International Harmonized Research Activities - Intelligent Transport Systems (IHRA-ITS) Working Group Report

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ABSTRACT

The International Harmonized Research Activities Working Group (IHRA) on Intelligent Transport Systems (ITS) was established to coordinate, collaborate and exchange information on research aimed at optimizing the safety performance of ITS. This report describes some of the key activities in recent years. The working group has also started to publish a IHRA-ITS newsletter through INRETS that describes these research activities. The working group continues to pursue seven priority research topics. This group recently offered to support the UN-ECE World Forum for the Harmonization of Vehicles (WP 29) Informal Group on ITS in their efforts to establish a common understanding of new in-vehicle ITS technologies and to exchange information. In the next year, this working group will brief the WP.29 ITS informal group on a number of key safety issues for ITS. In sum, the IHRA-ITS working group continues to be an effective forum for international harmonized research on ITS safety.

BACKGROUND

At the ESV conference held in Melbourne, May 1996, the Government Focal Point Committee developed an International Harmonized Research Agenda (IHRA). The need for collaborative research in Intelligent Transport Systems (ITS) was identified as a high-priority research area, in recognition of the rapid advances in related technologies and their considerable potential to influence motor vehicle safety. Canada was identified as the lead country for this activity and tasked with coordinating harmonized research in ITS.

The primary goal of harmonized research in ITS is to develop test procedures to assess driver-vehicle interaction as a means for determining the safety potential of ITS crash avoidance and driving enhancement for in-vehicle systems. The scope of the research program in ITS was defined and limited by emphasis on three key elements:

1. Government orientation: The research is intended to support the needs of governmental authorities with responsibilities for establishing vehicle safety regulations, promulgating national standards, and for related programs requiring national leadership. The ultimate aim is to develop the scientific basis for internationally harmonized regulations in this area.

2. Safety Evaluation: The main focus of the research is to foster ITS technologies which will have a positive influence on motor vehicle safety. It is anticipated that the research will lead to a) the identification of vehicle-based technologies which can be used for the prevention and mitigation of traffic collisions, and b) the development of regulations that will inhibit technologies which are likely to have an adverse affect on safety. ITS technologies are evolving rapidly and neither design nor performance criteria can adequately address the safety assurance requirements of systems for which the underlying technologies and functionality are constantly changing. For this reason, there will likely be an increasing need for prospective techniques for evaluating system safety in the development and certification of ITS vehicles.

3. Driver-ITS interaction: The collaborative research will emphasize crash avoidance interventions and focus on developing methodologies for assessing the safety of driver-ITS interaction as a means to minimizing the risk of collision. The human-machine interface is arguably the most critical element of the system since the vast majority of crashes involve human errors. The ergonomics of the interface and human factors underlying driver-vehicle interactions are paramount to the realization of the full safety potential of ITS technologies. Conversely, unless the interface is designed to support the driving task and take into consideration driver capabilities and limitations, its impact on safety can be highly negative. Hence, driver-ITS

interaction represents an area in which collaborative research can identify important opportunities for developing internationally harmonized safety interventions which are not unduly hampered by incompatible, pre-existing strategies.

Participation

The following countries have actively participated in the ