	74
Side window	2	23	1	1		27
Side, other	1				7	8
A-pillar		29	1			30
B-pillar	14	20	1			35
Not side	79	51	4	10	14	158
Unknown	159	70	10	12	21	272
Total	620	203	18	42	75	958

Plus: 2 unknown body region, unknown contact
1 whole body, not from side contact

Percent of Total:	Torso	Head/ Face	Neck	Arm	Leg	Total
Side surface, hardware, or armrests	79.2	7.5	12.5	63.3	61.1	62.3
Torso injury	64.7					
Torso-side	51.2					

Car occupants investigated = 500 (450 with data)

vehicle received at least one such injury (1.4 percent of the nationally-weighted data for all light truck occupants with serious injury, compared to 6.0 percent for cars). Some of these occupants received other serious injuries (to other body regions or from other sources), as well; occupants were included in this count if they had at least one torso injury from these side contacts, even if it was not the most severe injury received. Some of these occupants received multiple serious torso injuries from these side contacts; if so, they were included only once in this count. Another 23 investigated occupants received no serious torso injuries from these side contacts, and there were insufficient data to classify another nine occupants (Table 1).

There were 210 unejected light truck near-side, front-seat occupant fatalities in side impacts with another light passenger vehicle identified in 1989 (FARS). The nationally-weighted NASS data for this crash situation produce an estimate that 33.9 percent of seriously-injured occupants had at least one serious torso injury from the side surface, hardware, or armrest (based on 1,732 of the 5,105 with known injury data). The NASS injury rate multiplied by the number of relevant fatalities identified in FARS (and adjusted for missing FARS classification data by prorating the number of fatalities with unknown damage area, impacting object, vehicle type, or occupant ejection status) produce an estimate that 79 near-side, front-seat light truck occupant fatalities received serious torso injuries from these sources in 1989. Therefore, the side impact moving barrier test conditions resemble those experienced by an estimated 79 fatalities that year.

The 13 NASS light truck occupants known to have suffered a serious torso injury from these side contacts can be further classified by the specific injuries received, but it is difficult to generalize from so few cases. Three occupants investigated by NASS had a dislocated shoulder from side surface contact, with no other serious injury; four had skeletal fracture from side contact, without any serious internal organ injuries; four had serious internal organ injury from side contact, but no serious skeletal injury; and three had both serious internal organ injury and serious skeletal fracture from side contact.

Far-Side Light Truck Occupants. There were 29 far-side, seriously-injured occupants retained in the front seats of light trucks side-impacted by another light passenger vehicle and investigated by NASS during these seven years. Three were fatalities with incomplete injury data. The other 26 people had a total of 37 serious and more severe injuries, shown by body region and injury source in Table 6.

Of the 37 coded injuries, 16 (43.2 percent) involved the torso. Of the 16 coded torso injuries, three (23.1 percent of the 13 cases with known data) were caused by side surface contact. The product of these two proportions (10.0 percent) is the proportion of the investigated serious injuries to far-side occupants in these crashes that were attributed to side surface contact with the torso. This is close to the 13.9 percent estimated for car occupant contact with side surface, hardware, and armrest contact in similar crashes. These injury-level results may make the occupant-level results that follow easier to understand.

There were only three investigated serious torso injuries from side surface contact received by light truck occupants in crashes of this type, and two were received by a single person. Of the 29 far-side light truck occupants described here, two were known to have received such an injury (representing 0.1 percent of the weighted number of all seriously-injured light truck occupants), 21 were known not to have received such an injury, and data were incomplete for the other six occupants.

There were 126 unejected light truck far-side, front-seat occupant fatalities in side impacts with other light vehicles identified by FARS in 1989. The nationally-weighted NASS data produce an estimate that 5.2

Table 6. Serious Injuries to Far-Side, Front-Seat Retained Occupants in Side Impacts involving Two Light Passenger Vehicles (Injury-Level Data from NASS Investigated Cases)

Light trucks	Torso	Head/ Face	Neck	Arm	Leg	Total
Side surface	3	2		1		6
Side hardware or armrest						0
Side window		3				3
Side, other						0
A-pillar		3				3
B-pillar		1				1
Not side	10	3	2		1	16
Unknown	3	4	1	–	–	8
Total	16	16	3	1	1	37
Percent of Total:						
Side surface, hardware, or armrests	23.1	16.7	0.0	100.0	0.0	20.7
Torso injury	43.2					
Torso-side	10.0					

Light truck occupants investigated = 29 (26 with data)

Passenger cars	Torso	Head/ Face	Neck	Arm	Leg	Total
Side surface	46	23	2	1	4	76
Side hardware or armrest	4	4		1		9
Side window	1	6				7
Side, other	3	5				8
A-pillar	1	14	3			18
B-pillar		3	1			4
Not side	146	59	7	9	12	233
Unknown	108	60	10	7	11	196
Total	309	174	23	18	27	551

Plus: 1 unknown body region, unknown contact
1 whole body, not from side contact

Percent of Total:						
Side surface, hardware, or armrests	24.9	23.7	15.4	18.2	25.0	23.9
Torso injury	56.0					
Torso-side	13.9					

Car occupants investigated = 284 (260 with data)

percent (an estimated 165 of 3,006 with known injury data) of those seriously-injured in these situations had a serious torso injury from side surface, hardware, or armrest contact. This suggests that about seven far-side light truck occupant fatalities (5.2 percent of the 140 fatalities in 1989, adjusted for missing FARS accident type and ejection status) had torso injuries from these sources in 1989. These are the fatalities that resembled the passenger car dynamic side impact test that year.

The two far-side light truck occupants with serious torso injuries from side contacts cannot provide a good basis for more detailed analysis, but they do indicate that these injuries are relatively rare. One of the two occupants investigated had a dislocated shoulder from side contact, but no other serious injury. The other occupant suffered chest fractures and internal organ injuries from side contact, and also received a more serious (AIS 5) head injury from B-pillar contact.

Near-Side Passenger Car Occupants. The procedure for estimating the number of serious injuries in light truck side impacts that resemble the moving barrier test by crash severity and striking vehicle weight can be repeated for car occupants. The results are shown in Tables 1, 2, and 3. The results provided here are not directly comparable to estimates in the Final Regulatory Impact Analysis (FRIA) *New Requirements for Passenger Cars to Meet a Dynamic Side Impact Test (FMVSS 214),* August 1990) because the earlier analysis considered benefits in accidents that do not resemble the test procedure (as defined here) but that do produce torso injuries from side contacts. The expected benefits provided in the FRIA included fatalities in all types of crashes from design changes that were expected to be made to meet the test requirement. Table 7 suggests the effect of this definitional distinction. Estimates from NASS are that 72 percent of the near-side and 31 percent of the far-side passenger car front-seat occupants who received serious torso injuries from side surface, hardware, and armrest contacts were in crashes that resembled the side impact test. Other serious torso injuries from these sources were received in crashes with objects, in crashes with medium and heavy trucks, or by people who were ejected. There are important differences between the approach used in the FRIA and the scope of the explorations reported here, and the results of the two approaches are not comparable.

Table 7. NASS Light Passenger Vehicle Occupants in Side Impacts, with a Serious Torso Injury from Side Surface, Hardware, and Armrest Contact—by Ejection and Impacting Vehicle Type or Object (Occupant-Level Data)

	Passenger Car Front Seats				Light Truck Front Seats			
	Near-Side		Far-Side		Near-Side		Far-Side	
	Raw	Estimate	Raw	Estimate	Raw	Estimate	Raw	Estimate
Retained								
Object impact	48	4,457	14	1,700	6	800	1	80
Light vehicle	210	25,614	21	1,415	13	1,732	2	165
Other vehicle	26	3,627	5	355	3	403	1	193
Totally ejected								
Object impact	6	556	1	39	2	73	0	0
Light vehicle	7	700	5	567	0	0	1	16
Other vehicle	0	0	2	196	2	41	0	0
Partially ejected								
Object impact	4	145	0	0	0	0	0	0
Light vehicle	7	434	1	25	0	0	0	0
Other vehicle	3	61	0	0	1	40	0	0
Unknown degree								
Object impact	0	0	0	0	2	186	0	0
Light vehicle	0	0	0	0	0	0	0	0
Other vehicle	0	0	0	0	0	0	0	0
Unknown if ejected								
Object impact	1	11	1	15	0	0	0	0
Light vehicle	1	133	1	176	0	0	0	0
Other vehicle	2	34	1	117	0	0	0	0
Total	315	35,772	52	4,605	29	3,275	5	454
Percent of total retained in light vehicles		72%		31%		53%		36%

NASS identified injury mechanisms for 372 seriously-injured unejected near-side, front-seat occupants of cars side-impacted by another light passenger vehicle. These cases produce an estimate of 45,855 occupants, of whom

25,614 (55.9 percent) suffered a serious torso injury from side surface, hardware, or armrest contact. Applying this rate to the FARS car occupant fatalities in this seating position in crashes of this type in 1989 (2,526 identified by FARS) and adjusting for missing data produces an estimate of 1,504 near-side car occupant fatalities with injuries in crashes that resemble the dynamic side impact test.

Far-Side Passenger Car Occupants. NASS also identified injury mechanisms for 203 seriously-injured far-side, front-seat passenger car occupants in side impact crashes that resembled the test condition. The weighted data produce an estimate that 5.6 percent of these suffered serious torso injury from side surface, hardware, or armrest contact, for an estimate of 63 far-side car occupant fatalities in 1989 in crashes that resembled the dynamic test procedure.

Characteristics of Crashes that Resemble the Moving Barrier Test

Modifying the passenger car dynamic side impact test to reflect the crash circumstances in which light truck occupants are killed requires additional detailed accident data. NASS includes information on the damage type and severity for light truck occupants who received serious torso injuries from side surface contact in side impacts with another light passenger vehicle. The passenger car moving barrier side-impact test involves a 3,000 pound moving barrier that strikes the side of a car at a velocity of 30 miles-per-hour (mph). The NASS damage type and severity distributions could be applied to the FARS fatality counts to estimate the annual number of fatalities in situations and with severities like the passenger car side-impact moving barrier test, but there are not enough detailed data for this purpose. There are only 13 NASS near-side and two far-side unejected front-seat occupants with serious torso injury from side surface, hardware, and armrest contact in light trucks side-impacted by other light passenger vehicles. Using the damage descriptions from a broader group of NASS cases might misrepresent the circumstances of serious injuries. As additional years of NASS data become available, it may be possible to make better estimates of the number of light truck crashes that resemble the moving barrier test, to describe the damage type and severity of these crashes, and to explore the effect on belted occupants and on occupants of the smaller light trucks. However, these data will accumulate very slowly.

Table 8 provides anecdotal information on the vehicle, damage, and occupant for the 13 cases with serious torso injuries. Most of the side-impacted light trucks were pickups (ten of the 13), and the most common striking vehicle was a passenger car. The average curb weight of the struck vehicle was 3,500 pounds, about the same as the average striking vehicle curb weight. This is 500 pounds heavier than the 3,000 pound barrier being used in the passenger car test, and exceeds the test weight by even more if the weight of the occupants in the striking vehicle is included. Eight of the 13 striking vehicles might be too heavy (more than 3,500 pounds) to be adequately represented by the current moving barrier, but a determination would need to consider the striking vehicle speed, which is frequently unknown.

Table 8. NASS Light Truck Near-Side Cases that Resemble the Car Test (Occupant-Level Data)

	Body Types		Vehicle Weights				Change in Velocities		
			Struck		Other		Struck		Other
Case	Struck	Other	Curb	Cargo	Curb	Cargo	Total	Lateral	Total
1	pickup	car	2500	0	4200	0	22	19	13
2	pickup	utility	3300	400	3700	200	.	.	.
3	van	car	3800	500	4500	0	.	.	.
4	pickup	van	3800	100	4200	0	10	8	9
5	pickup	car	3600	100	4100	0	.	.	.
6	van	car	4200	1500	3700	0	24	24	35
7	pickup	van	4100	.	3200	.	28	-21	37
8	pickup	car	2900	0	3900	0	.	.	.
9	pickup	car	2700	400	3700	0	17	17	14
10	pickup	car	3300	1000	2200	0	7	0	12
11	van	pickup	3700	400	3000	0	15	14	19
12	pickup	car	3600	.	2000	.	17	9	31
13	pickup	car	3900	0	3300	.	.	.	.

	Force Direction		Damage Area		Struck Vehicle Damage (CDC)		
Case	Struck	Other	Struck	Other	Horizontal	Vertical	Extent
1	10	12	Left	Front	Whole side	Below	5
2	10	.	Left	Front	Front 2/3	All	4
3	8	12	Left	Front	Front 2/3	Below	3
4	10	2	Left	Front	Back 2/3	Below	2
5	7	.	Left	Front	Back 2/3	Below	2
6	9	12	Left	Front	Whole side	All	5
7	12	11	Right	Front	Whole side	Below	4
8	10	1	Left	Front	Front 2/3	Below	4
9	9	12	Left	Front	Front 2/3	Below	3
10	9	3	Left	Front	Center 1/3	Below	2
11	10	1	Left	Front	Whole side	Below	3
12	11	2	Left	Front	Front 2/3	Below	5
13	10	.	Left	Front	Front 1/3	Below	4

	Seriously-Injured Occupant				National
Case	Age	Weight	Height	Belted	Weight
1	40	175	68	no	127
2	59	200	72	no	30
3	56	195	70	no	375
4	51	175	67	no	237
5	62	240	77	no	236
6	25	180	73	no	56
7	35	.	.	yes	154
8	62	195	71	no	37
9	62	162	71	no	44
10	24	185	72	no	245
11	59	164	68	yes	56
12	56	180	68	no	58
13	32	135	70	no	78

Delta V was estimated for eight of the 13 cases. The average lateral delta V for the side-impacted vehicle was 14 mph. One or two of these crashes may have involved a lateral impact too severe (more than 20 mph) to be well-represented by the passenger car test. The average delta V for the striking vehicle was 21 mph, less than the current test speed of 30 mph. One crash had a striking vehicle delta V of 37 mph, substantially above the impact speed of the moving barrier in the passenger car test.

Only three of the 13 cases had a striking vehicle weight of 3,500 pounds or less, a lateral delta V of 20 mph or less on the struck vehicle, and a total delta V of 35 mph or less for the striking vehicle; nine cases had a heavier striking vehicle or greater crash severity; the other case could not be classified. Only three of the eight cases with estimated delta V fell below these crash severity thresholds. A more severe crash test (with a heavier barrier or greater crash severity) could represent a larger number of the estimated 79 near-side fatalities estimated to have occurred that year.

One of the two available NASS far-side cases had a striking vehicle weight and delta V that did not greatly exceed those in the passenger car test: striking vehicle weight of 3,500 pounds or less, struck vehicle lateral delta V under 21 mph, and striking vehicle total delta V under 36 mph. The small number of cases do not permit any useful generalizations except that crashes of this type do not occur frequently.

NASS investigators record vehicle damage using the Collision Deformation Classification (CDC), which is composed of several elements that describe the location and extent of vehicle damage for inspected vehicles. For each of the 13 cases with serious torso injuries, Table 8 shows the direction of force and damage area for both involved vehicles; the specific horizontal location, specific vertical location, and the extent zone for the struck vehicle; the victim age, height, weight, and belt use; and the national weighing factor associated with each case. The sum of the national weighing factors is an estimate of the number of occurrences over the seven years included here, but this estimate is not very accurate because there are so few cases in this table, and the estimate has not been adjusted for missing data in any of the elements used to identify these cases. Missing data for elements included in the table are noted by a dot in place of the information. The information would not fit on a single line, so the results are shown in three subtables. The data for the 13 cases are linked by the case number provided in each subtable.

Eight of the 13 cases involved a CDC direction of force on the struck vehicle that was forward of a direct side hit (10, 11, or 12 o'clock). Even in 90 degree impact configurations, the forward motion of the struck vehicle affects the force direction and tends to shift it this way. Seven of the ten striking vehicles with known data had 11, 12, or 1 o'clock force directions. Twelve cases involved a left side impact, and the other involved a right side impact. All striking vehicles received frontal damage in the crash.

The CDC specific horizontal location describes where along its side the vehicle was damaged. The codes must be interpreted differently for vans than for other light trucks. For vans, the damage to the front third of the side face (including damage that extends along the front two-thirds and damage distributed along the whole side) involves the front-seat passenger door. For other light trucks and for cars, passenger door involvement is indicated when the damage includes the center third of the side face (including damage that extends along the front two-thirds, damage along the rear two-thirds, and damage distributed along the whole side). Twelve cases involved damage at least to the passenger door, and one case involved only damage forward of the pickup truck passenger compartment.

The CDC specific vertical location describes the relative height of the damaged area. At least the whole vertical area below the belt line (noted as "Below" in the table, and including the frame and the door height area) was damaged in all light trucks, and in two of these cases the area above the belt line was damaged as well.

The CDC extent zone measures the maximum crush. For side damage, the extent zones are defined by a set of imaginary parallel planes perpendicular to the ground and to the front face of the vehicle. Side extent zones 1 and 2 are crush no further than the bottom and top edges, respectively, of the side window. The side window angle determines the difference between the first two extent zones. Ten cases involved damage into extent zones 3 (beyond the plane defined by the inner edge of the side window) through 5 (close to the mid-line of the vehicle, which falls between extent zones 5 and 6), which could indicate a reduction in the occupant compartment space, depending on the horizontal location of the maximum damage. The other three cases included damage into extent zone 2 of pickup trucks.

The people ranged in age from 24 to 62 years old (average of 48 years), weighed between 135 and 240 pounds (average of 182 pounds), and were between 5 feet, 7 inches and 6 feet, 1 inch tall (average of 5 feet 11 inches). Thus, the victims tend to be large, mature people. These averages may change as light truck use changes (for example, as minivans replace station wagons for families with small children), and in any case are based on very small samples. Two of the 13 fatalities were using the available safety belt. However, as these data were collected between 1982 and 1989, this does not reflect belt use habits since the passage of state occupant protection laws.

Crashes that Do Not Resemble the Moving Barrier Test

A moving barrier side-impact test for light trucks would resemble a smaller portion of light truck occupant fatalities than it does for passenger cars and a smaller portion of serious torso injuries from side contacts received in side impacts (Tables 1, 2, and 3). Side collisions, multi-vehicle collisions, collisions with other light vehicles, and occupant retention in the vehicle accounted for a smaller portion of the light truck occupant safety problem than they did for passenger cars. For example, for fatalities in light trucks with side damage:

- 39 percent involved collisions with other light vehicles,
- 16 percent involved collisions with medium and heavy trucks, and
- 45 percent involved collisions with objects.

A benefits analysis for a moving barrier test applied to light trucks would assess the potential fatality reductions in crashes other than those side impact crashes involving two light passenger vehicles.

Impacts with Heavier Vehicles. Table 2 explores light passenger vehicle side impacts with heavier vehicles in more detail, repeating the injury and fatality distributions by damage area and side-impact contact provided in Table 1 and providing a description of ejection, relation to impact, and seating location for these side impacts, parallel to the description for light vehicle impacts provided in the earlier table. An estimated 12 percent of the NASS light truck occupant injuries and fatalities involved ejection. There were a relatively large number of far-side occupants among these unejected NASS serious injuries and fatalities. However, this pattern is not supported by the FARS fatality data, suggesting that it may be a random effect of the small number (32 people) of investigated cases. There was only one back-seat occupant (in a far-side crash) among the investigated cases.

Applying the weighted NASS rates of torso injury from side surface, hardware, and armrest contact to the FARS fatality counts for unejected occupants and adjusting for missing FARS classification data produces an estimate that 74 fatalities received a serious injury of this type in 1989: an estimated 62 were near-side and 12 were far-side, relative to the vehicle damage.

Some portion of these fatalities may have involved crash forces that would be more manageable with the light truck design changes that might result from an extension of the moving barrier test. There is no good measure of the severity of these crashes because delta V usually cannot be calculated for collisions with heavy trucks. Striking vehicle weight was reported for two of the crashes: one involved an unloaded 21,300 pound truck and the other involved a 15,500 pound truck carrying 4,000 pounds in cargo, which brings into question how well the current moving barrier could represent these crashes.

The comparable estimates of torso injuries from these side contacts for passenger cars are 229 fatalities in near-side crashes and 63 fatalities in far-side crashes. Delta V was not available for any of these NASS passenger car crashes.

Impacts with Objects. Table 3 provides a description of ejection, relation to impact, and seating location for side impacts into an object. About half the NASS serious object side impacts involved occupant ejection. This is much higher than the rate for side impacts with other light vehicles or with medium and heavy trucks. The NASS weighted distributions for injury type and contact applied to the FARS fatality data produce estimates of 51 near-side and five far-side fatalities with serious torso injuries from side surface, hardware, and armrest contact in light truck side impacts with objects. The relationship between the moving barrier test and these crashes is unknown because delta V was estimated for none of the seven NASS cases (six near-side and one far-side). Delta V can be estimated for many fixed object collisions if the object is not moved or broken in the crash.

Comparable data for passenger car crashes, shown in Table 3, produces estimates of 237 near-side and 71 far-side unejected fatalities with torso injuries from side surface, hardware, and armrest contact in side impacts with objects. Delta V was estimated for some of these NASS cases, in contrast with none of the NASS light truck collisions with objects. The rate with which delta V was estimated for the car collisions suggests that cars (which tend to be lighter than light trucks) less-frequently move or break the objects struck.

Twenty-eight of the 48 investigated unejected near-side, front-seat passenger car occupants with serious torso injuries from these side contacts were in accidents for which delta V was estimated. The lateral component of the delta V was no greater than 20 mph for 12 of the 28 cases with an estimated delta V. Of the 14 investigated unejected far-side, front-seat passenger car occupants with serious torso injuries from relevant side contacts, only four had an estimated delta V. The lateral component was not greater than 20 mph for two of the four cases.

Conclusions

There are insufficient detailed data to generalize about the typical impacting vehicle speed and weight, impact angle, and impact point on the side-impacted vehicle. A review of the data suggests that the reason so few detailed cases were found is that serious injuries in light trucks are less likely (compared to serious injuries in passenger cars) to involve a side impact with another light passenger vehicle. The serious injuries that do occur in side-impacted light trucks are more likely (compared to serious injuries in side-impacted passenger cars) to involve ejection from the vehicle. Therefore, if the passenger car dynamic side impact test were applied to light trucks, it appears that requiring the door to stay closed during the test could be much more important for light trucks than for cars.

S5-O-28

Development of the MIRA Free-Flight Headform Rig to Simulate Occupant Side-Impact and Pedestrian Impacts

K.C. Clemo
Motor Industry Research Association

Abstract

The MIRA Free-Flight Headform Rig was designed to offer a convenient way of simulating occupant head impacts (for Interior Protection legislative requirements) on the interior surfaces of vehicle passenger compartments. The paper details the development of the rig and outlines new applications in the fields of occupant side impact and pedestrian head impact.

Introduction

Of all parts of the human body, it is the head which suffers the greatest risk of fatal or debilitating injury when striking some hard surface. Apart from being a major cause of death, such injuries can lead to life-long disability through loss of brain or sensory function, or else produce severe disfigurement, often with associated psychological effects. By its very nature, modern high-speed transport offers many ways in which such impacts may arise, for example, as a result of a moving vehicle striking a pedestrian, or impact of a passenger with a car interior as a result of a collision. It is essential that all types of vehicle should be designed so as to minimize the risk or severity of injury caused by such impacts.

There are two fundamentally different approaches which can be made to protecting the head on impact. In the first place, the protection can be worn on the head, as in the case of a safety-helmet. Such an approach is needed in protecting a motorcyclist, for example, where the head could potentially strike against virtually any form of surface. Clearly, it is almost impossible to ensure that even a small number of these surfaces encountered in the course of a journey offered any form of protection to the head on impact.

The occupant of an enclosed vehicle, on the other hand, is surrounded by the interior surfaces of the passenger compartment, and it is these surfaces which, in the majority of cases, the head is most likely to contact. In this case, therefore, impact protection may be designed into these surfaces in order to protect the occupant.

In addition to these two cases, the subject of pedestrian head impact represents a special case. The primary impact of a pedestrian with a vehicle is necessarily against it's external surfaces, and hence changes to these surfaces could conceivably benefit safety in this respect. However, it is also likely that injury will be caused in secondary impacts, where the victim is projected against some hard surface by the force of the impact.

MIRA has been closely involved with the technology of such protection from the very earliest times. Biomechanical and accident research have provided us with the design criteria on which to base our prediction of the likelihood or severity of injury in a given type of accident. The use of anthropomorphic dummies in simulated crash tests enables us to recreate the conditions occurring in such accidents to develop the interior surfaces of vehicles to incorporate a higher degree of protection.

However, for all their realism, crash tests are not enough to allow us to carry out a full development of the vehicle. There is, of course, considerable variation in the point of contact of the head with the inside surface of the passenger compartment from one accident to another, as well as variation in other impact parameters such as the direction and velocity of impact. To conduct a series of crash tests to encompass all of this variability would be impractical and expensive, especially in the case of prototype vehicles. It is therefore essential to conduct some form of component test, that is, a test which mimics behaviour of the head in an accident and whose impact parameters can be closely controlled to match a given accident scenario.

The standard form of component test to simulate head impact is that set out in the SAE Specification SAE J984. This involves an impact by a smooth, rigid, hemispherical impactor mounted on a pendulum arm such as the MIRA system shown in Figure 1. The dimensions of such a pendulum render it impossible to install within a normal car passenger compartment and therefore conducting such tests generally involve cutting sections of vehicle and mounting them for impact. Such preparation is inconvenient and expensive, and could also cause errors in the test result if the rigidity of the specimen's mountings did not match that of its installation in the vehicle. Although a pendulum rig can offer accurate control of impact velocity or energy, such a rig becomes

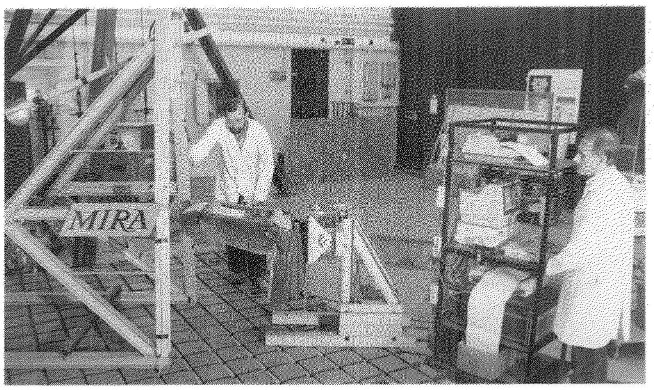


Figure 1. MIRA Pendulum Rig

impractically large for velocities much in excess of 24.1 km/h (15 mile/h). It was decided, therefore to develop a new form of test rig to simulate head impact, based upon the SAE J894 test, but incorporating many practical improvements. Thus, the MIRA Free-Flight Headform Impact Rig was devised.

Design Specification

On the basis of MIRA's experience in conducting headform impact tests, a list of requirements was drawn up, as follows:

1) The device should retain the 82.5 mm (3.25 in) radius, 6.8 kg (15 lb) mass hemispherical impactor as in the SAE specification, but should also be capable of conducting tests with other similar devices (for example, having different dimensions or mass) with a minimum of modification.
2) It should be capable of impacting specimens at higher velocities than the existing specification, up to at least 48.2 km/h (30 mile/h).
3) It should be capable of testing both the exterior surfaces of vehicles (for simulating pedestrian impact), and also the interior surfaces of the passenger compartment, without the need to cut and mount sections of bodywork.
4) Its size and shape should allow these interior tests to be conducted at all points and in all directions likely to be achieved by an occupant's head in an accident.
5) It should simulate the motion of an occupant's head in oblique impacts as well as those perpendicular to the target surface, by permitting headform rotation.
6) As with any head impact device, it should be essentially "monolithic" in construction, that is, there must be no discernible shift of the centre of gravity when struck. In particular, the accelerometer and its mountings must not exhibit any "ringing" within the normal filtering range of the instrumentation (CFC 1000).

Design Philosophy

In consideration of the above requirements, a design study was carried out to evaluate the different ways in which the objectives could be accomplished.

The first aspect to be considered was the means of guiding the impact device, particularly in order to meet the requirements of 5) above with regard to oblique impacts.

It is acknowledged in some head impact test specifications that the method is not suitable for oblique impacts. For example in Regulation ECE 21, the range of angles is limited to within 10 degrees of the normal to the surface. The reason for this is that at greater angles, the headform will be decelerated partly by friction forces as it slides along the surface of the test specimen. These forces would depend on many factors such as the nature of the headform and specimen surfaces, and the transverse stiffness of the pendulum beam, both of which would be difficult to control in order to obtain a repeatable result. Also, it was considered that a rigidly-guided headform would not simulate the motion of a human head in a real accident, except possibly one in which the reaction forces acted directly along the axis of the neck (in other words, a blow to the top of the head). For this reason it was decided that the impact device should be in free-flight at the instant of impact, that is, not directly linked to the launcher or its mounting frame.

The use of a free-flight device also eliminates a further problem associated with guidance of the headform; that of degradation of the accelerometer signal by vibration of the pendulum arm. Clearly, whenever a pendulum-mounted headform strikes a specimen, the pendulum arm must undergo deceleration just like the headform. By taking care to position the centre of percussion of the pendulum at the impact point on the headform, it is possible to ensure that the impact forces are not transmitted into the mounting frame of the pendulum. However, there is inevitably some deflection of the arm itself, and this mechanical oscillation is often apparent as "noise" or "ringing" on the accelerometer trace. The pendulum arm which is used on MIRA's rig is constructed from lightweight composite materials to minimize this effect, but does not eliminate it entirely.

Having decided on the nature of the impact device, we then turned our attention to the design of a suitable launcher, and in particular how this could be accommodated within the vehicle to carry out impacts on the interior surfaces of the passenger compartment. In order to achieve the required accuracy of aiming the device, and also the required accuracy of impact velocity, it was considered essential to make the supporting frame entirely independent of the vehicle body. It was felt that this could best be achieved by mounting the launcher on a framework positioned to pass through a door, window or tailgate aperture. The framework could then be attached to a rigid base quite independently of the vehicle body and its own mountings.

It was obvious that, in order to attain the necessary impact velocity within the confined dimensions of the passenger compartment, the distance available for acceleration of the headform would be limited. Thus, the headform would have to undergo a high level of acceleration on launching, leading to high reaction forces being transmitted to the mountings of its launching device. Both the accuracy of aiming the device and the accuracy of impact velocity depend on the deflection of the launcher being kept within acceptable limits. Therefore, by minimizing the mass of the moving parts, an acceptable level of rigidity can be maintained with a framework of lighter construction. It was reasoned that, by designing the headform as the piston in an open-ended pneumatic cylinder, all of the associated moving parts required to launch the headform could be eliminated and thus the total mass of the moving parts could be reduced to that of the headform alone. At the same time, the cylinder becomes the guidance system for the headform.

The problem then presented itself of how to incorporate the stored charge of air. Although there were clear packaging benefits to be gained in positioning this remote from the launcher, it was felt that the performance of the system would depend to some extent upon the resulting flow characteristics of the pipework connecting the storage device and the cylinder. It was decided, therefore, that an acceptable solution was to form the storage chamber as an annulus around the cylinder, with the chamber and cylinder being connected by a number of ports in the cylinder wall. In this way, the required volume of air could be accommodated close to the cylinder, within a package of small enough dimensions to allow it to be positioned inside a car in all of the required attitudes.

Having decided on this course of action, there still remained many design problems to be overcome. Nevertheless, it was felt that we had the basis of a design which would achieve all of our original objectives, and which would prove to be a practical tool in conducting the head impact tests which are clearly such an important part of safety testing.

Description of Equipment

The MIRA Free-Flight Headform Launcher Rig may be seen in Figures 2 and 3. Its principle of operation is shown in the schematic diagram, Figure 4. The rig consists of four parts: the impact device (headform), the launcher, the pneumatic charging circuit, and the mounting frame.

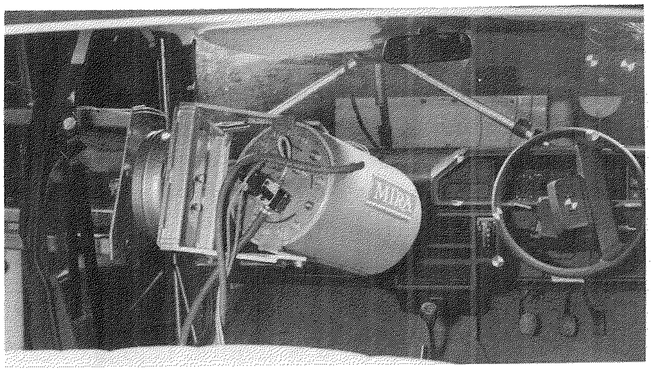


Figure 2. MIRA Headform Rig (Earlier Version)

The impact device consists of a cylindrical piston, to whose front surface a part-spherical impactor is attached. The front surface of the impact device describes a segment of a sphere of radius 82.5 mm (3.25 in), and this blends smoothly into the cylindrical surface of the piston, the spherical surface subtending an arc of 140 degrees about its centre. An array of accelerometers is mounted on the rear surface of the impactor, within a cavity in the centre of the piston. These measure the acceleration of the device in the direction of firing and also in two other mutually-perpendicular directions. A ballast plate is fitted to the rear surface of the piston, and this serves to close the accelerometer cavity, to position the device in its firing cylinder, and to place the centre of gravity of the device at the centre of the spherical surface (which is also very close to the seismic centre of the accelerometer array). The accelerometer lead exits from the headform through a slot in the ballast plate, on the rear face of the device.

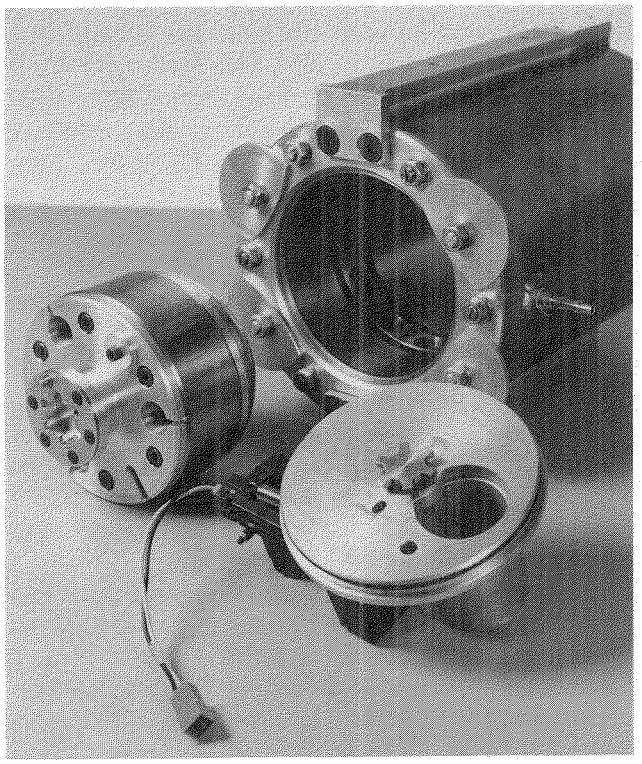


Figure 3. MIRA Headform Rig (Recent Version)

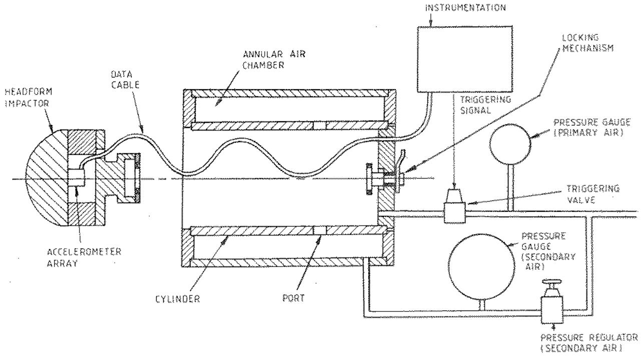


Figure 4. Free-Flight Headform Launcher Rig

The launcher consists of an open-ended cylinder of 158 mm (6.22 in) diameter and 330 mm (12 in) length, around which an annular air chamber holds the stored charge of air to fire the device. The cylinder and the annular air chamber are connected by a ring of ports within the wall of the inner cylinder. These are aligned with the piston in its firing position. The piston blocks the ports and, in conjunction with two seals in the cylinder, prevents the stored charge of air from escaping from the annular chamber. The seals are of a special type which remain stable under the high shear forces generated by the high piston velocity. The space behind the piston is initially ventilated to atmosphere, and since the pressure on the front and rear faces of the piston is thus equal, it experiences no net axial force. Air is fed to the annular chamber from a pneumatic charging circuit, and the impact velocity of the device is determined by the charging pressure.

The rear end of the cylinder is closed by a removable "breech plug." This not only forms the rear wall of the cylinder, but also serves to locate the piston axially in the firing position and provides a sealed aperture through which the accelerometer lead passes out of the cylinder. The breech plug is made removable in order to facilitate the assembly of this lead before firing; the device and the breech plug are first connected together outside the cylinder, the accelerometer lead is then coiled into the annular space between them, and the whole unit is then assembled into the rear of the cylinder, the breech plug being secured by four clamp plates on the rear face of the cylinder. Sufficient length of lead is allowed so that it will trail behind the headform on firing, transmitting the signal to the data recording system. The breech plug also incorporates a port into which a pulse of air may be introduced to trigger the device. This moves the piston forwards slightly, uncovering the ring of ports, and allowing the stored charge of air to flow quickly into the main cylinder, firing the device.

The pneumatic charging system consists of two separate circuits, a charging circuit which charges the annular chamber so as to provide the main propulsive charge, and a triggering circuit which provides the pulse of air to initiate the firing sequence. The charging circuit consists of a high precision pressure regulator, which reduces and controls the supply pressure to a level suitable for firing the device at the correct velocity, a gauge by which the charging pressure can be set, and a valve which controls the flow from these into the annular chamber. The triggering circuit also incorporates a regulator and gauge, but of lower accuracy than those of the charging circuit and these are connected via a solenoid valve, which thus introduces the pulse of air to the rear of the cylinder in response to an external electrical signal, firing the device. When not activated, this valve ventilates the space behind the piston to atmosphere, so as to ensure that leakage past the rear seal would not cause pressure to build up behind the piston, firing the device prematurely.

The entire launcher forms a package of cylindrical shape, 275 mm (10.8 in) in diameter and 350 mm (13.8 in) long. This is positioned in a suitable attitude in front of the point to be tested, generally at a distance of approximately 300 mm (12 in) from the impact point. A guard, usually in the form of a wire mesh sleeve coaxial with the cylinder, is positioned so as to restrain the device after impact, and the front surface of the launcher is protected against rebound of the device by a pad of energy-absorbing material.

The signals from the accelerometer array are passed to a "standard" MIRA instrumentation trolley, where they are amplified, filtered and then recorded on a digital data-acquisition system. The velocity of the headform at impact is determined by integration of the longitudinal acceleration signal.

Development of the Test Rig

MIRA first constructed a free-flight headform rig of this type in 1984, and since that time we have produced a number of examples, both for our own use and for sale to member companies. During this time, the rigs have been used for a wide variety of testing, involving in some cases different impact devices to the standard 6.8 kg (15 lb) rigid impactor defined in SAE J984.

The experience which has been gained in carrying out these tests have led to several improvements in the design of the rig, and these have led to it becoming more consistent in its performance, more versatile and more convenient in use.

One of the more significant changes has been in the method of retaining the headform in the firing position. In its original form, the headform was attached to the breech plug by a powerful magnet. Although this was sufficient to prevent the headform from moving away from the firing position under the effects of gravity when conducting a downward-pointing impact, for example, it was felt that, in certain applications, a more positive form of location of the headform in its firing position would be beneficial. Thus, a locking mechanism was introduced, which may be seen in Figure 4. This consists of a rotating locking plate in the breech plug, incorporating radial projections which engage with cut-outs in a mating plate attached to the rear of the impact device. When in the locked position, the radial projections of the rotating plate engage with those of the stationary plate, preventing the headform from moving relative to the breech plug, and so preventing the possibility of accidental firing of the device. To prepare the rig for firing, the locking plate, is rotated through a small angle to align the projections with the cut-outs in the mating plate, allowing the two to separate. The locking plate is rotated by means of an electric motor on the outside of the breech-plug activating it via a short lever.

A second major change in the design has been in the arrangement of the seals. In its original form, the seals were incorporated into the piston, and not the cylinder. This arrangement was chosen in order to maintain the seal around the piston throughout the stroke, with the intention of making the firing velocity more consistent. However, experience has shown that the energy loss as a result of seal friction acting over the entire stroke of the device has a more detrimental effect on repeatability that the loss of sealing through the latter part of the stroke. The present launcher therefore has two seals which are located in grooves in the cylinder, either side of the ring of ports. In this form the drag induced by the seal on the piston acts over a distance of 45 mm (1.77 in) in the case of the front seal, and a negligible distance in the case of the rear. It is interesting to note that the life of the seals in both instances has been much greater than was at first anticipated; there has been no recorded instance of seal damage resulting from the headform striking a specimen in the vicinity of the seals, or as a secondary effect of indentation of the mating piston surface by the same cause.

Much of the early development work involved examining the motion of the headform after firing, using high speed cine film. In particular, it was necessary to ensure that the alignment of the headform was preserved during the interval between firing and initial contact with the impact point. This was required in order that the longitudinal acceleration signal could be used to calculate the impact velocity (as discussed below), and it was felt that some rotation might arise due to tension in the accelerometer cable, for example. In all cases, no rotation of the headform was noted, up to the point of impact.

Test Procedures

With a novel test device such as the MIRA Free-Flight Headform Rig, it became necessary to devise new forms of test procedure in order to take advantage of the benefits of the design whilst avoiding any inherent problems. Although it is possible to follow the general procedures laid down in the Test Specifications such as SAE J921, there are several practical considerations which need to be addressed in using this device.

The most important of these is the positioning of the headform and its launcher in relation to the impact point. There are three considerations here; the alignment of the launcher, the distance the launcher is placed from the impact point, and the angle at which it strikes the surface.

With regard to the alignment of the launcher, the details of impact point (whether the intersection of the locus of the headform centreline with the surface, or the point of initial contact) is laid down in the test specification. With a guided impactor, it is possible to move the headform by hand until it contacts the specimen, and to observe its contact with the impact point directly. However, with an unguided impactor such as this one, this is not possible and we must trace the path in a more indirect manner.

A simple gauge of the type shown in Figure 5 may be used for initial alignment of the device. This locates in the end of the cylinder. The pointer then traces the extended centreline of the launcher, and the circular template (representing a section through the hemispherical impactor) may be moved to a position which indicates the point of initial contact.

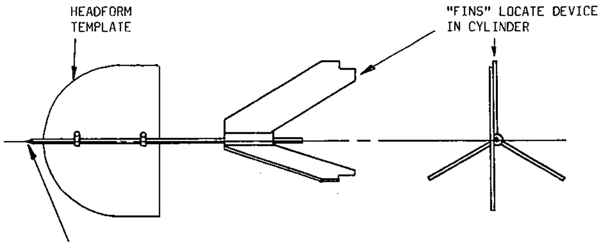


Figure 5. Diagram of Gauge

However, in the interval between leaving the cylinder and striking the specimen, the headform is subject to the effects of gravity, and either its path will be deviated slightly (in horizontal impacts) or else its velocity will be changed slightly (in vertical impacts). These changes are generally small. During a typical flight over a distance of 300 mm (12 inches), a headform launched horizontally at 24.1 km/h (15 mile/h) will fall 10 mm (0.39 in), and one fired vertically will change its velocity by 1.6 km/h (1 mile/h). These deviations are normally accommodated by aiming the launcher at a "referred" impact point which incorporates the necessary corrections.

Although it is clear from the above that the distance the launcher is placed from the impact point should be minimized in order to maintain accuracy of speed and aiming, it is also important that the distance is not made too small, or else the headform may rebound into the front face of the launcher. This might present a risk of damage to the headform or produce a secondary impact which might not be easily distinguished from the main impact in the acceleration signal.

It can be seen in the photographs of the headform and launcher (Figure 3) that these parts have been designed so far as possible to present smooth surfaces and to protect vulnerable items such as the accelerometer cable. In addition to this, the front face of the cylinder is fitted with a layer of energy-dissipating material to protect the headform on rebound. The main function of this is not to reduce the acceleration of the headform on striking the launcher, but to distribute the impact forces in a manner which will prevent indentation of the surface.

As far as the secondary impact signal is concerned, a typical flight distance of 300 mm (12 in) would result in a gap of 140 mm (5.5 in) between the rear of the headform and the front surface of the launcher at impact. Since the headform is unlikely to rebound at more than half if its impact velocity, for a 48.2 km/h (30 mile/h) impact there would be an interval of at least 20 ms between the primary and secondary deceleration pulses, which would enable them to be easily distinguished from one another when plotted out from the data acquisition system.

Finally, on the subject of the angle of the impact to the surface, there must obviously be a limiting value, beyond which the headform will no longer offer a true representation of the human head. It is difficult to place a definite value on this angle, however.

At the present time, all of the oblique impacts which have been conducted have been concerned with the linear acceleration of the headform, and experience suggests that the magnitude of this quantity tends to reduce sharply as the impact angle is increased beyond approximately 30 degrees to the normal. During development work, impacts at 45 degrees to the normal have been carried out with no apparently unrepresentative behaviour in the headform. It is intended that future work will involve testing to criteria which include angular acceleration of the head and in this case we hope to investigate further this aspect of the headform.

A typical acceleration trace obtained from an impact test on the headform is shown in Figure 6. This represents the longitudinal acceleration in a perpendicular impact, in which case the vertical and transverse accelerations would be monitored but should each present a flat trace. For an oblique impact, these would carry significant data and would be combined with the longitudinal acceleration to determine the magnitude of the acceleration vector when evaluating the headform acceleration.

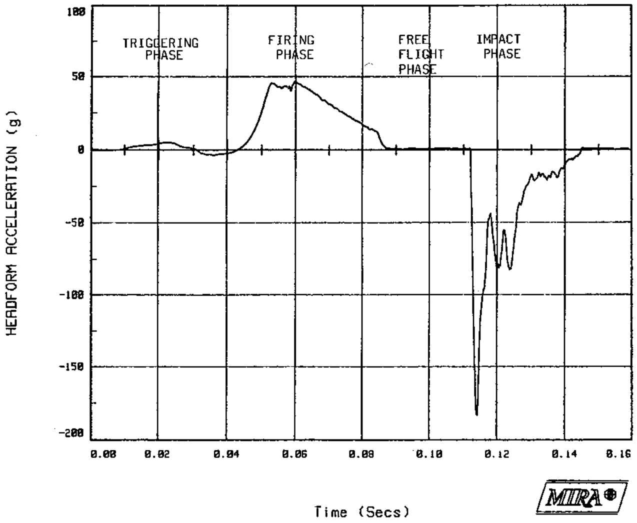


Figure 6. Trace

The curve shows three distinct phases: the initial firing pulse which occurs as the headform is accelerated in the launcher, the free-flight phase after the headform has left the launcher, and the impact pulse as the headform strikes the target. These may be followed by further secondary impacts of the headform, but these are easily distinguished as discussed above.

The velocity of the headform at impact may be determined by integration of the longitudinal acceleration with respect to time from the point of firing up to the impact point. This method is preferred to other, more direct means of measuring impact velocity, since the latter requires a separate stable platform for the velocity measuring equipment, and this is often difficult to arrange within a vehicle, alongside the launcher mountings. In addition to this, a direct measurement may not account for the small velocity change which occurs due to gravity (see above).

The measurement of velocity by integration of the accelerometer signal has proved to be accurate, provided certain precautions are taken in processing the signal, particularly taking account of zero drift in the accelerometer output.

It must be emphasized that this technique is only valid for the initial phases, when the longitudinal accelerometer remains aligned with the cylinder axis. During the impact phase, it is likely that the headform would rotate and that the alignment of its reference axes would change.

Pedestrian Headform Impacts

The most recent application of the device has been to carry out a series of pedestrian headform impacts on the bonnet of a large saloon car, using the test developed by BASt and proposed as a legislative standard for Europe. The test makes provision for simulating both adult head impact (using a 4.8 kg headform) and a child head impact (using a 2.5 kg headform) but only the adult head test was carried out in this case.

The headform employed was made to drawings supplied by BASt (the spherical headform) but was modified to enable it to be launched by the MIRA Free-Flight Headform Rig (by means of the piston). The total mass of the unit was 4.8 kg for the test, as in the BASt specification.

The Free-Flight Headform Rig proved an ideal device for the test, being capable of the 48.2 km/h (30 mile/h) impact velocity required in the specification and also the oblique configuration of the impacts. A major influence on this work was proximity of items such as engine components for example underneath the skin of the bonnet. Large deceleration peaks occurred when the deflected bonnet contacted the engine components. It is likely that, if this or a similar test specification is adopted as a European Standard, manufacturers will need to carry out extensive development work since they will need to test a variety of body/power train configurations.

Conclusion

Knowledge of the mechanisms of injury suffered by the head in automotive accidents is now well established. It is vitally important that we should apply this knowledge, and design all types of vehicle to incorporate the highest level of protection from such injuries, both to the occupants and also to pedestrians likely to be struck by the vehicle.

Both full-scale crash testing and component testing play an important role in the development of vehicles to incorporate such protection, but it is the economy of component testing which permits us to investigate the wide variety of conditions encountered in "real-world" accidents and to develop vehicles which offer protection under the full range of circumstances.

Existing test rigs tend to be designed around the test specifications adopted for legislative standards, but it was felt that they do not address the full range of conditions seen in accidents in this case. In addition, it was recognized that future test rigs should minimize the time taken in preparing for a test, in order to enable development work to be conducted as cheaply as possible.

It is with these requirements in mind that the MIRA Free-Flight Headform Rig was devised. It is hoped that the existence of such rigs will encourage motor vehicle manufacturers to undertake development work not just to the minimum statutory standards, but in all of the zones likely to be contacted by the head in accidents, both by occupants in interior impacts and also by pedestrians in exterior impacts. At the same time, it is also hoped that the manufacturers of other types of vehicle such as aircraft, railway rolling-stock etc will also wish to develop their own vehicles to provide similar protection.

References

1. A Free-Flight Headform Impact Device for Evaluating the Energy-Absorption Characteristics of Vehicle Interiors. Dale, K.J. and Clemo, K.C. (1985), Tenth International Technical Conference on Experimental Safety Vehicle, Oxford, England, July 1985.
2. Bodyforms for Use in Motor Vehicle Passenger Compartment Impact Development. SAE J984.

S5-W-29

Experience of Using EUROSID-1 in Car Side Impacts

M.C. Beusenberg, E.G. Janssen
TNO Crash-Safety Research Centre
R. Lowne, A. Roberts
Transport and Road Research Laboratory
K.-P. Glaeser
Bundesanstalt für Strassenwesen
D. Cesari
INRETS

Abstract

A database on EUROSID-1 performances in 31 full scale side impact tests is set up. Specific attention is given to the dummy results in relation to protection performance criteria. Mainly tests according to the proposed European side impact regulation with passenger cars are studied. Other tests included in the database are tests according to the American procedure, reconstructions of tests performed with cadavers ("FAT-tests") and several tests according to the European procedure with special vehicles. Analysis of the database, considered representative for almost 20% of European cars on the current market, show that EUROSID-1 is sensitive to car design. Differences in thorax and abdomen response of this dummy are obvious between 2/3-door vehicles and 4/5-door vehicles. Differences in dummy responses on the basis of vehicle test weight are less obvious, however it appears that dummy responses decrease with increasing vehicle test weight. The design of EUROSID-1 corresponds with injury assessment needs in side impact car testing. As far as sensitivity is concerned, EUROSID-1 is considered an appropriate anthropomorphic test device for approval and research purposes to improve side occupant protection.

Introduction

An anthropomorphic test device has to comply with several guidelines before it can be used in a test environment. For side impact dummies, quantitative guidelines have been developed (and some are still under consideration) for biofidelity, repeatability, reproducibility, measurement capability and calibration. Sensitivity, handling and durability are more qualitative characteristics of crash dummies, but also highly determine whether a dummy is suitable for car safety evaluation [1].

EUROSID-1, the production version of the European Side Impact Dummy and successor of the production prototype EUROSID, was released in April 1990. Since then, about 18 months have passed and hundreds of tests with this dummy have been conducted. The biofidelity and in some cases repeatability and reproducibility of this dummy, have been assessed in several research programmes comprising numerous sled, drop and impactor tests [2,3,4]. During the past 12 months or so, also quite a large number of full scale tests (FST's) with EUROSID-1 have been conducted. Objectives of these FST's vary: determining the status of and improving current passenger cars to proposed regulations, comparison of side impact dummies between each other and comparison of EUROSID-1 with cadaver responses.

The objective of this paper is to show EUROSID-1 responses in a number of full scale side impact tests with passenger cars. From these responses an impression is given of what can be expected from EUROSID-1 under these test conditions. The results are further studied as to what can be expected from current and proposed side impact regulations.

Results of FST's are gathered in a database set up by the TNO Crash-Safety Research Centre. Dummy responses collected merely concern performance criteria defined in side impact regulations. Discussion is held concerning sensitivity of EUROSID-1 during the FST's, performance of current car designs and possible effects resulting from side impact regulation.

EUROSID-1 Measurement Capability

The European Side Impact Dummy EUROSID-1 is designed for the evaluation of vehicle occupant protection under lateral impact. The dummy represents a 50th percentile male subject, weights 72 kg and has no lower arms. The specifications for this dummy have been developed by TRRL (UK), INRETS (F), APR (F), BASt (G) and TNO (NL) in co-operation with the EEVC Working Group on the Development of a Side Impact Dummy. EUROSID-1 is produced by Ogle Design Limited (UK) and the TNO Crash-Safety Research Centre (NL).

Figure 1 illustrates the position of the instrumentation for EUROSID-1. Measurement capabilities are available for the head (triaxial acceleration at centre of gravity), thorax (upper spine triaxial acceleration, lower spine lateral acceleration, lateral rib acceleration and lateral rib displacement for each of the three ribs), abdomen (three forces) and pelvis (triaxial pelvis acceleration and lateral pubic symphysis force). With this instrumentation the EUROSID-1 comprises 20 channels [5].

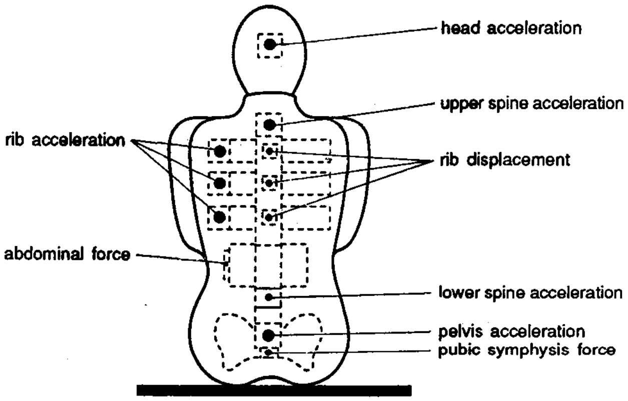


Figure 1. EUROSID-1 Instrumentation for Left Hand Side Impacts (Convertible to Right Hand Side Impact)

Side Impact Procedures

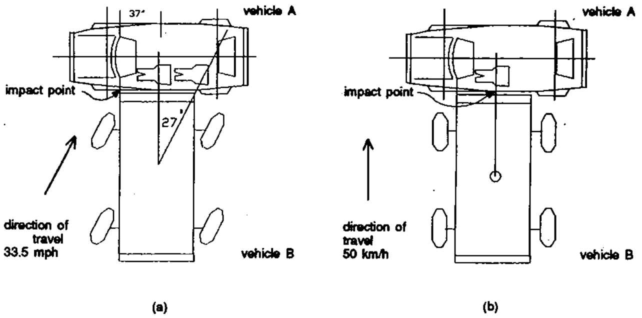
Legislative bodies in the United States of America and Europe are very active in preparing safety regulations for vehicle occupant protection in side impact. Regulations, although still under consideration, are very well elaborated. In the USA, the National Highway Traffic Safety Administration (NHTSA) is responsible for preparing a safety standard for occupant protection in side impact, released as Federal Motor Vehicle Safety Standard 214 "Side Impact Protection" (referred to as FMVSS 214) [6]. In Europe, the European Experimental Vehicles Committee (EEVC) has proposed a side impact procedure to the European Community (EC). This procedure was further elaborated by ECE/GRSP (Economic Commission for Europe/Working Party on the Construction of Vehicles) (referred to as EEVC-procedure) [7].

The database set up, comprises FST's according to both the proposed European and the American procedure. Furthermore tests are included in the database being reconstructions of cadaver tests performed at the University of Heidelberg under commission of the Forschungsvereinigung Automobiltechnik e.V. (FAT) [8]. Below a short description is given only of the EEVC-procedure and FMVSS 214 because results and discussions presented in this paper will concentrate on tests performed according to these two procedures.

FMVSS-Test Set-Up

The American procedure FMVSS 214 describes a side impact on a passenger car with a movable deformable barrier (MDB). The MDB, weighing 3000 pounds (ca. 1360 kg), impacts the stationary vehicle laterally at a velocity of 33.5 mph (53.9 km/h). The wheels of the barrier are positioned at an angle of 27 degrees (this procedure is also referred to as "crabbed"). The barrier front is constructed of aluminum honeycomb, representing a deformable vehicle front including its bumper. FMVSS 214 specifies the US.SID as the dummy to be used to assess dynamic performance. Recently, the Working Group on Anthropomorphic Test Devices of the International Organization for Standardization (ISO/TC22/SC12/WG5) considered BIOSID and EUROSID-1 acceptable dummies to be specified in the ISO full scale side impact test procedure [9]. This has also led to rulemaking activities at NHTSA for these two dummies to be included in FMVSS 214.

Figure 2a shows the principle of the FMVSS 214 test set-up. Dummy performance criteria specified in this regulation are given in Table 1.



(a) (b)

Figure 2. Principles of the Test Set-Up for FMVSS 214 (a) and EEVC-Procedure (b)

EEVC-Test Set-Up

The European Side Impact Procedure also describes a passenger car to be laterally impacted by a MDB. The wheels of the "European barrier" are, however, not positioned at an angle. Impact velocity should be 50 km/h. The barrier is constructed of a trolley equipped with a deformable foam front representing the crushable zone of an average European passenger car including its bumper. Total mass of the barrier is 950 kg. The European procedure specifies EUROSID-1 as the dummy to be used.

Figure 2b shows the principle of the EEVC-procedure test set-up. Dummy performance criteria specified in this regulation are given in Table 1.

Table 1. Dummy Performance Criteria for FMVSS 214 and EEVC-Procedure

Dummy Body Part	Regulation/Dummy FMVSS 214/US.SID		EEVC-proc./EUROSID-1	
Head			HPC	≤ 1000 (s)[1]
Thorax	TTI	≤ 90 (G)[2] ≤ 85 (G)[2]	V*C D	≤ 1.0 (m/s)[3] ≤ 42 (mm)[4]
Abdomen			F_{tot}	≤ 2.5 (kN)[5]
Pelvis	$a_{lat,max}$	≤ 130 (G)[6]	F_{ps}	≤ 10 (kN)[7]

[1]: HPC = Head Protection Criterion;
[2]: TTI = Thoracic Trauma Index, 90 G applies to 2-door vehicles, 85 G applies to 4-door vehicles;
[3]: V*C = Viscous Criterion, applies to all 3 ribs of EUROSID-1;
[4]: D = lateral rib Displacement, applies to all 3 ribs of EUROSID-1;
[5]: F_{tot} = peak value of the sum of 3 abdominal forces of EUROSID-1;
[6]: $a_{lat,max}$ = peak lateral acceleration of the pelvis;
[7]: F_{ps} = peak pubic symphysis force.

Dynamic Performance Criteria

The dynamic performance criteria for the dummy given in the European and American side impact regulation differ. FMVSS 214 specifies only acceleration requirements for the dummy's thorax and pelvis. The EEVC-procedure specifies various requirements for the head, thorax, abdomen and pelvis. Other performance criteria than those assessed by the dummy, such as door opening after the test, are not further discussed here. Table 1 provides an overview of dummy performance criteria for FMVSS 214 and the EEVC-procedure.

The Database

The database contains results of 31 FST's with EUROSID-1, conducted from January 1991 through August 1991. The data are provided by TRRL (UK), BASt (G), INRETS (F) and TNO (NL). All tests included are MDB-type tests on passenger cars. In all tests the dummy (driver or passenger position) was seated at the struck side. Table 2 provides an overview of the most important characteristics of the database discussed in this paper.

Specific attention will be given in this paper to the tests according to the EEVC-procedure and to the tests according to FMVSS 214 (bold-faced italics in Table 2). The data are further analyzed for differences between different vehicle weight classes (note: test weight is used here to divide the data) and between 2/3-door and 4/5-door vehicles. Also differences between EUROSID-1 in driver and passenger position are studied.

Table 2. Characteristics of the Database on EUROSID-1 in Full Scale MDB Tests

- All tests were conducted with EUROSID-1
- Total number of tests: 31
  - No. EEVC tests: 26
    - No. EEVC tests with European passenger cars: ***22***
      - No. dummies in driver position: ***22***
      - No. dummies in passenger position: ***12***
    - No. EEVC tests with "special" cars: 4
  - No. FMVSS tests: ***3***
      - No. dummies in driver position: ***3***
      - No. dummies in passenger position: ***3***
  - No. "FAT-tests" 2
- All dummies were seated on struck side of the vehicle.
- Of the 22 EEVC tests with European passenger cars, 9 were right-hand-side and 13 left-hand-side impacts.
- Of the 22 EEVC tests with European passenger cars 7 tests were conducted on vehicles having a test weight below or equal to 1200 kg, 7 tests on vehicles having a test weight of more than 1200 kg but not more than 1450 kg and 8 tests on vehicles having a test weight above 1450 kg.
- Of the 22 EEVC tests with European passenger cars 5 vehicles had 2 or 3 doors and 17 vehicles had 4 or 5 doors.

Results

Detailed results are presented in the Annexes at the end of this paper. The Annexes contain the dummy part, the parameter measured or calculated from measurements, the minimum, maximum and average value of the parameter, the number of tests (No.T) from which the average value is calculated and the number of tests in which a specific parameter fails the criterion (No.F). For all parameters presented the appropriate filter classes are applied according to [6] and [7].

Figure 3 shows the principle of the graphical presentation of the test results. Maximum, minimum and average dummy responses are expressed as percentage of the performance criteria. If a dummy response exceeds 100% it fails the requirement. Absolute values of the response criteria are given in Table 1.

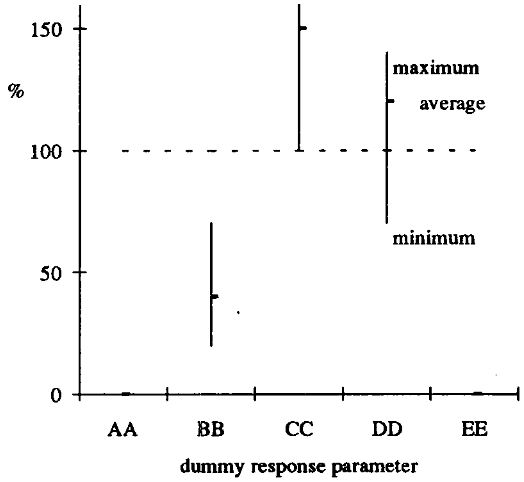


Figure 3. Example: Dummy Response as Percentage of Performance Requirement

EEVC Tests: European Passenger Cars (22 tests)

Figures 4 and 5 show EUROSID-1 responses in tests conducted according to the EEVC-procedure with European passenger cars for driver (22 tests) and passenger (12 tests) position respectively. Presented are Head Protection Criterion (HPC), Viscous Criterion for all three ribs (VC1, VC2, VC3), lateral rib displacement for all three ribs (D1, D2, D3), total abdominal force (F_a) and pelvis pubic symphysis force (F_{ps}). Tables 3 and 4 give the absolute values of the data shown in Figures 4 and 5 respectively. Annex 1 contains detailed data on this set of tests.

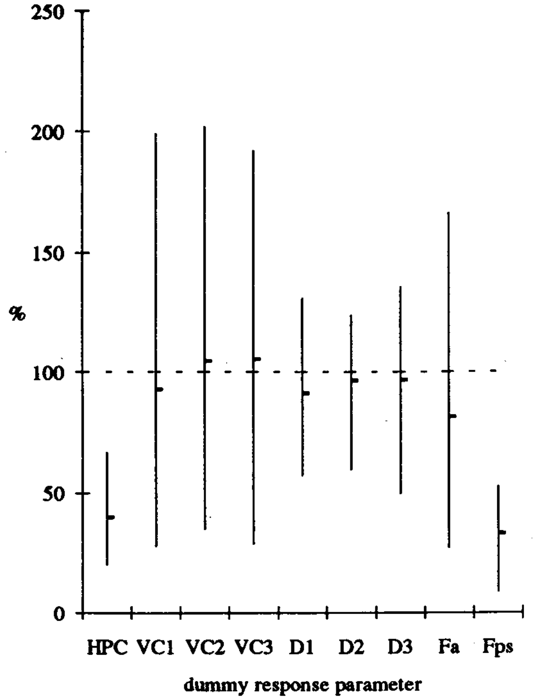


Figure 4. Results of Tests According to EEVC-Procedure: European Passenger Cars, Driver Position

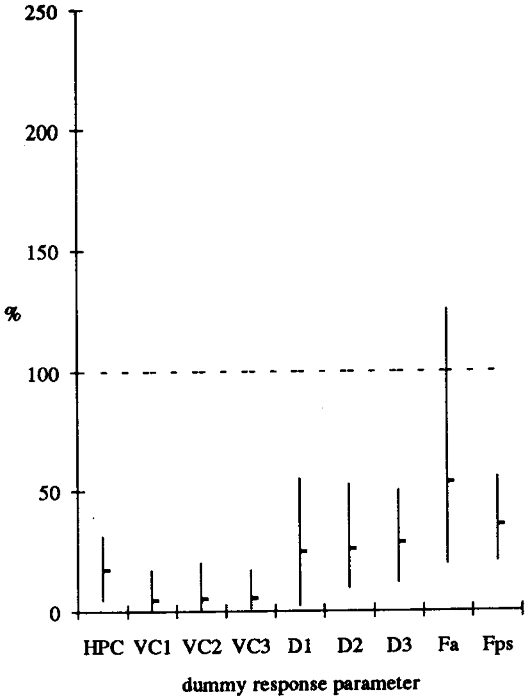


Figure 5. Results of Tests According to EEVC-Procedure: European Passenger Cars, Passenger Position

Table 3. Range and Average of EUROSID-1 Responses in EEVC Tests with European Passenger Cars, Driver Position

parameter	range	average
HPC	202 - 664	398
VC1	0.28 - 1.99	0.93
VC2	0.35 - 2.02	1.05
VC3	0.29 - 1.92	1.05
D1	24 - 55	38
D2	25 - 52	41
D3	21 - 57	41
F_a	0.7 - 4.2	2.0
F_{ps}	0.9 - 5.3	3.3

Table 4. Range and Average of EUROSID-1 Responses in EEVC Tests with European Passenger Cars, Passenger Position

parameter	range	average
HPC	48 - 311	170
VC1	0.00 - 0.17	0.04
VC2	0.00 - 0.20	0.05
VC3	0.01 - 0.17	0.05
D1	1 - 23	10
D2	4 - 22	11
D3	5 - 21	12
F_a	0.5 - 3.1	1.3
F_{ps}	2.1 - 5.6	3.6

For EUROSID-1 in driver position, values of dummy responses are observed both well above and below the performance criteria, except for HPC and F_{ps}: head and pelvis responses stay well below their requirement. VC values range from ca. 30% to ca. 200% of the performance criterion (1.0 m/s) for all three ribs. Rib displacements (D) range from ca. 50% to ca. 130% of the performance criterion (42 mm), also for all three ribs. Abdominal force (F_a) ranges from ca. 30% to ca. 160% of the performance criterion (2.5 kN). Average results for thorax (VC and D) and abdomen (F_a) approximate the criteria. Maximum values for HPC and F_{ps} lie more than 30% below the performance criteria.

The EEVC-procedure does not require a EUROSID-1 in passenger position for car approval. Nevertheless in 12 tests a passenger dummy is applied. In these 12 tests, all responses of EUROSID-1 in passenger position stay well below the criteria, except for the abdominal force which exceeds the criterion (2.5 kN) in 1 test. For this reason, dummy responses for EUROSID-1 in passenger position in tests according to the EEVC-procedure will not further be analyzed.

FMVSS Tests: American Passenger Cars (3 tests)

Figures 6 and 7 show EUROSID-1 responses in tests conducted according to FMVSS 214 with American passenger cars for driver (3 tests) and passenger (3 tests) position respectively. Presented are Thoracic Trauma Index (TTI) for all three ribs and peak lateral pelvis acceleration ($a_{lat,max}$) as percentage of the performance criteria. Tables 5 and 6 give the absolute values of the data shown in Figures 6 and 7 respectively.

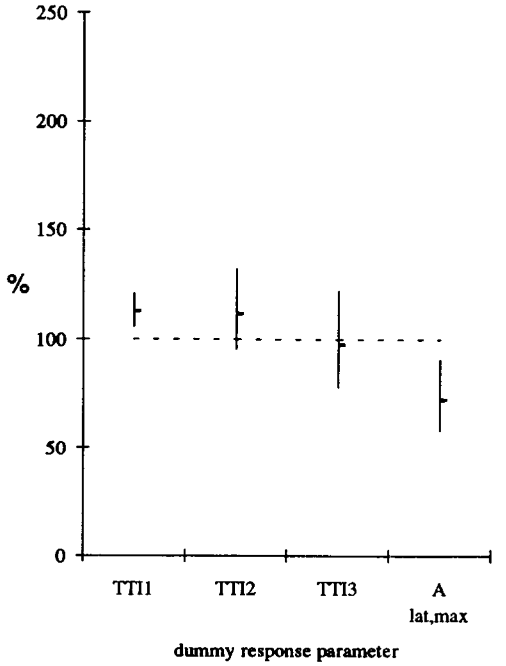


Figure 6. Results of Tests According to FMVSS 214: American Passenger Cars, Driver Position

Table 5. Range and Average of EUROSID-1 Responses in FMVSS Tests with American Passenger Cars, Driver Position

parameter	range	average
TTI1	95 - 109	102
TTI2	86 - 119	101
TTI3	71 - 110	88
$a_{lat,max}$	75 - 118	94

Results of the tests according to FMVSS 214 presented here form part of a research programme of the EEVC Working Group on the Development of a Side Impact Dummy. Objective of this study is to compare US.SID and EUROSID-1 responses in the same tests. Sled tests as well as FST's are or will be performed on EUROSID-1 up till the end of 1991. The results of the FST's according to FMVSS 214 will only be discussed to a limited extend, in order not to anticipate on results of the complete research programme yet to come. Furthermore the number of tests according to FMVSS 214 included in the database is low. Results shown in Figures 6 and 7 and Tables 5 and 6 thus are only limited representative of what can be expected of EUROSID-1 in tests according to FMVSS 214.

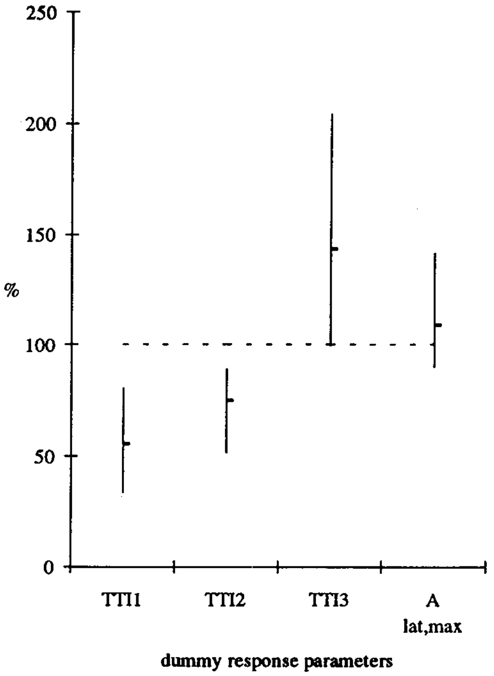


Figure 7. Results of Tests According to FMVSS 214: American Passenger Cars, Passenger Position

Table 6. Range and Average of EUROSID-1 Responses in FMVSS Tests with American Passenger Cars, Passenger Position

parameter	range	average
TTI1	30 - 73	50
TTI2	46 - 80	67
TTI3	90 - 184	129
$a_{lat,max}$	117 - 184	141

Annex 2 contains details of the dummy responses for the 3 tests with American passenger cars according to FMVSS 214. Average results for EUROSID-1 in driver position lie at or just above (ca. 10%) the performance criterion for TTI (85G) and ca. 25% below the criterion for pelvis acceleration. Average results for EUROSID-1 in passenger position lie well below (more than 25%) the performance criterion for upper and middle rib TTI but exceeds the performance criterion for lower rib TTI by more than 40%. The average result for EUROSID-1 in passenger position lie close to the performance criterion for peak lateral pelvis acceleration, however this average lies well above that found for EUROSID-1 in driver position.

EEVC Tests: Weight Classes (7-7-8 tests)

Responses of EUROSID-1 in tests according to the EEVC-procedure are further analyzed for differences in responses on the basis of differences in vehicle test weight (M). This test weight includes the dummy c.q. dummies, instrumentation, vehicle mounted camera's and additional weights. For this the set of 22 tests is divided into 3 sections/weight classes:

- vehicles with M ≤ 1200 kg (7 tests),
- vehicles with 1200 < M ≤ 1450 kg (7 tests), and
- vehicles with M > 1450 kg (8 tests).

Figures 8, 9 and 10 show the dummy responses as percentage of performance criteria for the three sections mentioned above. Tables 7, 8 and 9 give the absolute values of the data presented in Figures 8, 9 and 10 respectively. Annex 3 contains detailed data of the sections mentioned above.

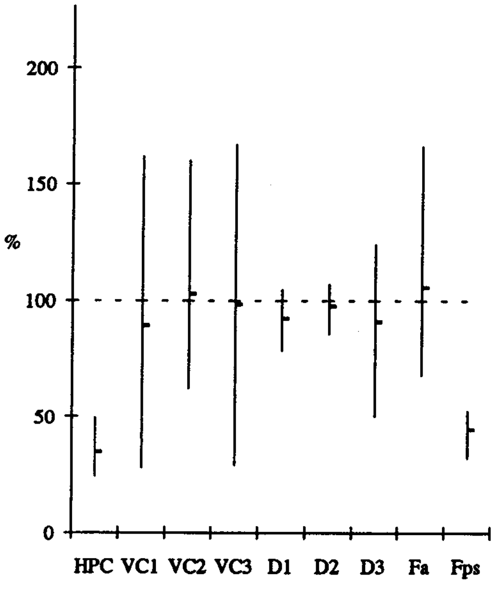


Figure 8. Results of Tests According to EEVC-Procedure: M ≤ 1200 kg, Driver Position

Table 7. Range and Average of EUROSID-1 Responses in EEVC Tests: M ≤ 1200 kg, Driver Position

parameter	range	average
HPC	243 - 496	348
VC1	0.28 - 1.62	0.89
VC2	0.62 - 1.60	1.03
VC3	0.29 - 1.67	0.98
D1	33 - 44	39
D2	36 - 45	41
D3	21 - 52	38
F_a	1.7 - 4.2	2.6
F_{ps}	3.2 - 5.3	4.4

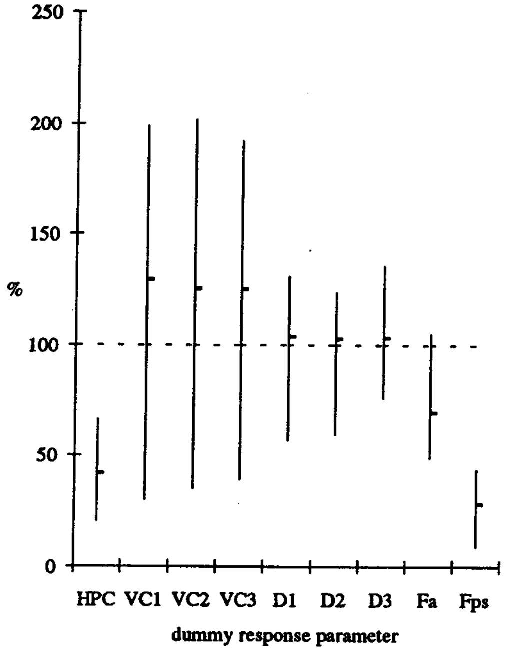


Figure 9. Results of Tests According to EEVC-Procedure 1200 < M ≤ 1450 kg, Driver Position

Table 8. Range and Average of EUROSID-1 Responses in EEVC Tests: 1200 < M ≤ 1450 kg, Driver Position

parameter	range	average
HPC	202 - 664	418
VC1	0.30 - 1.99	1.29
VC2	0.35 - 2.02	1.25
VC3	0.39 - 1.92	1.25
D1	24 - 55	44
D2	25 - 52	43
D3	32 - 57	43
F_a	1.2 - 2.6	1.7
F_{ps}	0.9 - 4.4	2.8

Average abdominal force is highest for the lowest vehicle test weight class. F_a is similar between the higher two weight classes. Values found for HPC and F_{ps} are all well below performance criteria (see also Figure 4) and will not be further discussed.

Average VC values for tests with vehicles having a test weight of 1200 kg or less, approximate the performance criterion for all three ribs of EUROSID-1. For vehicles with a test weight between 1200 and 1450 kg average VC values exceed the criterion by ca. 25%, again for all three ribs. Tests with vehicles having a test weight above 1450 kg show an average VC ca. 10% to 40% below the criterion. The same trend can be seen for rib displacements: average rib displacements are largest for vehicles weighing 1200 to 1450 kg and are slightly above the performance criterion; rib displacements for vehicles weighing more than 1450 kg show the lowest average values (ca. 5% to 20% below criterion) while vehicles with a weight below 1200 kg show average rib displacements slightly below the criterion.

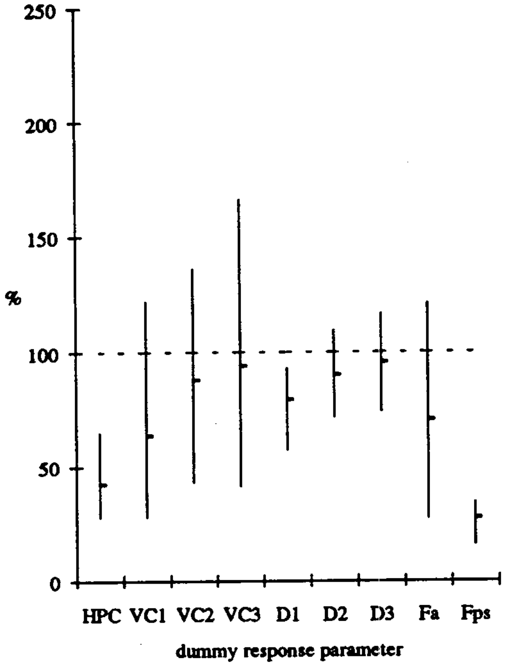


Figure 10. Results of Tests According to EEVC-Procedure: M > 1450 kg, Driver Position

Table 9. Range and Average of EUROSID-1 Responses in EEVC Tests: M > 1450 kg, Driver Position

parameter	range	average
HPC	278 - 648	422
VC1	0.28 - 1.22	0.64
VC2	0.43 - 1.36	0.88
VC3	0.41 - 1.66	0.94
D1	24 - 39	33
D2	30 - 46	38
D3	31 - 49	40
F_a	0.7 - 3.0	1.8
F_{ps}	1.6 - 3.4	2.7

EEVC Tests: Number-of-Doors Classes (5-17 tests)

From earlier experience in side impact testing, it is known that the position of the B-pillar highly affects dummy responses in FST's. B-pillar position and thus the number of doors is considered an important parameter in car safety design. For further analysis of the dummy responses in the database, the total set of 22 tests according to the EEVC-procedure is divided in 2 sections:

- vehicles with 2 or 3 doors (5 tests), and
- vehicles with 4 or 5 doors (17 tests).

Figures 11 and 12 show EUROSID-1 responses as percentage of performance criteria for the two sections mentioned above. Tables 10 and 11 give the absolute values of the data presented in Figures 11 and 12 respectively. Detailed data are contained in Annex 4.

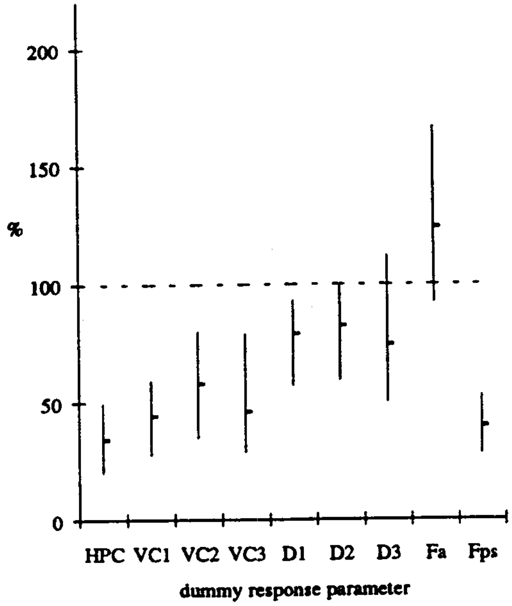


Figure 11. Results of Tests According to EEVC-Procedure: 2/3-Doors, Driver Position

Table 10. Range and Average of EUROSID-1 Responses in EEVC Tests: 2/3-Doors, Driver Position

parameter	range	average
HPC	202 - 496	342
VC1	0.28 - 0.59	0.44
VC2	0.35 - 0.80	0.58
VC3	0.29 - 0.79	0.46
D1	24 - 39	33
D2	25 - 42	35
D3	21 - 47	31
F_a	2.3 - 4.2	3.1
F_{ps}	2.8 - 5.3	4.0

Average as well as maximum VC values are below the performance criterion for 2/3-door vehicles for all three ribs of EUROSID-1, while average VC values exceed the performance criterion for 4/5-door vehicles for all three ribs. Average rib displacements are below the performance criterion for all three ribs of EUROSID-1 for 2/3-door vehicles, while average rib displacements approximate the performance criterion for 4/5-door vehicles. In general: 2/3-door vehicles show lower EUROSID-1 thorax responses in tests according to the EEVC-procedure compared to 4/5-door vehicles.

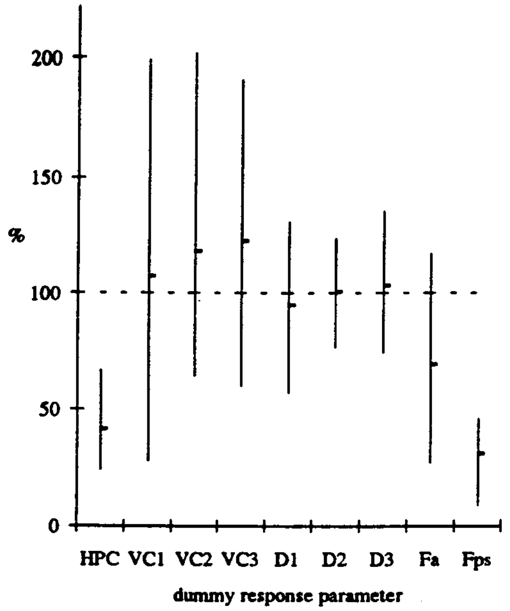


Figure 12. Results of Tests According to EEVC-Procedure: 4/5-Doors, Driver Position

Table 11. Range and Average of EUROSID-1 Responses in EEVC Tests: 4/5-Doors, Driver Position

parameter	range	average
HPC	243 - 664	414
VC1	0.28 - 1.99	1.07
VC2	0.64 - 2.02	1.18
VC3	0.60 - 1.92	1.23
D1	24 - 55	40
D2	32 - 52	42
D3	31 - 57	43
F_a	0.7 - 2.9	1.7
F_{ps}	0.9 - 4.6	3.1

The average abdominal force for 2/3-door vehicles exceeds the performance criterion by ca. 25%. Average abdominal force for 4/5-door vehicles is well below the criterion (ca. 30%). Average pubic symphysis force is higher for 2/3-door vehicles compared to 4/5-door vehicles but for both types of vehicles the pubic force stays well below the performance criterion. In general: 2/3-door vehicles show higher EUROSID-1 abdomen and pelvis responses in tests according to the EEVC-procedure compared to 4/5-door vehicles.

Discussion and Conclusions

The general objective of this study was to present responses of the EUROSID-1 found in a number of full scale side impact tests with passenger cars in order to show what can be expected of this dummy as a research and approval tool. Furthermore the data are used to show possible effects of side impact regulation on current car design. For this a database is set-up comprising 31 tests according to three procedures. The database includes tests conducted at four laboratories during January 1991 through August 1991. Presented in detail are results obtained with EUROSID-1 in 22 tests according to the EEVC-procedure and in 3 tests according to FMVSS 214.

Responses of EUROSID-1, in tests according to the EEVC-procedure as well as according to FMVSS 214, show a reasonable spread around the performance criteria. This implies that EUROSID-1 is sensitive to car design. Comparison of dummy responses in tests according to the EEVC-procedure for different vehicle weights did not show great differences, although it appears that for increasing vehicle test weight dummy responses decrease. Differences between 2/3-door and 4/5-door cars are more obvious. Thorax responses of EUROSID-1 in driver position are considerably lower for 2/3-door cars compared to 4/5-door cars. On the other hand abdomen and to a lesser extend pelvis responses are higher for 2/3-door cars compared to 4/5-door cars. Usually the B-pillar is positioned further backwards relative to the dummy for 2/3-door cars compared to 4/5-door cars. Furthermore the B-pillar construction will be stiffer in 2/3-door cars compared to 4/5-door cars. These two features may account for a large part of the differences observed in dummy responses between 2/3-door vehicles and 4/5-door vehicles.

Differences in the test set-ups used in the EEVC-procedure and FMVSS 214 are indicated by different performances of the dummy in passenger position relative to the performance criteria. Barrier stiffness and impact position in FMVSS 214 are such that (rear) passengers on the struck side will be more involved in the impact than compared to the EEVC-procedure and higher dummy responses are likely.

In no test according to the EEVC-procedure head responses of the EUROSID-1 exceeds the performance criterion. This affirms the general opinion that during the proposed full scale side impact test no head contact with the car interior occurs. Within EEVC consideration is given to a separate head to car interior impact tests as a possible addition to car safety evaluation. Accident studies have shown that head contact may occur in side collisions. The initiative of EEVC of preparing an additional procedure for head impact for side impact occupant protection is supported by the results presented in this paper.

Analysis of thorax responses of EUROSID-1 in tests according to the EEVC-procedure (driver position) show that in 14 tests VC exceeded 1.0 m/s. In 12 of these 14 cases this concerns 2 or 3 ribs. Thus in a majority of the tests according to the EEVC-procedure in which the VC criterion was exceeded, more than 1 rib showed a VC exceeding 1.0 m/s. This implies that three thoracic ribs suffice to assess the risk of injury to this body part. The design of EUROSID-1's thorax thus is considered satisfactory.

Further analysis of abdominal force responses of EUROSID-1 in tests according to the EEVC-procedure in driver position, show that maximum force readings are largest for the rear transducer in ca. 65% of the tests and for the middle transducer in ca. 35% of the tests. In no test the front transducer gave the highest response for the driver. Reason for this is the non-lateral intrusion of the door. Highest car deformation is usually seen at or very close to the B-pillar which lies somewhat to the backside of the dummy.

Pubic symphysis loads all lie well below the performance criterion of 10 kN. This tolerance level of 10 kN was determined by reconstruction of impactor tests on cadavers with the production prototype EUROSID [10]. The production prototype EUROSID incorporated an aluminum pelvis construction. EUROSID-1, however, incorporates plastic iliac wings and is less stiff than the production prototype EUROSID. Thus lower pubic symphysis loads are likely for EUROSID-1 compared to the production prototype in the same tests. Nevertheless the low pubic symphysis loads observed in the tests affirm the fact that in side collisions very few serious pelvic injuries occur.

Data included in the database merely concern tests with European passenger cars according to a recently developed procedure. Research laboratories and car manufacturers are concerned op to now with the performance of current car designs. No tests are included in the database with modified/improved vehicles and thus the results of this study represent part of the current status of European passenger cars as far as side impact is concerned. The database presented in this paper represents almost 20% of the cars sold in Europe in 1990. In 4 tests according to the EEVC-procedure dummy responses completely fulfilled the performance criteria. Also in 4 EEVC tests more than 5 (out of 9) criteria were not met. In the remaining 14 EEVC tests, 1 to 5 dummy responses failed the requirements. This indicates that for a substantial part of the car types included in the database, modifications to current car design are likely to result in side impact approval for these vehicles. Examples of the beneficial effect of vehicle modifications on the basis of EUROSID-1 responses are in progress and some of them are already presented [11].

Up to now, the database presented in this paper contains 31 MDB-type side impact tests with EUROSID-1. The intention is to extend this database in the future. Car-to-car impacts, tests with other side impact dummies, more vehicle types and possibly cadaver tests will be included in the database. Furthermore additional database parameters concerning car design and barrier specifications will be included. This paper has shown some features of such a database to help improving vehicle side impact crashworthiness.

Acknowledgement

The database was set up with the help of several car manufacturers, not further mentioned by name here, which we thank for the use of the data. Thanks also to Mr. D. Twisk for his effort in setting up the database and helping out with graphical presentation of the results.

References

[1] Janssen, E.G. (1991), "Mechanical Human Body Simulators." In "Literature to the Injury Biomechanics Course", Eindhoven University of Technology, May 1991; TNO Crash-Safety Research Centre, Delft; the Netherlands.

[2] Roberts, A.K., M.C. Beusenberg, D. Cesari, K.-P. Glaeser (1991), "The Biofidelity of the Production Version of the European Side Impact Dummy EUROSID-1." Presented to 13th Int. Techn. Conference on Experimental Safety Vehicles. November 4-7, Paris; 1991.

[3] Bendjellal, F., "CCMC Evaluation Programme of Side Impact Dummies EUROSID-1 and BIOSID According to ISO Biofidelity Requirements." ISO/TC22/SC12/WG5 document 295.

[4] JAMA/JARI (1990), "Report on Evaluation of EUROSID-1 and BIOSID Performance." ISO/TC22/SC12/WG5 document 297.

[5] TNO Road-Vehicles Research Institute (1990), EUROSID-1 User's Manual, Delft, the Netherlands; November 1990.

[6] U.S. Department of Transportation, National Highway Traffic Safety Administration (1990), Federal Motor Vehicle Safety Standard 214 "Side Impact Protection," Federal Register, Vol. 55, No. 210; October 30, 1990.

[7] Economic Commission for Europe, Experts on Passive Safety (GRSP) (1991), "Proposal for Draft Regulation: Uniform Provisions Concerning the Approval of Vehicles with Regard to the Protection of the Occupants in the Event of a Lateral Collision." Document TRANS/SC1/WP29/GRSP/R.48, including revisions and amendments Geneva; 1991.

[8] Kallieris, D., R. Mattern, W. Härdle (1986), "Belastbarkeitsgrenzen und Verletzungsmechanik des angegurteten Pkw-Insassen beim Seitenaufprall; Phase II Ansätze für Verletzungsprädiktionen" FAT Schriftenreihe Nr. 60; FAT e.V.; Frankfurt, Germany; 1986.

[9] Resolution 1 of 24th Meeting of ISO/TC22/SC12/WG5, -untitled-; ISO/TC22/SC12/WG5 document 298.

[10] Cesari, D., M. Ramet, "Pelvic Tolerance and Protection Criteria in Side Impact." SAE 821159, Proceedings of 26th Stapp Car Crash Conference; 1982.

[11] Coo, P.J.A. de, E.G. Janssen, A.P. Goudswaard, J. Wismans, M. Rashidy, "Simulation Model for Vehicle Performance Improvement in Lateral Collisions." Presented to 13th Int. Techn. Conference on Experimental Safety Vehicles. November 4-7, Paris; 1991.

ANNEX 1. EUROSID-1 Responses in Tests According to the EEVC-Procedure with European Passenger Cars

Driver position, 22 tests

HEAD	parameter	Min	Max	Average	No.T	No. F
	HPC	202	664	398	22	0
	peak head res acc.	38	154	76	22	
	peak head res acc 3ms	37	102	62	18	
THORAX	parameter	Min	Max	Average	No.T	No.F
	peak lateral T1 acc.	54	157	89	22	
	TTI upper rib	70	185	123	22	
	TTI middle rib	73	188	129	22	
	TTI lower rib	82	166	119	21	
	V*C upper rib	0.28	1.99	0.93	22	10
	V*C middle rib	0.35	2.02	1.05	22	13
	V*C lower rib	0.29	1.92	1.05	22	11
	peak upper rib displ.	24	55	38	22	8
	peak middle rib displ.	25	52	41	22	9
	peak lower rib displ.	21	57	41	22	10
	peak upper rib acc.	77	383	189	22	
	peak middle rib acc.	72	343	214	22	
	peak lower rib acc.	92	307	186	21	
	peak lateral T12 acc.	70	157	97	22	
ABDOMEN	parameter	Min	Max	Average	No.T	No.F
	peak front force	0.2	1.3	0.4	22	
	peak middle force	0.2	2.1	0.8	22	
	peak rear force	0.5	2.0	1.0	22	
	peak total force	0.7	4.2	2.0	22	5
PELVIS	parameter	Min	Max	Average	No.T	No.F
	peak lateral pelis acc.	53	112	81	22	
	peak res. pelvis acc.	55	119	86	22	
	peak pubic symph. force	0.9	5.3	3.3	22	0

Passenger position, 12 tests.

HEAD	parameter	Min	Max	Average	No.T	No. F
	HPC	48.13	311.48	170.22	12	0
	peak head res acc.	24.76	105.71	66.17	12	
	peak head res acc 3ms	21.44	78.33	53.51	12	
THORAX	parameter	Min	Max	Average	No.T	No.F
	peak lateral T1 acc.	16.65	31.68	24.88	12	
	TTI upper rib	23.11	53.00	30.31	12	
	TTI middle rib	23.30	43.30	30.25	12	
	TTI lower rib	23.70	44.00	31.56	12	
	V*C upper rib	0.00	0.17	0.04	12	0
	V*C middle rib	0.00	0.20	0.05	12	0
	V*C lower rib	0.01	0.17	0.05	12	0
	peak upper rib displ.	1.00	23.00	10.25	12	0
	peak middle rib displ.	4.00	22.00	10.75	12	0
	peak lower rib displ.	5.00	21.00	11.83	12	0
	peak upper rib acc.	21.92	69.91	30.87	12	
	peak middle rib acc.	23.15	43.12	31.00	12	
	peak lower rib acc.	22.91	56.07	33.92	12	
	peak lateral T12 acc.	16.87	48.84	30.26	12	
ABDOMEN	parameter	Min	Max	Average	No.T	No.F
	peak front force	0.16	1.09	0.51	12	
	peak middle force	0.20	1.48	0.52	12	
	peak rear force	0.16	0.66	0.33	12	
	peak total force	0.49	3.14	1.33	12	1
PELVIS	parameter	Min	Max	Average	No.T	No.F
	peak lateral pelis acc.	32.00	66.83	44.94	12	
	peak res. pelvis acc.	35.97	70.62	50.95	12	
	peak pubic symph. force	2.06	5.55	3.55	12	0

ANNEX 2. EUROSID-1 Responses in Tests According to FMVSS 214 with American Passenger Cars

Driver position, 3 tests

HEAD	parameter	Min	Max	Average	No.T	No. F
	HPC	132.80	184.50	158.33	3	
	peak head res acc.	-	-	-	-	
	peak head res acc 3ms	-	-	-	-	
THORAX	parameter	Min	Max	Average	No.T	No.F
	peak lateral T1 acc.	-	-	-	-	
	TTI upper rib	95.20	108.80	101.53	3	3
	TTI middle rib	86.20	118.80	100.67	3	2
	TTI lower rib	70.50	110.10	87.80	3	1
	V*C upper rib	-	-	-	-	
	V*C middle rib	-	-	-	-	
	V*C lower rib	-	-	-	-	
	peak upper rib displ.	33.20	46.50	38.40	3	
	peak middle rib displ.	25.90	41.30	33.77	3	
	peak lower rib displ.	15.20	34.90	26.57	3	
	peak upper rib acc.	-	-	-	-	
	peak middle rib acc.	-	-	-	-	
	peak lower rib acc.	-	-	-	-	
	peak lateral T12 acc.	-	-	-	-	
ABDOMEN	parameter	Min	Max	Average	No.T	No.F
	peak front force	0.30	1.10	0.60	3	
	peak middle force	1.20	1.80	1.53	3	
	peak rear force	0.90	2.20	1.40	3	
	peak total force	2.37	3.77	3.17	3	
PELVIS	parameter	Min	Max	Average	No.T	No.F
	peak lateral pelis acc.	75.30	118.10	94.27	3	0
	peak res. pelvis acc.	-	-	-	-	
	peak pubic symph. force	3.50	5.20	4.30	3	

Passenger position, 3 tests.

HEAD	parameter	Min	Max	Average	No.T	No. F
	HPC	142.70	305.90	225.20	3	
	peak head res acc.	-	-	-	-	
	peak head res acc 3ms	-	-	-	-	
THORAX	parameter	Min	Max	Average	No.T	No.F
	peak lateral T1 acc.	-	-	-	-	
	TTI upper rib	30.40	72.50	49.77	3	0
	TTI middle rib	46.40	80.10	67.20	3	0
	TTI lower rib	89.60	183.70	129.00	3	2
	V*C upper rib	-	-	-	-	
	V*C middle rib	-	-	-	-	
	V*C lower rib	-	-	-	-	
	peak upper rib displ.	9.00	30.70	17.73	3	
	peak middle rib displ.	15.60	56.20	35.63	3	
	peak lower rib displ.	16.30	41.30	28.80	2	
	peak upper rib acc.	-	-	-	-	
	peak middle rib acc.	-	-	-	-	
	peak lower rib acc.	-	-	-	-	
	peak lateral T12 acc.	-	-	-	-	
ABDOMEN	parameter	Min	Max	Average	No.T	No.F
	peak front force	1.20	2.10	1.63	3	
	peak middle force	0.60	2.20	1.33	3	
	peak rear force	0.30	0.90	0.67	3	
	peak total force	2.20	5.13	3.51	3	
PELVIS	parameter	Min	Max	Average	No.T	No.F
	peak lateral pelis acc.	117.10	183.70	141.37	3	1
	peak res. pelvis acc.	-	-	-	-	
	peak pubic symph. force	4.20	5.00	4.60	2	

ANNEX 3. EUROSID-1 Responses in Tests According to the EEVC-Procedure with European Passenger Cars

M ≤ 1200 kg, driver (7 tests)

HEAD	parameter	Min	Max	Average	No.T	No. F
	HPC	243	496	348	7	0
	peak head res acc.	53	96	70	7	
	peak head res acc 3ms	48	78	68	3	
THORAX	parameter	Min	Max	Average	No.T	No.F
	peak lateral T1 acc.	57	129	78	7	
	TTI upper rib	100	150	121	7	
	TTI middle rib	114	169	136	7	
	TTI lower rib	103	145	121	6	
	V*C upper rib	0.28	1.62	0.89	7	3
	V*C middle rib	0.62	1.60	1.03	7	5
	V*C lower rib	0.29	1.67	0.99	7	4
	peak upper rib displ.	33	44	39	7	2
	peak middle rib displ.	36	45	41	7	2
	peak lower rib displ.	21	52	38	7	3
	peak upper rib acc.	162	265	196	7	
	peak middle rib acc.	161	330	247	7	
	peak lower rib acc.	122	244	191	6	
	peak lateral T12 acc.	75	108	91	7	
ABDOMEN	parameter	Min	Max	Average	No.T	No.F
	peak front force	0.3	1.3	0.6	7	
	peak middle force	0.6	2.1	1.1	7	
	peak rear force	0.7	2.0	1.1	7	
	peak total force	1.7	4.2	2.6	7	3
PELVIS	parameter	Min	Max	Average	No.T	No.F
	peak lateral pelis acc.	77	112	98	7	
	peak res. pelvis acc.	81	119	104	7	
	peak pubic symph. force	3.2	5.3	4.4	7	0

1200 < M ≤ 1450 kg, driver (7 tests)

HEAD	parameter	Min	Max	Average	No.T	No. F
	HPC	202	664	418	7	0
	peak head res acc.	38	154	100	7	
	peak head res acc 3ms	37	102	68	7	
THORAX	parameter	Min	Max	Average	No.T	No.F
	peak lateral T1 acc.	54	157	103	7	
	TTI upper rib	70	185	139	7	
	TTI middle rib	73	188	136	7	
	TTI lower rib	82	166	133	7	
	V*C upper rib	0.30	1.99	1.29	7	6
	V*C middle rib	0.35	2.02	1.25	7	5
	V*C lower rib	0.39	1.92	1.25	7	4
	peak upper rib displ.	24	55	44	7	6
	peak middle rib displ.	25	52	43	7	5
	peak lower rib displ.	32	57	43	7	3
	peak upper rib acc.	88	383	237	7	
	peak middle rib acc.	72	343	220	7	
	peak lower rib acc.	98	307	220	7	
	peak lateral T12 acc.	73	157	107	7	
ABDOMEN	parameter	Min	Max	Average	No.T	No.F
	peak front force	0.3	0.6	0.4	7	
	peak middle force	0.4	1.1	0.7	7	
	peak rear force	0.5	1.6	0.8	7	
	peak total force	1.2	2.6	1.7	7	1
PELVIS	parameter	Min	Max	Average	No.T	No.F
	peak lateral pelis acc.	53	89	73	7	
	peak res. pelvis acc.	55	103	79	7	
	peak pubic symph. force	0.9	4.4	2.8	7	0

M > 1450 kg, driver (8 tests)

HEAD	parameter	Min	Max	Average	No.T	No. F
	HPC	278	648	422	8	0
	peak head res acc.	45	93	59	8	
	peak head res acc 3ms	43	73	54	8	
THORAX	parameter	Min	Max	Average	No.T	No.F
	peak lateral T1 acc.	69	132	85	8	
	TTI upper rib	76	155	111	8	
	TTI middle rib	84	155	117	8	
	TTI lower rib	83	149	106	8	
	V*C upper rib	0.28	1.22	0.64	8	1
	V*C middle rib	0.43	1.36	0.88	8	3
	V*C lower rib	0.41	1.66	0.94	8	3
	peak upper rib displ.	24	39	33	8	0
	peak middle rib displ.	30	46	38	8	2
	peak lower rib displ.	31	49	40	8	4
	peak upper rib acc.	77	260	139	8	
	peak middle rib acc.	94	266	180	8	
	peak lower rib acc.	92	240	151	8	
	peak lateral T12 acc.	70	150	94	8	
ABDOMEN	parameter	Min	Max	Average	No.T	No.F
	peak front force	0.2	0.4	0.3	8	
	peak middle force	0.2	1.2	0.7	8	
	peak rear force	0.5	1.4	0.9	8	
	peak total force	0.7	3.0	1.8	8	1
PELVIS	parameter	Min	Max	Average	No.T	No.F
	peak lateral pelis acc.	61	86	73	8	
	peak res. pelvis acc.	70	90	77	8	
	peak pubic symph. force	1.6	3.4	2.7	8	0

ANNEX 4. EUROSID-1 Responses in Tests According to the EEVC-Procedure with European Passenger Cars

2/3-door vehicles, driver (5 tests)

HEAD	parameter	Min	Max	Average	No.T	No. F
	HPC	202.45	495.70	341.82	5	0
	peak head res acc.	48.48	86.34	61.09	5	
	peak head res acc 3ms	40.00	48.46	45.00	3	
THORAX	parameter	Min	Max	Average	No.T	No.F
	peak lateral T1 acc.	54.24	72.45	63.15	5	
	TTI upper rib	69.88	108.60	88.69	5	
	TTI middle rib	72.95	128.03	98.92	5	
	TTI lower rib	81.77	106.10	93.18	5	
	V*C upper rib	0.28	0.59	0.44	5	0
	V*C middle rib	0.35	0.80	0.58	5	0
	V*C lower rib	0.29	0.79	0.46	5	0
	peak upper rib displ.	24.00	39.00	33.20	5	0
	peak middle rib displ.	25.00	42.00	34.60	5	0
	peak lower rib displ.	21.00	47.00	31.20	5	1
	peak upper rib acc.	76.80	189.70	127.79	5	
	peak middle rib acc.	71.96	221.60	141.13	5	
	peak lower rib acc.	92.27	139.90	111.26	5	
	peak lateral T12 acc.	72.72	82.66	77.81	5	
ABDOMEN	parameter	Min	Max	Average	No.T	No.F
	peak front force	0.27	1.31	0.63	5	
	peak middle force	1.09	2.05	1.41	5	
	peak rear force	0.65	2.00	1.21	5	
	peak total force	2.31	4.16	3.10	5	3
PELVIS	parameter	Min	Max	Average	No.T	No.F
	peak lateral pelis acc.	72.36	111.90	91.43	5	
	peak res. pelvis acc.	73.72	119.00	97.78	5	
	peak pubic symph. force	2.81	5.25	3.97	5	0

4/5-door vehicles, driver (17 tests)

HEAD	parameter	Min	Max	Average	No.T	No. F
	HPC	243	664	414	17	0
	peak head res acc.	38	154	80	17	
	peak head res acc 3ms	37	102	65	15	
THORAX	parameter	Min	Max	Average	No.T	No.F
	peak lateral T1 acc.	57	157	96	17	
	TTI upper rib	91	185	133	17	
	TTI middle rib	98	188	138	17	
	TTI lower rib	87	166	127	16	
	V*C upper rib	0.28	1.99	1.07	17	10
	V*C middle rib	0.64	2.02	1.18	17	13
	V*C lower rib	0.60	1.92	1.23	17	11
	peak upper rib displ.	24	55	40	17	8
	peak middle rib displ.	32	52	42	17	9
	peak lower rib displ.	31	57	43	17	9
	peak upper rib acc.	102	383	206	17	
	peak middle rib acc.	131	343	235	17	
	peak lower rib acc.	129	307	209	16	
	peak lateral T12 acc.	70	157	103	17	
ABDOMEN	parameter	Min	Max	Average	No.T	No.F
	peak front force	0.2	0.6	0.4	17	
	peak middle force	0.2	1.5	0.6	17	
	peak rear force	0.5	1.6	0.9	17	
	peak total force	0.7	2.9	1.7	17	2
PELVIS	parameter	Min	Max	Average	No.T	No.F
	peak lateral pelis acc.	53	105	78	17	
	peak res. pelvis acc.	55	107	83	17	
	peak pubic symph. force	0.9	4.6	3.1	17	0

S5-W-30

Fatally Injured Occupants in Side Impact Crashes

Diane C. Lestina
Insurance Institute for Highway Safety

Peter F. Gloyns, Stephen J. Rattenbury
Vehicle Safety Consultants, Ltd.

Abstract

Injury patterns of fatally injured motor vehicle occupants in side impact crashes were examined based on crashes in the United Kingdom during 1981-85. Detailed Coroners' records for 91 struck side and 49 opposite side fatalities were assessed. The characteristics of the side impact crashes and the fatally injured occupants were described, and possible countermeasures that could have prevented the fatality based on existing technology were identified. Occupants killed in side impact crashes had a high incidence of head and chest injuries; severe injuries to multiple body regions were common. Opposite side fatalities were more likely to sustain serious head injuries than were struck side fatalities. Forty-four percent of the fatalities were judged preventable using existing technology. In the present study stronger side structure and energy absorbing padding was the most common potential vehicle design countermeasure identified; this countermeasure alone was estimated to be capable of preventing 6 percent of the fatalities and an additional 11 percent when combined with other countermeasures. Additional design features addressing head injury in side impact crashes are needed to achieve further reductions in fatalities.

Introduction

Passenger car occupants fatally injured in side impact crashes accounted for 34 percent of all car occupant fatalities in the United States in 1989 (IIHS, 1990). Previous studies using the National Crash Severity Study (NCSS) concluded that head and chest injuries account for the majority of the deaths to side impact occupants (Partyka and Rezabek, 1983; Rouhana and Foster, 1985). A study of 224 side impacts found that for occupants seated on the struck side of the vehicle the most likely vehicle interior contacts are the side interior, side hardware, and armrests (Otte et al., 1984). For occupants seated on the opposite side of the impact, there was more contact with the vehicle's front interior structures, such as the instrument panel and windshield. Field studies have noted that injuries to the struck side occupant are both more frequent and more severe than those to the far side occupant (Danner and Langwieder, 1976; Rouhana and Foster, 1985).

Based on data from the NCSS and the National Accident Sampling System (NASS), the National Highway Traffic Safety Administration (NHTSA) has proposed amendments to Federal Motor Vehicle Safety Standard 214 intended to improve protection of motor vehicle occupants in side impacts. These amendments include a proposed dynamic test procedure and performance requirements for thorax and pelvis protection (NHTSA, 1988a). The current standard provides only for a static crush resistance test for side doors. The proposed crash test procedure consists of a moving deformable barrier traveling at a speed of 54 km/h (33.5 mph) in a crabbed motion that impacts a stationary vehicle so that the barrier face is perpendicular to the passenger compartment of the test vehicle. The mass of the barrier is 3,000 lbs, representing a 1990s' vehicle of 2,700 lbs and 300 lbs for passengers. The stiffness of the barrier is similar to a light truck. Instrumented side impact dummies are to be unrestrained in the front and rear seating positions on the struck side unless the vehicle is equipped with an automatic belt. Certain threshold requirements will have to be met for the Thoracic Trauma Index (TTI), an injury criteria based on rib and spine accelerations (Eppinger et al., 1984), and for the measurement of pelvic acceleration. However, there has not been complete agreement among researchers in this field on certain technical aspects of the test dummy and injury criteria to be used (see e.g., Viano, 1987). Opposite side occupants are not directly addressed in the proposed test procedure, but they are expected to benefit, especially in crashes with a high degree of intrusion and contact with the opposite side interior where side interior padding can reduce injuries.

Head injuries are not covered in the current side impact proposal. However, in a separate preliminary rulemaking action, NHTSA has requested comments on ways to reduce head injuries from contact with interior parts of the vehicle (NHTSA, 1988b).

This paper describes the injuries to occupants in fatal side impact crashes based on crashes in the United Kingdom during 1981-85. Injury patterns of struck side and opposite side fatalities are compared. Potential countermeasures to reduce side impact fatalities are identified. The effects of upgraded crash test procedures on reducing these injuries are evaluated, and the need for other improvements is discussed.

Method

This study is based on data drawn from a study of 571 car occupant fatalities in the United Kingdom using information extracted from the records of seven H.M. Coroners' Offices. The information is generated by the police and pathologists to allow H.M. Coroners to decide on the circumstances of sudden deaths. In the United Kingdom, inquests are held into all sudden deaths, and car occupant fatalities represent a subset of these data. Information on file typically consists of a postmortem report, police statements, photographs of the vehicle and scene, and witness statements. The study period covered one year (October 1981 - September 1982) prior to the introduction of the mandatory seat belt use law and two years after (April 1983 - March 1985). Details of data collection are described more fully in another report (Gloyns et al., 1989). The current study focused on side impacts where the direction of force on the vehicle was 2 o'clock through 4 o'clock and 8 o'clock through 10 o'clock. Only cases with direct loading on the passenger compartment by the striking object were included. Struck side occupants are those in side impact crashes seated on the side of the vehicle that was struck. A detailed description of the experience of struck side occupants is available in another report (Gloyns and Rattenbury, 1989). Opposite side occupants are those in side impact crashes seated opposite the side of the vehicle that was struck.[1] Cases where the seating position of the occupant was not known and rear seat passengers sitting in the center position are not included. Fatalities whose major injuries were sustained due to ejection were not included in the analyses but are described.

The Collision Deformation Classification (CDC) is a coding system that describes vehicle damage in terms of direction of force, location, and extent of damage (SAE, 1980). The damage extent codes of the CDC, which range from 1 (least severe) to 9 (most severe), were compared for struck side and opposite side crashes. For example, a damage extent code of 5 for a side impact corresponds to crush extending halfway across the vehicle, and a damage extent code of 9 is a very severe impact that is likely to extend across the entire vehicle resulting in both struck side and opposite side fatalities.

Sources of injury were determined from the police photographs. In cases where the side of the vehicle interior was the cause of injury but the specific contact point, such as the armrest or window frame, could not be determined the source of injury was coded as general side. Injuries were examined in terms of frequencies of injured body regions and severity using the 1985 Abbreviated Injury Scale (AIS) (AAAM, 1985). Driver age in fatal side impact crashes was compared with driver age in a sample of fatal frontal crashes also based on H.M. Coroners' records.

Possible countermeasures that could have prevented the fatality based on existing technology were established. Following methods described in a previous report (Gloyns et al., 1989), information on crash configuration, vehicle damage, and injury was used by the authors for the assessment of the countermeasures. Countermeasures included improvements to the restraint system, case vehicle design, striking vehicle design, and the road environment. A list of all countermeasures considered is given in the Appendix. The assessment allowed up to three individual countermeasures to be cited in any one case.

Results

Side impacts accounted for 29 percent of the fatalities in crashes in the study sample. There were 91 fatally injured struck side occupants and 49 opposite side occupants that fit the study criteria. The seating position of the fatalities and the presence of a front seat passenger next to a driver are given in Table 1. Based on information in the Coroners' records, 54 percent of the struck side fatalities and 43 percent of the opposite side fatalities were judged to have been restrained. No rear seat fatalities were restrained.

Table 1. Number of Fatally Injured Occupants in Side Impact Crashes by Seating Position

	Struck Side		Opposite Side	
	No.	(%)	No.	(%)
Drivers				
alone	24	(26)	20	(41)
accompanied	24	(26)	15	(31)
Passengers				
Front Seat	30	(33)	8	(16)
Rear Seat	13	(14)	6	(12)
	91	(99)*	49	(100)
All Fatalities				
Restrained	49	(54)	21	(43)
Unrestrained	34	(37)	22	(45)
Unknown	8	(9)	6	(12)
	91	(100)	49	(100)

* Percent does not total 100 due to rounding

For all side impact crashes, the most frequent object struck was another car. Fixed objects and heavy goods vehicles were also important sources of crash impacts for both struck side and opposite side fatalities (Table 2). Thirty-three percent of the opposite side fatalities occurred in crashes with severe damage extent codes (6-9) compared with 14 percent of the struck side fatalities; this difference was statistically significant ($X^2 = 5.66$, $p<0.05$).

Table 2. Object Struck in Side Impact Crashes

	Struck Side		Opposite Side	
Object	No.	(%)	No.	(%)
Car	48	(53)	29	(59)
Light Goods Vehicle	7	(8)	2	(4)
Motorcycle/Moped	2	(2)	-	-
Bus/Coach	3	(3)	1	(2)
Heavy Goods Vehicle	11	(12)	9	(18)
Fixed Object	19	(21)	8	(16)
Unknown	1	(1)	-	-
Total	91	(100)	49	(99)*

* Percent does not equal 100 due to rounding

Four age groups of fatally injured drivers in side impact crashes are compared with those in frontal

---

[1] Opposite side fatalities are described in detail in a report (*Fatalities in Side Impacts—The Experience of Both Struck Side and Opposite Side Occupants* prepared in support of this work by Vehicle Safety Consultants Ltd.) available from the authors.

crashes in Table 3. Drivers over age 50 years were 35 percent of the fatalities in side impacts and 24 percent of the fatalities in frontal impacts. This difference was statistically significant (X^2=7.96, p<0.05); however, the difference was due to the larger percentage of fatally injured drivers over age 50 in struck side impacts (46 percent) compared with those in opposite side impacts (20 percent). The age distribution of fatally injured passengers in side impacts and frontal impacts was similar, and overall there were no significant differences between occupants killed in side impacts compared to those killed in frontals (Table 4).

Table 3. Comparison of Fatally Injured Driver Age Groups in Fatal Side Impact and Frontal Crashes

Age Group (years)	Side Impacts						Frontal Impacts	
	Struck Side		Opposite Side		Total			
	No.	(%)	No.	(%)	No.	(%)	No.	(%)
≤ 20	7	(15)	8	(23)	15	(18)	27	(14)
21-30	11	(23)	10	(29)	21	(25)	44	(23)
31-50	8	(17)	10	(29)	18	(22)	74	(39)
≥ 51	22	(46)	7	(20)	29	(35)	47	(24)
Total	48	(101)*	35	(101)*	83	(100)	192	(100)

* Percent does not equal 100 due to rounding

Table 4. Comparison of Fatally Injured Occupant Age Groups in Fatal Side Impact and Frontal Crashes

Age Group (years)	Side Impacts		Frontal Impacts	
	No.	(%)	No.	(%)
≤ 20	34	(24)	51	(18)
21 - 30	29	(21)	66	(23)
31 - 50	26	(19)	83	(29)
≥ 51	51	(36)	84	(30)
Total	140	(100)	284	(100)

Injury Patterns

Body regions with an AIS ≥ 3 injury for all struck side and opposite side fatalities are illustrated in Figure 1. For struck side fatalities, 85 percent had serious chest injuries, 64 percent head injuries, and 59 percent abdominal injuries. For opposite side fatalities, the body region most often injured was the head (82 percent) followed by chest (73 percent) and abdomen (49 percent). The opposite side fatalities has a statistically higher involvement of head injuries than those on the struck side of the vehicle (X^2 = 4.40, p<0.05).

As shown in Table 5, severe injuries to more than one body region were common. Twenty-one percent of the struck side fatalities and 22 percent of the opposite side fatalities had AIS ≥ 3 injuries to the head, chest, and abdomen. Sixteen percent of struck side fatalities had AIS ≥ 3 injuries to four or more body regions (head, neck, chest, and abdomen or pelvis). Fourteen percent of struck side fatalities had injuries to the chest and abdomen, and 14 percent of opposite side fatalities had injuries to the head and chest. Upper and lower limb injuries were not included in Table 5 but were included for completeness in Figure 1.

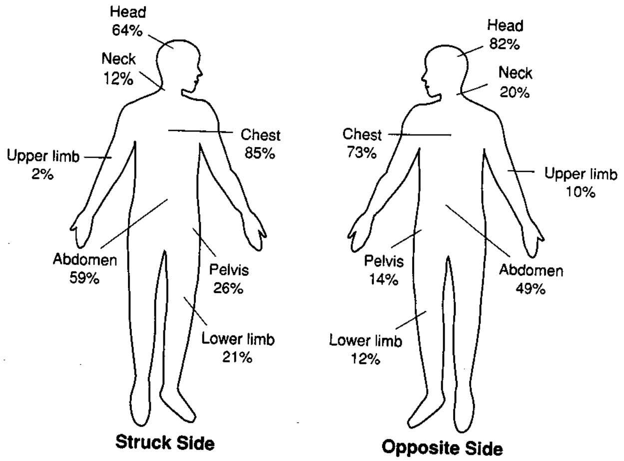


Figure 1. AIS ≥ 3 Injuries by Body Region for Fatalities in Struck Side and Opposite Side Crashes

Table 5. Side Impact Fatalities with AIS ≥ 3 Injuries by Body Region

Body Region(s) Injured	Struck Side (N=91)		Opposite Side (N=49)	
	No.	(%)	No.	(%)
Head, Chest & Abdomen	19	(21)	11	(22)
Head, Chest & Pelvis	6	(7)	1	(2)
Three other major regions[1]	3	(3)	3	(6)
Four or more	15	(16)	7	(14)
Head & Chest	11	(12)	7	(14)
Head & Other	1	(1)	6	(12)
Chest & Abdomen	13	(14)	1	(2)
Chest & Other	3	(3)	1	(2)
Abdomen & Pelvis	3	(3)	0	
Head only	7	(8)	6	(12)
Neck only	0		1	(1)
Chest only	9	(10)	5	(10)
Abdomen only	1	(1)	0	

[1] Other: neck, abdomen, and pelvis

The number of AIS ≥ 3 injuries for each body region was also analyzed separately for belted and unbelted fatalities in struck side and opposite side crashes. Opposite side fatalities who were not wearing seat belts had significantly more AIS ≥ 3 head injuries (94 percent) compared with those who were belted (67 percent) (Fishers exact, p=0.019). There were no other differences in body regions injured among belted and unbelted struck side and opposite side fatalities.

Head and Neck Injuries

Seventy-four percent of opposite side fatalities with brain injury also sustained a skull fracture, and 58 percent of struck side fatalities had both brain injury and a skull fracture. An AIS ≥ 3 neck injury was sustained by 18 percent of all front seat fatalities in side impact crashes.

The vehicle side interior was the source of head injury for approximately 60 percent of the struck side and opposite side fatalities (Table 6). Head injury due to the striking vehicle surfaces or intruding fixed objects accounted for 40 percent of head injury to struck side fatalities but only 23 percent to opposite side fatalities.

Table 6. Head Injury Sources for Fatalities in Side Impact Crashes

	Struck Side		Opposite Side	
Injury Source	No.	(%)	No.	(%)
General side structure	33	(57)	21	(53)
Other vehicle intruding	11	(19)	6	(15)
Fixed object intruding	12	(21)	3	(8)
Door/side structure	-		3	(8)
Windscreen frame	-		1	(2)
Other occupant	-		1	(2)
Roof	-		1	(2)
Indirect door/side structure	1	(2)	-	
Not Known	1	(2)	4	(10)
Number of Fatalities with AIS ≥ 3 head injury	58	(101)*	40	(100)

* percent does not equal 100 due to rounding

Chest Injuries

Both struck side and opposite side fatalities had a high incidence of chest injury. Sources of chest injuries are given in Table 7. The door/side structure was identified as the injury source for 86 percent of chest injuries for struck side fatalities and 44 percent for opposite side fatalities. Intrusion of the striking vehicle or fixed object was the source of chest injury for the same proportion of struck side and opposite side fatalities. The other occupant was the source of chest injury for three of the 36 opposite side fatalities.

Abdominal and Pelvic Injuries

The door/side structure was the source of abdominal injury for more than three-fourths of the struck side and two-thirds of opposite side fatalities in the study (Table 8). Intrusion of the striking vehicle was the second most frequent source for both struck side and opposite side fatalities. The other occupant was cited as the source of abdominal injury for four struck side fatalities.

Table 7. Chest Injury Sources for Fatalities in Side Impact Crashes

	Struck Side		Opposite Side	
Injury Source	No.	(%)	No.	(%)
Door/side structure	66	(86)	16	(44)
Other vehicle intruding	6	(8)	3	(8)
Fixed object intruding	3	(4)	1	(3)
General side structure	-		4	(11)
Seat belt webbing	2	(3)	1	(3)
Other occupant	-		3	(8)
Belt and intrusion	-		2	(6)
A pillar/door area	-		1	(3)
Front seat	-		1	(3)
Not known	-		4	(11)
Number of Fatalities with chest injury AIS ≥3	77	(101)*	36	(100)

* Percent does not equal 100 due to rounding

Table 8. Abdominal Injury Sources for Fatalities in Side Impact Crashes

	Struck Side		Opposite Side	
Injury Source	No.	(%)	No.	(%)
Door/side structure	41	(76)	16	(67)
Other vehicle intruding	5	(9)	3	(13)
Other occupant	4	(7)	1	(4)
Seat belt webbing	3	(6)	-	
Fixed object intruding	-		1	(4)
Belt and intrusion	-		1	(4)
General side	-		1	(4)
Not known	1	(2)	1	(4)
Number of Fatalities with AIS ≥ 3 abdominal injury	54	(100)	24	(100)

Pelvic fractures were sustained by 26 percent of the fatalities seated on the struck side and 14 percent of the opposite side fatalities. The vehicle's door/side structure was identified as the injury source for 92 percent of the struck side fatalities and for 86 percent of the opposite side fatalities.

Ejected Occupants

Four additional cases were not included in the preceding analyses because of ejection related injuries but are described for completeness. One opposite side unrestrained driver was partially ejected via the windshield opening, crushed between the car and an embankment, and suffered severe chest compression. Two struck side fatalities suffered massive head and neck injuries as a result of ejection from their vehicles, which disintegrated after the collision. One unrestrained struck side fatality, involved in a side impact with subsequent rollover, was completely ejected and suffered multiple head, chest, and abdominal injuries.

Countermeasures

Potential countermeasures were assessed for crashes where there was sufficient information to make a decision as to survivability; this included 86 percent of the struck side crashes and 75 percent of the opposite side crashes (see Appendix list of countermeasures). In struck side crashes with sufficient information to determine survivability, 42 percent of the deaths were considered preventable using current technology, and in opposite side crashes 49 percent of the deaths were considered preventable (Table 9). In 75 percent of these cases a single countermeasure would have been sufficient.

Table 9. Fatality Reductions Achievable for Struck Side and Opposite Side Occupants by Existing Countermeasures

Number of Countermeasures	Struck Side No.	(%)	Opposite Side No.	(%)	All Side Impacts No.	(%)
One	25	(32)	13	(35)	38	(33)
Two	7	(9)	5	(14)	12	(10)
Three	1	(1)	0		1	(1)
Unsurvivable	45	(58)	19	(51)	64	(56)
Total*	78	(100)	37	(100)	115	(100)

* There were 13 struck side fatalities and 12 opposite side fatalities with insuficient data to determine survivability that are not included in the total.

Countermeasures estimated to be capable of preventing deaths of belted and unbelted struck side and opposite side fatalities are given in Tables 10 and 11. For struck side fatalities, 48 percent of the applicable countermeasures were road design changes such as the protection of off-road objects with barriers. Changes in vehicle design accounted for 37 percent of the countermeasures for struck side fatalities; the most frequently cited of these was stronger side structures together with energy absorbing padding. Twelve percent of the countermeasures cited for struck side fatalities involved belt use by other occupants. Thirty-five percent of the countermeasures for opposite side fatalities required road design changes, 30 percent required belt use by the fatally injured occupant, and 26 percent required stronger side structure plus padding.

Table 10. Countermeasures that Would Have Prevented Fatalities in Struck Side Impact Crashes

Countermeasure	Belted		Unbelted		All Fatalities	
	Single Countermeasure	Combined with Others	Single Countermeasure	Combined with Others	Total Countermeasures mentioned No.	(%)
Measures to Inhibit submarining	-	1	-	-	1	(2)
Front belt use by other occupant	-	-	-	2	2	(5)
Rear belt use by other occupant	-	-	-	3	3	(7)
Stronger side structure and padding	6	2	-	6	14	(33)
Laminated side glass to inhibit ejection	-	-	-	1	1	(2)
Strong front under-run guard (Heavy goods vehicles)	-	1	-	-	1	(2)
Frangible furniture	1	-	1	1	3	(7)
Protect off-road object	6	-	1	-	7	(17)
Provide car central crash barrier	5	-	2	-	7	(17)
Correct the height of central barrier	1	-	-	-	1	(2)
Close gap in central barrier	-	-	2	-	2	(5)
All Countermeasures	19	4	6	13	42	(99)

Table 11. Countermeasures that Would Have Prevented Deaths of Opposite Side Impact Crashes

Countermeasure	Belted		Unbelted		All Fatalities	
	Single Countermeasure	Combined with Others	Single Countermeasure	Combined with Others	Total Countermeasures mentioned No.	(%)
Front belt use	-	-	1	3	4	(17)
Rear belt use	-	-	3	-	3	(13)
Stronger side structure and padding	1	2	-	3	6	(26)
Strong front under-run guard (Heavy goods vehicles)	-	2	-	-	2	(9)
Protect off-road object	-	-	2	-	2	(9)
Provide car central crash barrier	3	-	2	-	5	(22)
Close gap in central barrier	-	-	1	-	1	(4)
All Countermeasures	4	4	9	6	23	(100)

Discussion

This study has shown that occupants killed in side impact crashes have a high incidence of head and chest injuries and that severe injuries to multiple body regions are common. These findings are consistent with studies conducted in the United States (Partyka and Rezabek, 1983; Rouhana and Foster, 1985).

Improved side impact test procedures should improve struck side occupant protection by reducing the frequency and severity of thoracic injuries with modifications to the vehicle side interior such as strengthening the doors and the addition of energy absorbing padding. In the present study, stronger side structure and padding was the most common vehicle design countermeasure cited and would, alone or in combination with other countermeasures, have prevented 14 (42 percent) of the 33 preventable deaths of struck side occupants.

The proposed NHTSA test procedure does not directly address the protection of opposite side occupants; however, one-third of the deaths of opposite side occupants in this study were judged preventable by side interior padding, usually in combination with some other countermeasure. In addition, the presence of another occupant can be an important factor in aggravating or reducing injuries. The proposed test procedure does not consider the presence of additional occupants in the vehicle. A recent study of side impacts noted that the non-struck side occupant can apply additional loads and thus increase the severity of injuries to struck side occupants (Thomas and Bradford, 1989). In the present study, the other occupant was a source of injury for both struck side and opposite side fatalities.

The countermeasure analysis found that less than 50 percent of the crashes were considered survivable using current technology and that many of the countermeasures that would have prevented deaths are road design changes. This can be compared to the potential survivability of belted occupants in frontal crashes (Gloyns et al., 1989), where 74 percent of the crashes were considered survivable and approximately 80 percent of the countermeasures had to do with improvements to the vehicle or improved design of heavy goods vehicles. It is estimated that approximately 6 percent of the fatalities in this sample, where survivability could be assessed, would have been prevented by vehicle design changes that the improved side impact test procedures should encourage; an additional 11 percent of the fatalities could have been prevented by these changes in combination with one or more additional countermeasures.

Unfortunately, the high incidence of serious head injury to fatally injured side impact occupants is not addressed in the current NHTSA proposal. Struck side and particularly opposite side occupant fatalities in the present study had a high incidence of serious head injuries. Future improvements in side impact protection must focus on the reduction of head injuries in side impact crashes to achieve greater reductions in fatalities.

References

American Association for Automotive Medicine (1985). *The Abbreviated Injury Scale; 1985 Revision.* Arlington Heights, IL.

Danner, M., and Langwieder, K. (1976). Car/Vehicle Side Impacts—A Study of Accident Characteristics and Occupant Injuries. *Proceedings of the 6th Experimental Safety Vehicle Conference.* Washington, DC.

Eppinger, R.H., Marcus, J.H., and Morgan, R.M. (1984). Development of Dummy and Injury Index for NHTSA's Thoracic Side Impact Protection Research Program. SAE Paper 840885. Warrendale, PA.

Gloyns, P.F., and Rattenbury, S.J. (1989). Fatally injured struck side occupants in side impacts. Contractor Report 113. Transport and Road Research Laboratory, Crowthorne, United Kingdom.

Gloyns, P.F., Rattenbury, S.J., and Jones, I.S. (1989). Characteristics of Fatal Frontal Impacts and Future Countermeasures in Great Britain. *Proceedings of the 12th Experimental Safety Vehicle Conference.* Gothenburg, Sweden.

Insurance Institute for Highway Safety. (1990). Fatality Facts 1990: Passenger Vehicles. Arlington, VA.

National Highway Traffic Safety Administration (1988a). Notice of Proposed Rulemaking to Revise Federal Motor Vehicle Safety Standard 214—Side Impact Protection. *Federal Register*, Vol. 53, No. 17, January 27, 1988.

National Highway Traffic Safety Administration (1988b). Notice of Proposed Rulemaking to Revise Federal Motor Vehicle Safety Standard 214—Side Impact Protection. Narrow Objects and Head Impacts. *Federal Register*, Vol. 53, No. 161, August 19, 1988.

Otte, D., Suren, E.G., Appel, H., and Nehmzow, J. (1984). Vehicle Parts Causing Injuries to Front Seat Car Passengers in Lateral Impacts. *Proceedings of the 28th Stapp Car Crash Conference.* Chicago, IL.

Partyka, S.C. and Rezabek, G.E. (1983). Injury Patterns in Side Impacts a Coordinated Industry/Government Accident Data Analysis. SAE Paper 830459. Warrendale, PA.

Rouhana, S.W. and Foster, M.F. (1985). Lateral Impact—An Analysis of the Statistics in the NCSS. *Proceedings of the 29th Stapp Car Crash Conference.* Washington, DC.

Society of Automotive Engineers (1980). Collision Deformation Classification, Recommended Practice SAE J224. Society of Automotive Engineers, Warrendale PA.

Thomas, P., and Bradford, M. (1989). Side Impact Regulations: How do they relate to real world accidents? *Proceedings of the 12th Experimental Safety Vehicle Conference.* Gothenburg, Sweden.

Viano, David C. (1987). Evaluation of the SID Dummy and TTI Injury Criterion for Side Impact Testing. *Proceedings of 31st Stapp Car Crash Conference.* Warrendale, PA: Society for Automotive Engineers.

Appendix: List of Countermeasures

Restraint System

- Front belt use
- Rear Belt use (3-point belt)
- Child restraint use
- Addition of steering wheel air bag, given existing belt use, and pretensioner
- Measurers to inhibit submarining (better belt geometry/seat design)
- Measures to improve belt design to prevent release or webbing failure
- Prevention of rear loading from luggage
- Provision of front seat passenger side air bag in addition to existing 3-point belt use and pretensioner
- Provision of front seat passenger air bag alone (available for passive options only)
- Provision of driver side air bag alone (available for passive options only)
- Provision of strong front seat to prevent additional loading from unrestrained rear occupant (available for passive options)
- Front belt use by other occupant
- Rear belt use by other occupant
- Do not use seat belt
- Strong front seat to prevent front occupant loading rear occupant in rear impact
- Child restraint design improved to prevent submarining

Vehicle Design

- Control steering wheel intrusion with anti-intrusion design within column
- Improve seat strength in rear impacts to prevent major distortion in rear impact
- Provide self-aligning wheel with good load spreading for chest
- Provide wheel with energy absorbing padding for head/face contact

Stronger passenger compartment to postpone onset of major intrusion at facia level in frontal impacts
Stronger side structures and energy absorbing padding for side impact protection
Provide improved vehicle/vehicle compatibility to prevent road wheels of larger vehicles ramping up the deformed car structure
Provide bonded laminated windshield
Provide well-retained laminated side glass to inhibit partial ejection in side impacts and rollovers
Improved fuel system integrity to reduce changes of fuel fed fire
Keep side doors closed
Keep door of hatchback/estate closed with addition of suitable bonded glazing
Avoid use of unsuitable body panel materials such as fiber glass
'A' pillar padding
Front seat designed to safely absorb energy of rear seat passenger in fatal
Effective head restraint
Stronger roof structure
Retention of rear edge of bonnet
Sun roof to retain occupant
Reduce flammability of trim
Front suspension designed to resist rearward movement
Stiffen up rear of vehicle to postpone onset of passenger compartment intrusion
Bonded laminated rear window screen to prevent ejection

Design of Other Vehicles
Provision of effective rear underrun protection on heavy goods vehicles and public service vehicles
Provision of strong side underrun protection on heavy goods vehicles
Provision of strong energy absorbing from underrun protection on heavy goods vehicles and public service vehicles
Provision of suitable load retention on heavy goods vehicles
Keep trailer connected to towing vehicle

Off Road Objects
Provide frangible street furniture
Protect off road object with barrier etc. to prevent car contact
Improve compatibility between vehicle and barrier
Provision of central crash barrier (conventional car type)
Re-site lamppost
Fitch type barrier
Correct the height of central barrier to be compatible with carriageway
Remove fixed object
Provision of central crash barrier capable of holding HGV
Close gap in central barrier with car type barrier
Close gap in central barrier with heavy goods vehicles type barrier

S5-W-31

Side Impact Into a Fixed Object: What is at Stake ?

Mouloud Haddak, Michelle Ramet,
Gilles Vallet, Dominique Cesari
INRETS

Abstract

This paper looks at the results of a statistical analysis of side impacts against rigid obstacles; side impact with another vehicle are also considered. The analysis was based on data extracted from the bidisciplinary accident database maintained by INRETSLCB. The study was restricted to accidents since 1980 for reasons of uniformity of coding and deformation measurement accuracy. Multi variate data analysis was carried out on the database using SPADN, to examine the nature and severity of occupant injuries and also the accident conditions and vehicle deformations. The primary aim of the study was to try and identify possible means of improving occupant protection in side impact.

Introduction

This study is based on the file containing the results of bidisciplinary surveys carried out by INRETS between 1970 and 1985. This file includes all data relating to:

- the accident: date, place, type
- the vehicle: characteristics and interior (V1D1) and exterior (VD1) deformations
- the occupant(s): their past history and injuries.

This study was limited to the more recent cases, i.e to accidents that occurred between 1980 to 1985 for a number of reasons: the older data generally corresponds to vehicles that are too old and the occupants were unrestrained. In addition, since 1980, crush depth measurements have demonstrated a higher accuracy and measurements have become more consistent.

From this file, we extracted side impacts against fixed obstacles (eg utility poles, lamp standards, billboards, road signs, trees, etc.). We also looked at side impact with other cars for the purposes of comparison. All other types of obstacle (eg. heavy vehicles etc.), were eliminated.

After discarding the cases for which there was a higher number of missing and/or invalid data, we selected:

- 189 vehicles
- 338 occupants
- 78 variables

i.e., approximately 13% of the total population studied and 50% of the variables.

Table 1

DATE	VEHICLES	OCCUPANTS
1970-85	3023	5567
1980-85	1531	2557
LAT.IMP.	189	338

General Analysis

Processing of Missing Injury Data

There was a large amount of missing data, particularly occupant injuries. This is due either to the lack of information or the lack of injuries. This is true, indeed, for uninjured occupants, but this is also true for fatally injured occupants of which more than a half received no coded injury. This may result from the fact that since 1980, post-mortem examinations have no longer been performed on fatally injured people in road accidents in France.

Such a situation led to selecting for each occupant only the three most severe injuries of body segments. They are classified by decreasing order of severity for each occupant. The first injury of an injured occupant will correspond here to the injury with the highest injury score.

Few severely injured occupants, with an O.A.I.S of 3, 4 or 5, were recorded. Therefore, occupants were divided into 4 categories instead of 7:

- "fatal injury" corresponds to an O.A.I.S. of 6.
- "severe injury" includes an O.A.I.S equal to 3, 4 or 5
- "minor injury" includes an O.A.I.S equal to 1 or 2, and represents approximately half the occupants.
- "no injury" corresponds to an O.A.I.S. of 0.

Table 2. Injuries and O.A.I.S Categories

O.A.I.S. SCORE	O.A.I.S NUMBER	FIRST INJURY	SECOND INJURY	THIRD INJURY
MINOR INJURY	168	169	110	52
SERIOUS INJURY	64	81	60	28
FATAL INJURY	65	29	2	0
NO INJURY	39	57	164	256
MISSING DATA	2	2	2	2

Note 1: When comparing the overall O.A.I.S to the column corresponding to the principal injury of the involved occupants, it should be noted that the severity of accidents is underestimated when taking account of the injury table data only. This is due to the lack of data.

Methodology Adopted

In this study, the SPADN data processing software was used. Preliminary analyses performed allowed eliminating, gathering or supplementing low "significant" variables or variables including too much missing data. Different types of analysis were carried out:

- Factorial analysis of multiple correspondences (FAMC) (see appendices I and II)
- Hierarchical Ascending Classification (HAC) of initial factorial table coordinates
- Computer-aided tools for the interpretation of factorial axes and partitions.

The factorial analysis of multiple correspondences has been performed on 338 subjects characterized by 78 variables which were all qualitative variables or rendered such. This analysis considered occupant characteristics as active variables (appendix I), and vehicle and accident characteristics as illustrative variables (appendices II). Study of the results obtained, in particular for the first main plane, allowed the observation of four clouds of points globally corresponding to four accident types:

- Very distinct fatal injury crashes
- Minor property-damage-only crashes regrouping no-injury occupants which are relatively distinct too.
- Minor-injury crashes
- Finally, severe-injury crashes.

It should be observed that these two last groups are relatively close to each other and significantly differ from the two other groups.

It should also be noted that the first main axis distinguishes severe or fatal injury accidents from the other cases, while the second axis refines such a discrimination. Severe accidents are distributed into fatal and non-fatal injury crashes. Minor accidents are divided into minor-injury crashes and property-damage-only crashes.

The Hierachical Ascending Classification allows corroborating this topology. The two-class partition confirms the partition obtained with the first factorial axis: severe and minor accidents. The three-class partition globally maintains the severe accident group and the minor accident group is divided into two subgroups: the property-damage-only group and the minor injury group. The four-class partition yields the same representation as that obtained when using the factorial analysis of multiple correspondences.

A more refined topology with five or six classes showed the instability of minor or severe injury subclasses, which allows confirming that the limit between slightly and severely injured occupants is not well defined. This can be partly explained by the attribution of a global severity score (O.A.I.S), limited to 7 possible codes, which is indeed a reducing approach. This can also be explained by the large number of injuries not coded. Hence the inaccurate distinction between these two groups.

General Characteristics

As mentioned above, the vehicle occupation rate was 1.8. Thus, across the 338 occupants coded, 189 occupants were seated in the left front seat. In addition, it should be noted that these occupants were generally better coded than the others, in particular relating their immediate environment after the crash: restraint usage, seat and backrest state, etc. Front seat occupants represented 80% of the whole population studied. Sex did not seem to be a determinating variable as related to crash severity, age was slightly more determinating. The impact more often occurred on the vehicles rightside than leftside.

Save the variables characterizing occupants (see tables 6 and 7), the most discriminating variables with respect to the four-class topology selected for this analysis are in order of significance (appendices I and II):

- seating position (table 5)
- crush width significance (table 8)
- crush depth
- crush width location
- vertical location of the contact surface
- occupant's age
- type of object struck (table 9)
- horizontal location of the contact surface.

The following variables are less significant for such a partition:

- collision type
- struck area (table 3)
- crash clock direction (table 4).

Among the additional variables, the most representative are:

- restraint-involved injuries
- door state
- movements of the steering column
- windshield state
- movements of the left front seat and backrest

Table 3. Struck Area and O.A.I.S. Score

NUMBER	RIGHTSIDE	LEFTSIDE	MARGIN
NO INJURY	29	13	39
MINOR INJURY	89	79	168
SERIOUS INJURY	30	34	64
FATAL INJURY	29	36	65
MISSING DATA	0	2	2
MARGIN	174	164	338

Table 4. Impact Direction and O.A.I.S. Score

O.A.I.S. IMPACT DIR.	UNINJURED	MINOR INJURY	SERIOUS INJURY	FATAL INJURY	MARGIN
ID 02	3	21	9	8	41
ID 03	22	58	18	19	117
ID 04	2	5	3	2	12
ID 08	2	11	2	0	15
ID 09	9	50	28	29	118(*)
ID 10	1	23	4	7	35
TOTAL	39	168	64	65	338

Table 5. O.A.I.S. Score and Seating Position

O.A.I.S. SEAT.POS.	UNINJURED	MINOR INJURY	SERIOUS INJURY	FATAL INJURY	TOTAL
FRONT LEFT	33	83	36	36	189(*)
FRONT CENT	0	1	1	1	3
FR. RIGHT	2	46	17	18	83
REAR LEFT	2	15	3	3	23
REAR CENT.	0	6	2	0	8
REAR RIGHT	2	17	5	7	31
TOTAL	39	168	64	65	338(*)

(*) Two lacking data for O.A.I.S

Note: from the analysis of these two tables, it can be concluded that vehicle rightside crashes are more frequent that leftside crashes and that they are relatively less severe. This can be justified in that 56% of crash-involved people coded in this sample were seated in the left front seat.

Owing to the occupation rates observed, if we consider the seating position, it can be concluded that:

1. front-seated occupants are more exposed than rear seated ones
2. right-seated occupants are slightly more exposed than left seated ones.

Characteristics of the Different Groups

Minor accidents. Minor accidents included crashes where vehicles sustained low property damages and occupants did not receive any injury. In general, these crashes occurred in daylight, at a junction and with a dry road. Most often, the object struck was another passenger car whose laden weight was less than 1.5 tons or a fixed object—in particular a pole but not a natural object. The damage area was most often the vehicle's rightside and the occupant involved was seated at the left front. The crash direction was 3 o'clock in most cases, the crush depth 02 or 03 with a low crush width in the majority of the cases studied.

The steering column was undamaged. Doors were closed and were normally operating. Seats and backrests were undamaged. The restraint type used was a 3-point automatic belt.

The occupant received no injury or minor injuries on the skull, face or in neck. They did not sustain any cranial traumatism nor loss of consciousness. They did not require any hospital care. Restraint usage was correct.

Moderate accidents. Moderate accidents correspond to crashes where the vehicle and occupant involved did not receive any significant damage or injury. The object struck was, most frequently, another passenger car, and less frequently fixed objects such as posts. The crush width significance was between 10% and 30%. The crush width position was on the rightside. The crush depth was of type 01 to 04. The crash direction was 8 o'clock or 10 o'clock, there was also a relatively significant number of 3 o'clock or 9 o'clock directions. The steering column was undamaged. The door could have been damaged. The seats and backrests were undamaged. The occupant involved was mainly seated in the left front seat, and then the left rear seat. The occupant was rather young (0-14 years old) or aged (between 55 and 64 years old). Restraint usage was either unknown, or the occupant was not seatbelted.

Half of the occupants injured in this category received at least two injuries, the second one being a minor injury. The main injured segments observed were in occurrence order: lower and upper extremities, face, neck, thoracic bone and the torso-lumbar spine. The A.I.S. value for these injuries was 1 or 2. The injury was slightly more often located on the rightside than on the leftside, or the injury was not lateralized. The stay duration in hospital was less than 3 days. The temporary disablement duration was less than one month. The involved occupant suffered from a minor cranial traumatism. The object struck by the main injury segment was either the coded part of the interior surface or other, or the front of the passenger compartment leading to possible injuries due to the contact with the windshield.

Severe Accidents. These accidents, which are of most interest from a statistical perspective, are difficult to analyze as they gather a wide range of injured occupants with an O.A.I.S value between 3 and 5; and as it is not possible to study them separately due to the low number of cases in each category. In the sample studied, severe accidents were provided with some specific features.

The obstacle struck was rather a fixed object, in particular a natural object. The severely damage area was generally the left side rather than rightside. The crash direction was most often 04h, 02h or 09h rather than 03h, 08h or 10h. The crush width was greater than or equal to 40%. The crush depth was greater than 3. The code of the horizontal and vertical locations of contact surfaces was 01.

The steering column deformed to the left rather than to the right, was directed upward with a longitudinal upward movement. Left doors were either blocked or could be only closed with difficulty. The left side glass was generally broken. The left front seat was subjected to a lateral deformation and the backrest yielded rearward. Most often, the involved occupant's age ranged from 25 to 34. The risk age class was from 35 to 44. The occupant suffered from a severe cranial traumatism with loss of consciousness and several injuries. The principal injuries were located on the left side and the A.I.S value was greater than 3, they mainly related to the pelvis and abdomen sections which contacted the vehicle side structures. Secondary injuries were less severe, more often located on the right side and essentially affected lower extremities and thoracic bones. The temporary disablement period exceeded one month, and even 3 months. The stay duration in hospital was greater than 7 days, it even exceeded 22 days.

Fatal accidents. As related to fatally injured occupants, this study presents a main drawback for this crash type. In most cases, no post-mortem examination had been performed and therefore no coded injury was available. Accidents occurred in rural areas. Curves with no intersection were the cause of a number of such crashes. The obstacle could be a road sign, a wall or in a few cases a post or natural object. The clock impact direction was most often 9 o'clock; the crush depth ranged from 6 to 9 and the crush width exceeded 50%.

The vehicle sustained a hood intrusion into the passenger compartment. The windshield was broken. Front doors were opened during the crash and the left rear door as well. The steering wheel was broken or deformed. The steering column sustained a lateral deformation, mainly on the leftside rather the right one; it deformed upward rather than downward with a longitudinal upward movement. The anchoring system of the left front seat was broken and the backrest yielded rearward. The same phenomenon occurred for the right side but this result should be cautiously considered owing to the large amount of missing data.

The involved occupant died immediately or within a 3-day period. 65-year old or more occupants are very representative as well as the 25-34 year old range. The first harmful event seems to be the collision with an external object. The more characteristic injuries are bilateral. They relate to the skull, intrathoracic contents, abdomen and thoracic bones. Ejection-involved injuries and restraint-involved injuries are significant too.

Conclusion: Side Impact: What is at Stake?

Bilateral injuries are the more severe ones, and the leftside injuries seem to be more severe than rightside injuries.

The objects struck which result in severe injuries seem to be in first place vehicle lateral structures, accounting for 27% of severely or fatally injured occupants (see table 5). An object outside the passenger compartment is the second cause of severe injuries or fatalities, which means either an object intrusion in the passenger compartment or an occupant ejection. (see table 7).

Thus, occupants should be restrained, vehicle lateral structures be reinforced and padded, and doors should not open in impact. This could allow reducing crash severity by about 50% for severe accidents in case of side impact. Injuries are essentially due to contact with lateral structures and relate to thoracic bones, intrathoracic contents, pelvis and abdomen (see table 6).

Table 6. Frequency of the 3 Principal Injuries and Associated "Grouped" A.I.S: The Three Lines of Each Square Correspond to the Three Principal Coded Injuries for Each Case

INJURY TYPE SECTION	UNINJURED	MINOR INJURY	SERIOUS INJURY	FATAL INJURY	MARGIN
SKULL	57 28 67	35 6 6	10 4 0	16 0 0	120(*) 38 73
FACE	0 136 35	20 34 4	6 3 1	0 0 0	26 175(*) 40
NECK	0 0 154	9 5 5	3 3 4	1 1 0	13 8 165(*)
SPINE.	0 0 0	5 3 0	0 2 2	0 0 0	5 5 2
UPPER EXT.	0 0 0	22 12 16	2 2 2	0 0 0	24 14 18
THORACIC BONES	0 0 0	42 17 11	12 13 8	1 1 0	55 31 19
INTRATHOR. CONTENTS	0 0 0	1 4 0	14 15 2	7 0 0	22 19 2
PELVIS	0 0 0	5 3 5	15 3 5	0 0 0	20 6 10
ABDOMEN	0 0 0	1 3 0	12 6 1	3 1 0	16 10 1
LOWER EXT.	0 0 0	29 23 5	7 9 3	1 0 0	37 32 8
PRINC.INJ. SEC.INJ. TER.INJ..	57 164 256	169 110 52	81 60 28	29 2 0	338(*) 338(*) 338(*)
GLOBAL O.A.I.S	UNINJURED 39	OAIS 1-2 168	OAIS 3-5 64	OAIS 6 65	TOTAL 338(*)

(*) Two injuries with an undetermined A.I.S value

In the case of side impacts, severe injuries are essentially due to contact with lateral structures, whereas injuries to the face, neck, dorso-lumbar spine, lower and upper extremities essentially occur under minor accident conditions. Thoracic bone injuries are distributed between slightly, severely or fatally injured occupants. Head injuries are less specific to side impact, ie almost all accidents result in a head injury whether frontal or side impacts. This is due to the fact that this injury is systematically coded for occupants. This is also the case for face or neck injuries. It should nevertheless be noted that 50% of fatal injuries coded are skull injuries, and that skull and face severe injuries are due to contact with an outside object.

The large number of no injury cases is partly due to the sorting algorithm which selects the first out of the two injuries with the same severity score observed. If an occupant received no injury, the algorithm selects the three first no injury segments coded: the skull, the face and the neck.

Table 7. Struck Object and Body Section (Principal Injury)

STRUCK OBJECT INJURY	FRONT PASS COMP.	SIDE STR.	INT. PASS COMP	OUT SIDE	NO IMP. INJ.	MISSING DATA	TOTAL
SKULL	11	14	5	12	57	21	120
FACE	11	3	1	7	0	4	26
NECK	1	0	9	0	0	3	13
SPINE	1	1	1	0	0	2	5
UPPER EXT.	4	3	2	0	0	15	24
THOR.BONE	10	19	12	6	0	8	55
INTRATHO	3	6	0	3	0	10	22
PELVIS	0	14	2	2	0	2	20
ABDOMEN	1	2	1	1	0	11	16
LOWER EXT.	10	7	12	3	0	5	37
TOTAL	52	69	45	34	57	81	338

The study was mainly aimed at analyzing side impacts into fixed objects. Objects such as passenger cars are under represented. Other types of objects were deliberately discarded (see table 9).

In summary, side impacts on the righthand side of vehicles were more frequent than side impact on the lefthand side (table 3), but it seems to be comparatively less important owing to the predominance of occupants seated in the left front seats. On the other hand, with respect to the number of occupants, it seems that occupants seated in the front and rear left seats are slightly more exposed (table 5).

The impact clock directions (table 4) are low discriminating with respect to crash severity and their occurrence frequencies significantly differ:

- the 9 o'clock direction is likely to be the more severe compared with the 3 o'clock symmetric direction. These are the most frequent impact direction, accounting for 70% of the crashes.
- the 2 o'clock and 4 o'clock directions seem to be more severe than 8 o'clock and 10 o'clock.

Globally, objects of passenger car type are less dangerous in side impact than fixed, narrow objects such as poles, posts, road signs and natural obstacles (table 9). The significance of crush width is highly correlated with the O.A.I.S value severity and the occupant seating position (impact side or opposite). This is an incentive to further lateral structures reinforcement (table 8).

Table 8. O.A.I.S. Score and Crush Width Significance

INJURY TYPE CRUSH WIDTH	NO INJURY	MINOR INJURY	SEVERE INJURY	FATAL INJURY	TOTAL
NO CR. WIDTH	20	54	9	8	91
CR.WIDTH<10%	2	19	3	5	29
10%<CR.W<20%	1	23	3	4	31
20%<CR.W<30%	16	37	17	14	86(*)
30%<CR.W<40%	0	23	18	10	51
40%<CR.W<50%	0	8	7	11	26
CR.WIDTH>50%	0	4	7	13	24
TOTAL	39	168	64	65	338(*)

Table 9. O.A.I.S. Score and Object Type

INJURY TYP OBJECT	NO INJURY	MINOR INJURY	SEVERE INJURY	FATAL INJURY	TOTAL
VL < 1.5 T.	7	36	10	3	56
1.5T<VL<3.5T	0	3	0	0	3
ROLLOVER	0	2	0	0	2
POST/POLE	28	81	29	30	168
ROAD POSTS	0	6	2	4	12
SIGNS	3	16	9	13	43(*)
WALL	0	6	5	5	16
NAT.OBJECT	1	18	9	10	38
WHOLE	39	168	64	65	338(*)

(*) Two missing data for the O.A.I.S. score.

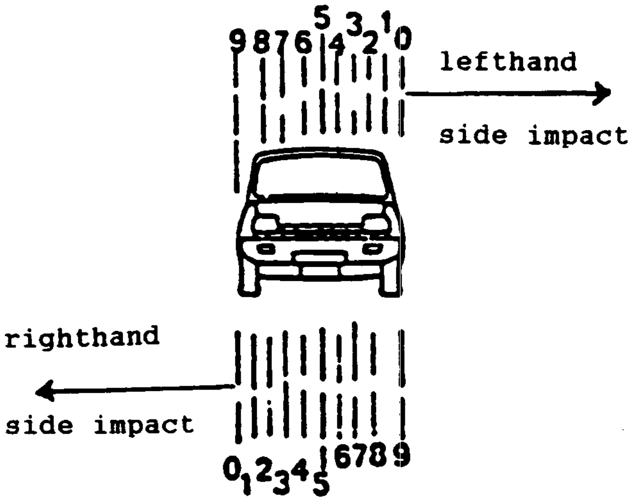
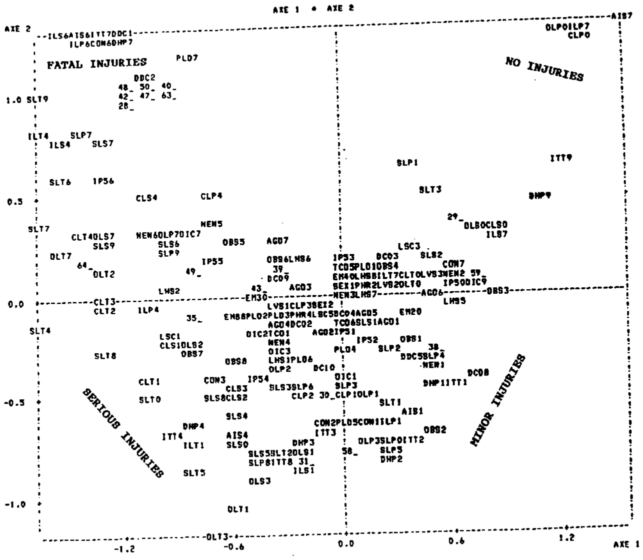


Figure 1. Crush Depth

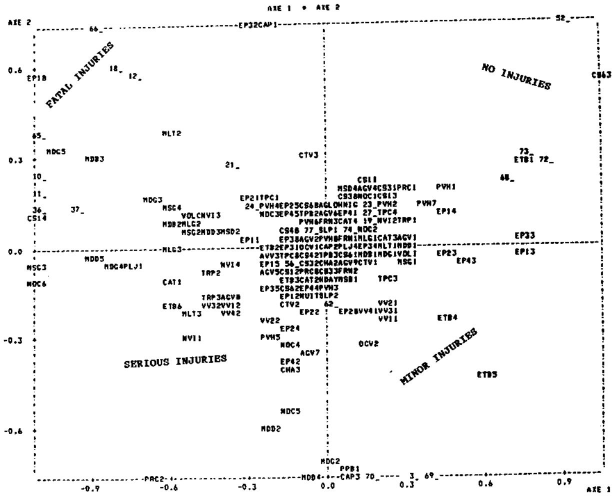
References

1. Cesari D., Ramet M. "Biomechanical Study of Side Impact Accidents" 5th ESV London 1974.
2. Cesari D., Ramet M., Cavallero C. "Influence of Intrusion in Side Impact" 6th ESV Washington D.C. 1976.
3. Warner C. Y., James M.B., Strother C.E. "A Perspective on Side Impact Occupant Crash Protection" SAE 900373.
4. Viano D. C., Lau I.V. Asbury C., King A.I., Begeman P. "Biomechanics of the human chest, abdomen, and pelvis in lateral impact" Accident Analysis & Prevention, Vol.21, No.6, Dec. 1989.
5. Henry C., Thomas C., Faverjon G., Tarriere C., Got C., Patel A. "Side Impacts Expected Benefits of Planned Standards" 12th E.S.V. Conference, Gothenburg, 1989.

Annex 1. Representation of the Main Active Modes on the Principal Factorial Plane



Annex 2. Representation of the Minor Modes on the Principal Factorial Plane



S5-W-32

Restrained Occupants on the Non-Struck Side in Lateral Collisions

G.M. Mackay, J. Hill, S. Parkin,
J.A.R. Munns
The University of Birmingham

Abstract

Field study accident data were analyzed in order to investigate some aspects of side impacts concerning the restrained occupant seated on the non-struck side. Seat belt performance was assessed in this situation for which they are not primarily designed. 7.7% of restrained occupants were exposed to this type of accident situation. The vehicle damage pattern and impacting object were described. Most (80%) injury 2 AIS 3 occurred when the passenger compartment intrusion exceeded 20 cm. A speed change ≤ 35 km/h was usually consistent with intrusion below that level. Injury causing contacts were assigned to many injuries so that it was possible to assess the role played by the far side structures, another occupant between case occupant and far side, and seat belt. Thus occupant egress from the seat belt diagonal was found to have occurred in 35% of cases. The head and face were particularly vulnerable, and chest injury was commonly caused by the seat belt. Also the lap section of seat belts posed a potential threat to the abdomen. An occupant beside proved to be a positive benefit in many cases showing that occupant interaction is an important consideration during crash simulation. Further consideration of seat belt design and supplementary technology are recommended.

Introduction

Lap/shoulder seat belts are designed to protect occupants in frontal collisions primarily. The geometry of the anchorages and the placement of the belt across the chest, the iliac spines of the pelvis and the lower abdomen, when combined with appropriate seat characteristics, limit forward excursion of the head, chest and knees and apply loads through the seat belt webbing which are tolerable for most of the exposed population in all but the most extreme collisions. Side impacts however constitute a significant part of the collision population at around 20 to 30%, increasing to 36% for fatalities with higher levels of seat belt use (Mackay, 1990). In side impacts most attention has been focused on the struck-side occupant and the recent rule making through FMVSS 214 addresses that condition. For that type of loading the seat belt has relatively little influence on outcome, because the main loads come from the occupant striking the side header and the door, contacts normally not influenced by a seat belt. Head excursion out through the side window can be reduced by a seat belt and of course ejection risk is diminished.

For an occupant on the non-struck side of a lateral collision however (Figure 1), the seat belt is of greater consequence. Crash severities and injury patterns have been described in other projects in Canada (Dalmotas, 1983), Germany (Otte et al, 1984) and Britain (Harms et al, 1987), and those studies emphasize the relative importance of head injuries for non-struck side, restrained occupants. Experimental work by Herbert et al (1976), and Horsch (1980) explored the limits of motion of the chest and hence the head in angled impacts, using dummies in sled tests. That work showed that the limit of retention of the torso was when the direction of the crash force was at 45 degrees from straight ahead. At greater angles head excursion markedly increased, although Horsch noted that even at angles of around 60 degrees, significant energy was removed from the upper part of the body by the seat belt before the torso slipped out of the belt.

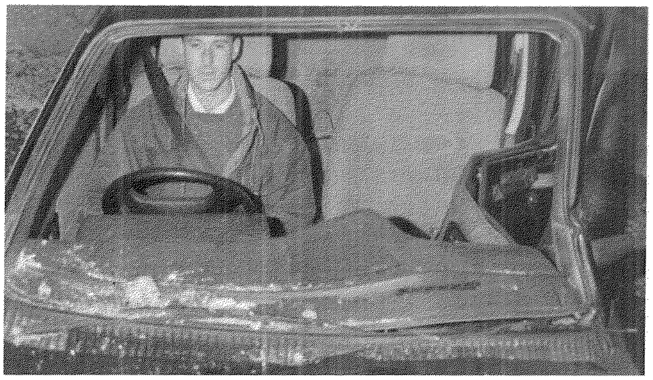


Figure 1. Front, Interior View of a Vehicle With Side Impact Damage, an Occupant is Seated on the Non-Struck Side

Thomas et al (1989) estimated that 32%, of side impact occupants were restrained and seated on the non-struck side. Their estimate only applies to the type of accident sampled for their database, that is one in which injury occurs in a relatively new car that is damaged enough to necessitate towaway from the accident scene.

This present study examined the injury causation aspects of non-struck side, restrained occupants in an effort to assess how seat belts function in a representative sample of real world collisions. Lateral collisions are seldom like sled tests in the sense that the direction of principal force is often changing during the crash phase because of rotation of the occupant's car. We wished therefore to assess how seat belts perform for a condition for which they are obviously not designed.

The Data Base

Since 1983 a stratified sample of car occupant collisions have been examined in the Midlands region. The sampling plan includes all fatalities, 50% of the police-reported "serious" cases i.e, requiring hospital admission for fractures and severe lacerations, and one third of lesser levels of injury in current model cars less than 6 years old. The cars are inspected at garages soon after their collisions and data from that inspection is co-ordinated with medical information from hospital records and questionnaire information from the people involved. The methodology is described elsewhere (Mackay, et al, 1985). Computerized records were available for the period October 1983 to September 1988. This five year period yielded 2429 crashed vehicles from the East and West Midlands.

Method

Two studies are brought together in this paper. The greater part of the paper concerns a computer based study of 186 cases, Sample A; this equally represented East and West Midland accidents. The former region is predominantly rural, and the latter urban. The second study considered some aspects of belt effectiveness via an in-depth, case by case, study of 193 vehicles, Sample B; these being from the predominately urban West Midlands region. Cases were not exclusive to either study.

Defining what a side impact is, precisely, is not clear cut. For example, occupants can move laterally to strike side structures when the front of the car is struck obliquely. We chose only those cases where the principal impact was on the side of the vehicle, and exclude sideswipe collisions. Sideswipe collisions have a principal direction of force near 12 or 6 o'clock, and vehicle structures do not engage the struck object.

Intrusion measures were available for various regions of the passenger compartment. The sample only contained front seat occupants, thus front occupant-compartment intrusion was most likely to have caused injury. For this reason the analysis used intrusion measurements taken in the front sitting zone adjacent to the struck side. Such intrusion was considered at the facia and windscreen level, and the maximum of these values was determined for all vehicles. Figure 2 defines the quantity referred to as "intrusion" in this paper. These intrusion data are, of course, measures of residual intrusion, and do not allow for the dynamic crash phase.

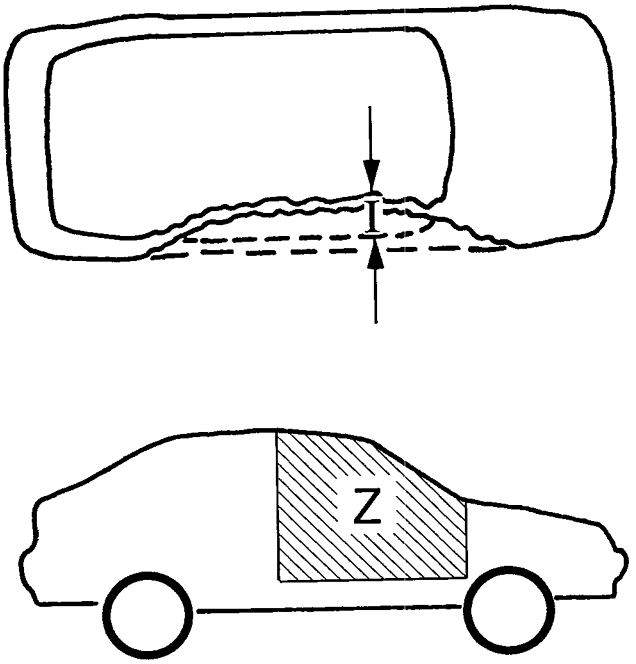


Figure 2. Intrusion Defined

"Intrusion" was defined the maximum lateral passenger compartment deformation (I) into the front zone Z.

Where possible, velocity change was calculated from external crush measurements and the known weights of the vehicles involved, but for side impacts the appropriate stiffness coefficients to be used are not well established for many of the cars in the sample.

Injury severity codes according to AIS 85 were assigned, and contacts within the vehicle were assessed. In most cases occupant height, weight, sex and age were known.

Results—Sample A

Sample Selection

The cause of primary vehicle damage was used to describe the range of impact type (Table 1). Side impact damaged vehicles made up 23.1%.

Table 1. Impact Type

Cause of Primary Vehicle Damage	N	%
Front Impact	1412	58.1%
Driver Side Impact	311	12.8%
Passenger Side Impact	251	10.3%
Rollover	270	11.1%
Rear Impact	108	4.5%
Front, Rear or Side Swipe	60	2.5%
Unclassified	17	0.7%
Total	2429	100 %

The numbers of candidate side impacts are shown in Table 2. 186 cases where there was a restrained occupant on the non-struck side were identified. For Britain, driving on the left side of the road in right hand drive cars, this produces a preponderance of drivers alone in left side (passenger side) collisions.

Table 2. Selection of Non-Struck Side Lateral Impacts

	Total Side Impacts	Cases Used	% of Cases Used
Driver Side Impacts	311	52	16.7 %
Passenger Side Impacts	251	134	53.4 %
Total	562	186	

The vehicles shown in Table 1 contained 2407 restrained front seat occupants. It follows that the 186 non-struck side occupants made up 7.7% of these.

Many (36.6%) of the 186 vehicles had a further, but less severe, impact. However these cases were included because the occupant motion under impact was judged to have occurred in response to the far side impact.

Crush Configuration and Overall Injury Outcome

Table 3 details the objects struck by the 186 vehicles in this study. Cars predominate (59.1%), followed by larger vehicles (22.1%) and road-side furniture (16.7%). Rollover had not occurred, to any degree of rotation, in any of the cases.

The direction of principal force in the collision was defined in each case. The cases analyzed exclude side swipe collisions. Table 4 shows that directions 2 and 3, and 9 and 10 o'clock predominate, at 77.4%.

In 20%, 38 cases, the impacting object did not directly strike the front sitting zone, thus little or no intrusion may have occurred. Figure 3 includes intrusion results as

Table 3. Object Struck

	N	%
Car	110	59.1 %
L.G.V.	14	7.5 %
H.G.V.	20	10.8 %
P.S.V.	7	3.8 %
Motor Cycle	1	0.5 %
Other Vehicle	3	1.6 %
Lamp Post	15	8.1 %
Tree	8	4.3 %
Wall	6	3.2 %
Other Road Furniture	2	1.1 %
Total	186	100 %

Table 4. Direction of Principal Force on the Clock Direction

	1/11	2/10	3/9	4/8	5/7	N.K.	Total
No. of Cases	17	61	83	18	6	1	186
%	9.1%	32.8%	44.6%	9.7%	3.2%	0.5%	100%

cumulative percentage distributions. Two curves are shown, MAIS ≥ 0, and MAIS ≥ 3. The former is for all non-struck side occupants where injury outcome and intrusion data were available, and they were occupants ranging in severity from uninjured to fatal. The latter are occupants with injury of a more serious or fatal nature.

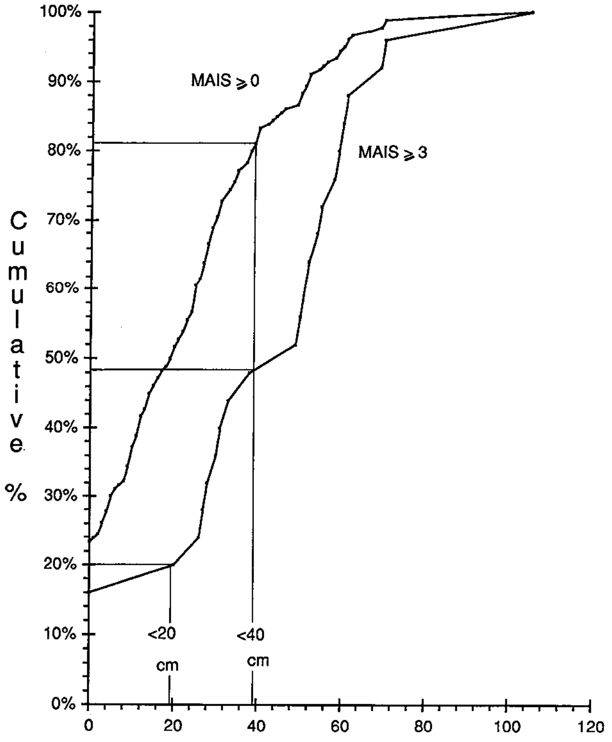


Figure 3. Cumulative Distributions of Intrusion for All Vehicles (MAIS ≥ 0), and Vehicles with Serious/Fatal Occupants (MAIS ≥ 3)

Percentiles are drawn on Figure 3 to show < 20 and < 40 cm of intrusion. Of all cases (MAIS ≥ 0), 81% had less than 40 cm of intrusion. For a typical small European car 40 cm is 31% of the internal width, and the equivalent distance in a typical large car measures 44cm. Considering cases that resulted in injury of MAIS ≥ 3, over half (52%) had intrusion extending beyond 40 cm, and the majority (80%) beyond 20 cm.

Width of the impacting object was defined, impacts were distinguished by measuring the width of direct contact damage on the vehicle exterior. Narrow impacts, which may be caused by poles, trees, or angled vehicle impacts, were those found to be less than 41 cm wide. There were 169 (91%) wide impacts and 12 (7%) narrow, 5 could not be so classified. To determine the affect that impact width had on intrusion, vehicles with direct contact damage overlapping the passenger compartment were considered, and results are shown in Figure 4. Narrow impacts typically resulted in more intrusion because loads are more concentrated.

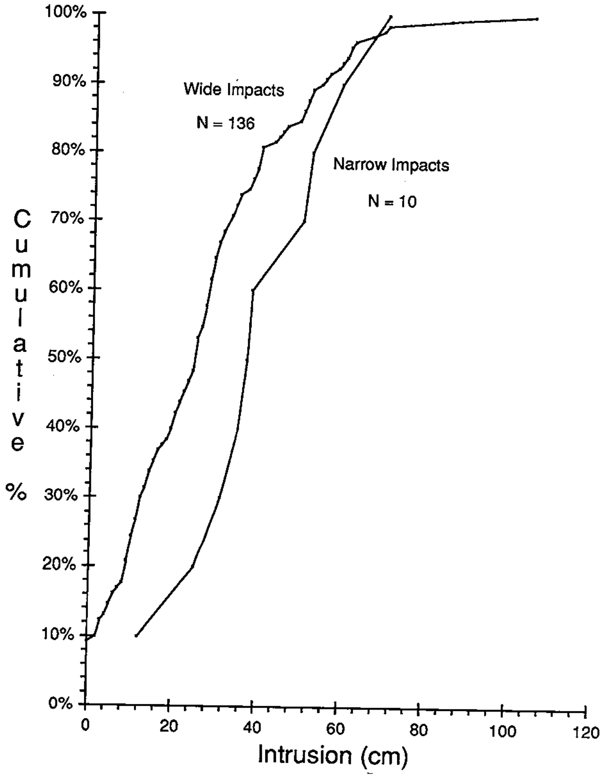


Figure 4. Cumulative Distributions of Intrusion for Wide and Narrow Impacts

Speed Change and Intrusion

Velocity change values were calculated for 85 (46%) of the relevant cases. of these vehicles, 75% underwent a speed change below 39 Km/h (Figure 5). It was found that intrusion was linearly correlated to delta V (r = 0.57, p < .0001). Within this general conclusion however there was a range of variation mainly influenced by location and width of impact. Clearly location of impact is influential, because if direct contact occurs away from the passenger compartment then intrusion may well be low. Regarding width of impact, for a given velocity change, there is more crush if the impact is narrow. Wide impact damage may also give a better estimate of delta V because the stiffness coefficients used are derived from barrier impacts. For these reasons, cases were excluded from the following analysis of delta V if direct-contact impact damage was narrow, or did not coincide with the passenger compartment. For this type of wide impact, delta V could be determined in 59 cases.

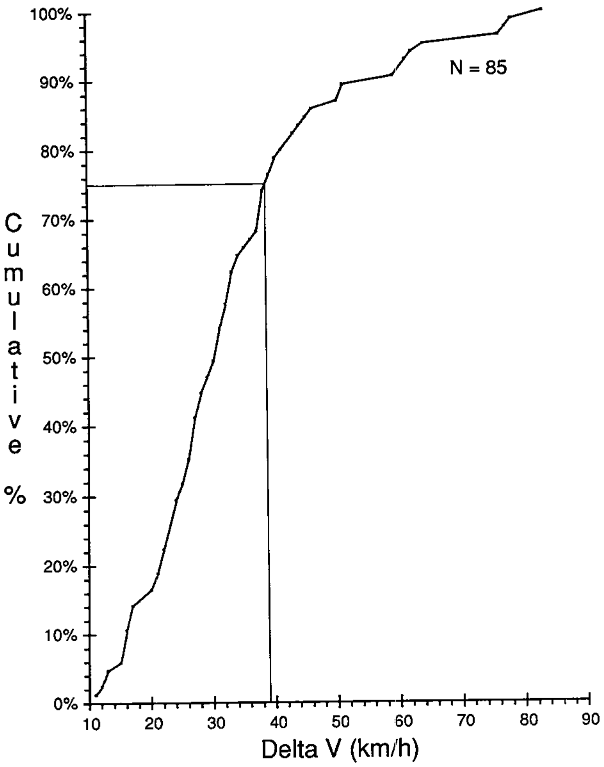


Figure 5. Cumulative Distribution of Delta V

Table 5 compares delta V values with intrusion for the 59 wide impacts that overlapped the passenger compartment. It can be seen that for cases with intrusion limited to the range zero to 19 cm, the inter-quartile range of delta V extends from 19 to 35 km/h. Figure 3 indicated that these levels of intrusion were not commonly (20%) related to injury of MAIS ≥ 3. Figure 3 also showed that over half (52%) of the serious or fatal cases had intrusion beyond 40 cm. We can relate these high levels of intrusion to speed change by considering Table 5, where it can be seen that such levels of intrusion typically (75% of such cases) occur when the speed change is over 33 km/h.

The above crush data can broadly be summarized, by saying that the major crush configuration had a wide impact, with velocity change less than 40 km/h, and with lateral intrusion over no more than approximately one third (< 40 cm) of the passenger compartment. 51 cases were of that type, that was 60% of cases for which delta V could be calculated.

Table 5. Intrusion and Delta V for 59 Wide Impacts that Overlapped the Passenger Compartment

Intrusion (cm)	Interquartile Range of Delta V (km/h)	N
0 - 19	19 - 35	26
20 - 39	27 - 43	19
≥ 40	33 - 62	14
Total		59

By way of summarizing injury outcome associated with crush data, we can say that little (20%) of the serious or fatal injury (MAIS ≥ 3) occurred with intrusion below 20 cm. In wide impacts, such low intrusion was most likely to have been achieved (75%) at a speed change below 35 km /h.

Injury Outcome and Occupant Contacts

For 173 cases injury details were established. These are now considered. Dividing between cases with and without another occupant beside, suggests that there is benefit in having an occupant between you and the impact ($p < 0.05$). Table 6 illustrates the injury outcome.

Table 6. Overall Injury Severity of Non-Struck Side Occupants With and Without Another Occupant Beside

Occupant Beside ?	MAIS 0-1	MAIS 2	MAIS 3+	Total
NO	34 (50%)	18 (27%)	16 (24%)	68 (100%)
YES	70 (67%)	25 (24%)	10 (10%)	105 (100%)

$X^2 = 7.4$, d.f. = 2, $p < 0.05$.

Injury outcome and occupant contacts are now considered by body region. Multiply injured body regions were not uncommon, and in such cases only the injury with the maximum AIS value was tabulated.

Head Injuries. The distribution of the highest AIS from the head/face region is shown in Table 7 along with other body regions. When injury could be rated, over half of the occupants (53%) were known to have head/face injury, and a large proportion were AIS ≥ 2 (28.8%).

For the non-struck side occupant an identified contact in the vehicle for the head or face is the prime indicator of the occupant's trajectory. Forty occupants were known to have head/face injury caused by such a contact, these are detailed in Table 8. The table also indicates if another person was present beside the non-struck side occupant. Contacts are mainly on the struck object, far side components, the occupant beside, or seat beside. Thus, as might be expected, most contacts (73%) resulted from a trajectory towards the struck side. However, 12.5% of contacts were on front components. Far side door and pillar contacts did not occur when another occupant was beside.

Table 7. Distribution of Maximum AIS by Body Region

	AIS 0	AIS 1	AIS 2	AIS ≥3	AIS N/K	Total
Head/Face	70 (47%)	36 (24.2%)	23 (15.4%)	20 (13.4%)	37 (-)	186 (100%)
Neck (excl. cervical spine)	172 (99.4%)	1 (0.6%)	0 (0%)	0 (0%)	13 (-)	186 (100%)
Thorax	109 (63%)	43 (24.9%)	8 (4.6%)	13 (7.5%)	13 (-)	186 (100%)
Abdomen and Pelvic Contents	142 (82.1%)	22 (12.7%)	4 (2.3%)	5 (2.9%)	13 (-)	186 (100%)
Spine	150 (86.7%)	19 (11%)	1 (0.6%)	3 (1.7%)	13 (-)	186 (100%)
Upper Extremities (shoulders, arms and hands)	109 (63%)	45 (26%)	16 (9.2%)	3 (1.7%)	13 (-)	186 (100%)
Lower Extremities (pelvis, thighs and legs)	99 (57.2%)	61 (35.3%)	9 (5.2%)	4 (2.3%)	13 (-)	186 (100%)

Table 8. Contacts Causing Maximum Head/Face Injury

Contact	Occupant Beside ?		Total	
	NO	YES		
Struck Object	5	1	6	15 %
Far Side Components				
Door Glass	1	0	1	42.5%
Door	6	0	6	
Header Rail/Grab Handle	1	3	4	
'A' Pillar	2	0	2	
'B' Pillar	2	0	2	
Other Component	2	0	2	
Occupant Beside	0	3	3	7.5%
Seat Beside	1	2	3	7.5%
Front				
Windscreen	1	1	2	12.5%
Facia	1	1	2	
Steering Wheel	1	0	1	
Other Components				
Occupants Own Seat	1	0	1	5 %
Glass	1	0	1	
Two Points of Contact	2	2	4	10 %
Total	27	13	40	100 %

Thoracic Injuries. Table 7 shows that 37% of the 186 non-struck side occupants were known to have thoracic injury. Thoracic spine injuries are not included. Occupants with highest AIS ≥ 2 made up 12.1%. These were typically multiple rib fractures with haemo/pneumothorax.

There were 60 identified contacts, made by the thorax (Table 9). These data show that thorax injuries are caused mainly by the seat belt. The low incidence of thorax contacts with far side structures, for cases with another occupant beside, is because in those collisions the other occupant was present between the case occupant and the zone of impact. Injury of AIS ≥ 3 occurred in three out of the four cases that were due to far side component contact without an occupant beside. Conversely, the occupant beside caused injury in 10 cases, but all cases scored ≤ AIS 2.

Abdominal Injuries. 17.9% of occupants had a known abdominal injury (Table 7). Injury ≥ AIS 2 was less common (5.2%) than at the head and thorax.

Table 9. Contacts Causing Thoracic Injury

Contact	Occupant Beside ?		Total
	NO	YES	
Struck Object	1	0	1
Far Side Components	4	0	4
Occupant Beside	0	10	10
Seat Beside	3	1	4
Belt Webbing or Buckle	10	26	36
Steering Wheel	1	0	1
Two Points of Contact	0	4	4
Total	19	41	60

Contacts were matched to abdominal injuries in 25 of the 186 non-struck side occupants (Table 10). The great majority, 72% of abdominal contacts, were with the seat belt. However all but one of these were minor (AIS 1). Furthermore, very many occupants with another occupant beside only had minor belt injuries.

Table 10. Contacts Causing Abdominal Injury

Contact	Occupant Beside ?		Total
	NO	YES	
Far Side Door	1	0	1
Occupant Beside	0	1	1
Occupant Beside, with Far Door or Struck Object	0	2	2
Seat Beside	1	0	1
Belt Webbing or Buckle	5	13	18
Other Components	1	1	2
Total	8	17	25

Spine Injuries. Table 7 shows that spine injuries of AIS ≥ 3 were rare. Two of the three serious or fatal spine injuries were caused by contact on the struck object, the third was due to loading by a rear seat occupant.

Extremity Injury. Injuries in the range AIS 1-2 were common at the extremities (Table 7). At the upper extremities far side components, belt webbing, and an occupant beside were the main causes of injury (Table 11). The belt webbing mainly caused minor contusions to the shoulders. The data suggest that occupants beside may have reduced the number of far side contacts. Contacts on the far side occupant did not result in injury greater than AIS 2.

Table 11. Contacts Causing Upper Extremity Injury

Contact	Occupant Beside ?		Total
	NO	YES	
Struck Object	1	0	1
Far Side Components	6	3	9
Occupant Beside	0	6	6
Seat Beside	1	1	2
Belt Webbing or Buckle	3	5	8
Other Components or Occupants	1	2	3
Total	12	17	29

Lower extremity injuries were, as might be expected, chiefly caused by contact on facia, centre console and gear lever.

Results—Sample B

Head Contact Resulting from Occupants Coming Out of their Belts

Figure 6 shows how an occupant may come out of their chest restraint and then contact their head on far side structures. It was desirable to assess if occupants had come out of their seat belt in order to make the contact. A detailed, individual case study was required. This was done using a set of 193 non-struck side occupant cases made available from accidents occurring in the West Midlands Sample B. Head injury cases were selected and evaluated individually. 51 head injury cases of AIS ≤ 2 were found, with the result that 18 (35%) were judged to have come out of their belt.

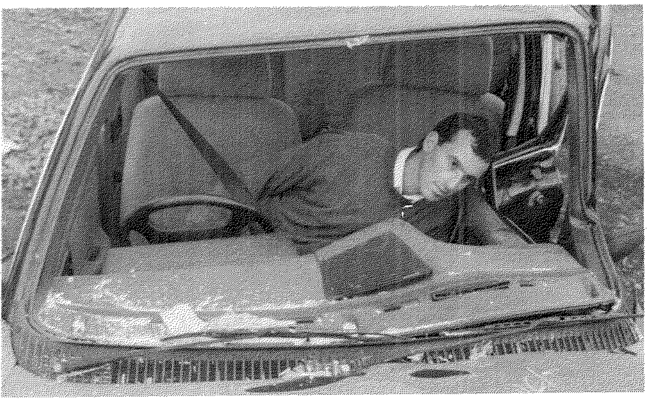


Figure 6. The Non-Struck Side Occupant May Come Out of Their Chest Restraint and Make Contact on Far Side Structures

In sample B, there were 13 additional head injury cases of AIS ≥ 3. In 9 of the 13 cases the intrusion was at least to the centreline of the car, and extended more than two thirds over the struck side seat in the remaining 4 cases. With such amounts of crush it was not possible to assess the function of the seat belt, and it became irrelevant if the intrusion extends up to or beyond the centreline of the car.

Seat Belt Performance

In-depth investigations provide useful feedback to the designer of the performance of various sub-systems in the car in circumstances which cannot be predicted in every respect in laboratory testing. Table 12 details some factors relating to seat belt performance.

Table 12. Seat Belt Function (Cases taken from Sample B)

	N	%
Satisfactory	140	74%
Buckle casing fractured	16	8%
180 degrees of twist in webbing	15	8%
Webbing roped at D ring	11	6%
Belt loose when loaded	6	3%
Webbing broken	2	1%
N/K	3	-
No. of belts examined	190	100%

The incidence of damage to buckle casings illustrates that in lateral collisions the buckle is exposed to specific high-energy blows from the tunnel, the seat or the central armrest structures. In none of those cases did the belt release, but in some instances it resulted in difficulties in undoing the buckle after the collision.

Some 8% of occupants had put their belts on with a twist. That conceivably may result in a less favourable loading across the abdomen in particular. The roping (and jamming) of the webbing at the 'D' ring is probably a consequence of the lateral direction in which the seat belt is being loaded, but it indicates the need for careful consideration of the dynamics of the 'D' ring in collisions which are not frontal. The ultimate consequence may be to encourage the webbing to break prematurely, and there were two cases of that occurring. Given the principle of a swivelling 'D' ring it is difficult to see how that can be avoided at the extremes of crash severity and lateral loading. In 3% of cases there was evidence of the belt being loose when loaded. This was probably due to poor adjustment of the belt combined with a retraction spring which was beginning to fatigue. No belts with comfort features were present in this sample. In no instances was the performance of the locking mechanism of the retractor judged to be unsatisfactory.

Discussion

An appreciable proportion (7.7%) of restrained front seat occupants were seated on the non-struck side during side impact. This paper set out to examine some aspects of side impacts relating to non-struck side occupants.

The available data base was biased towards the more serious or fatal types of accident. Consequently this study will reflect those types of injury situations.

The typical side impact investigated for this study resulted due to an impact from the two and three o'clock direction, or nine and ten. The latter, left hand passenger side impacts, made up the greater part because a driver is present in every case, but a front seat passenger is not always present. This asymmetry will be reversed in the United States where drivers sit on the left hand side.

The greater proportion of vehicles had undergone a wide impact, with velocity change below 40 km/h, and with lateral intrusion less than one third the width of the passenger compartment. However much (52 %) of the serious or fatal injury (MAIS ≥ 3) happened when intrusion was greater than this. When intrusion approaches, or exceeds, the car centre line consideration of belt performance becomes somewhat pointless because highly traumatic contacts on the struck side are inevitable.

In a group of cases with intrusion below 20 cm it was seen that occupants with no, or only minor injury, predominated. Of course intrusion and speed change are complimentary factors in injury causation. So it is interesting to note, that 75% of vehicles with intrusion below 20 cm, underwent a speed change no greater than 35 km/h.

The study of head contact evidence revealed that one third of occupants must have came out of the shoulder section of their seat belt in order to make the contact. A number of factors have a bearing on this event as well as the direction of the impact; the position and adjustment of the upper anchorage, the size of the occupant, the seat position, and the looseness of the seat belt. In the marginal condition the geometry of the upper anchorage will influence the retention of the shoulder, but for pure lateral impacts the torso will translate out of the belt anyway. Further work is needed to examine differences between two and four door cars and adjustable versus fixed upper anchorages, but that requires substantially more cases.

This work has highlighted the susceptibility of the non-struck side occupant's head and face to serious injury. Contacts were often made on the far side structures or intruding object. These contacts were less likely if there was another occupant present beside.

Seat belt webbing caused much of the injury to abdomen, chest, and shoulders. This was inevitable because forces of impact were often applied to the non-struck side occupant solely through the seat belt.

The majority of abdominal injuries were caused by the seat belt, and these tended to be minor contusions. Nevertheless, so many lap belt contusions over the abdomen are cause for concern because of the great danger of severe injury from loading in that region. Abdominal loads from the seat belt are a natural consequence of the crash configuration being considered in this study. The non-struck side occupant is being accelerated in the collision by means of forces applied through the seat belt acting in large part through the lap section. With the lateral flexion of the upper part of the body occurring, in 35% the torso was coming out of the shoulder belt, it is highly likely that the orientation of the pelvis is changing. That results in the inboard section of the seat belt loading the lateral aspect of the abdomen directly. All of the cars in this study had two bucket seats in the front, there were no bench seat designs. Thus most of the seat belt buckles were located relatively low near to the hip joint, often on rigid brackets attached to the seat. Even with such geometry the occurrence of abdominal injury does suggest that the belt is moving from the pelvis into the abdomen. Some cars have a buckle that is relatively highly positioned and thus the buckle itself is loading the abdomen. Some experimental work to examine the relative risks of lateral abdominal loading from various seat belt geometries would be of interest now that a potential means of assessing abdominal loads is available with the foam insert for Hybrid III developed by Rouhana et al (1989).

It seems likely that an occupant beside may reduce abdominal loads, often limiting injury outcome to the level of minor belt-caused contusion. By restricting thoracic displacement, the occupant beside may limit pelvic reorientation thereby avoiding lap-belt problems. The occupant beside can also act as a shield against far side vehicle structures.

The neck, spine and extremities suffered little injury above AIS 2. As for other body regions, there was a suggestion that an occupant beside could limit arm contacts on far side structures. However several injuries of AIS 2 were caused by contact on the occupant beside.

The occupant beside was a notable cause of injury to the head, thorax, and arms. These injuries were seldom severe (AIS ≥ 3) so that it could be said that there was some benefit in having another occupant beside. Indeed the number of non-struck side occupants with serious levels of MAIS was shown to be reduced if another occupant was present beside. Of course the occupant beside will most likely be injured, or have injury against the struck side compounded by this interaction. Further work is needed to consider such injuries. An object beside may limit lateral movement and act as 'padding' over far side structures. Possible design ideas might include suitable inboard support for the pelvis that would aid seat belt function in lateral impacts. Additional experimentation with side mounted air bags should also be carried out with both the struck, and non-struck side occupant in mind. Clearly occupant interactions cannot be disregarded when assessing injury outcome. Impact simulation should include tests with two occupants seated side by side.

This field study also points to some aspects of seat belt function in lateral collisions where the restraint is loaded somewhat differently than in the main design condition of the frontal impact. Buckle performance and 'D' ring operation particularly are of concern in some instances.

Conclusions

- 7.7% of restrained front seat occupants were seated on the non-struck side during a side impact.
- The major crush configuration (60%) had a wide impact, with velocity change less than 40 km/h, and with lateral intrusion over no more than approximately one third (< 40 cm) of the passenger compartment.
- Most injury ≥ AIS3 (80%) occurred when intrusion exceeded 20m.
- 75% of vehicles with intrusion below 20 cm underwent a speed change ≤ 35 km/h.
- The head and face were at high risk, 53% of occupants had such injuries.
- Egress from the seat belt chest section was a common occurrence (35%).
- The thorax and abdomen were vulnerable to injury caused by seat belt loads.
- Lateral movement in seat belts designed for the front impact situation can cause undesirable loads to the abdomen.
- While an occupant beside was shown to cause moderate levels of injury, their presence did reduce the

maximum injury severity. Crash simulation should include experiments with occupants seated side by side.

- There is scope for further experimental work to both, optimize, and investigate technology that might supplement the seat belt used by non-struck side occupants in lateral impacts.

Acknowledgements

The authors wish to thank the sponsors of this research, the Transport and Road Research Laboratory of the UK Department of Transport, the Ford Motor Company, the Rover Group, and Nissan (UK) Ltd. We are also grateful to all members of the Cooperative Crash Injury Project who have contributed to the data collection process, and the many police officers, hospital staff, garage owners and others who form an invisible laboratory for our research.

References

Dalmotas, D.J.; Injury mechanisms to occupants restrained by three-point belts in side impacts. S.A.E. Paper 830462, 1983.

Harms, P.L., Renouf, M., Thomas, P.D., Bradford, M.; Injuries to restrained car occupants, what are the outstanding problems? Proc. 11th E.S.V. Conf. pp. 183-201, 1987.

Herbert, D.C., Stott, J.D., Corben, C.W.; Cutting, D., Gillies, N.; Occupant head space in passenger cars. Traffic Accident Research Unit, Sydney, N.S.W., Jan. 1976.

Horsch, J.D.; Occupant dynamics as a function of impact angle and belt restraint. Proc. 24th Stapp Car Crash Conf. S.A.E. p-88, p. pp. 417-438, 1980.

Mackay, G.M., Cheng, L., Smith, M., Parkin, S.; Restrained front seat occupant fatalities. Proc. 34th A.A.A.M. Conf. Chicago. pp. 139-162, 1990.

Mackay, G.M., Ashton, S.J., Galer, M.D., Thomas, P.D.; The methodology of in-depth car crashes in Britain. S.A.E. p-159, pp. 365-390, 1985.

Otte, D., Suren, E.G., Appel, H., Nehmzow, J.; Vehicle parts causing injuries to front seat car occupants in lateral impacts. Proc. 28th Stapp Car Crash Conf. S.A.E., p-152, pp. 13-24, 1984.

Rouhana, S.W., Viano, D.C. Jedrzejczak, E.A., McCleary, J.D.; Assessing submarining and abdominal injury risk in the Hybrid III family of dummies. Proc. 33rd Stapp Car Crash Conf. S.A.E., p-227, pp. 257-280, Oct. 1989.

Thomas, P., Bradford, M.; Side Impact Regulations—How Do They Relate to Real World Accidents? Proc. 12th E.S.V. Conf. N.H.T.S.A. pp. 919-929, May 1989.

☆US GOVERNMENT PRINTING OFFICE : 1993 O - 354-702 (vol.1)

DOT HS 807 990
JULY 1993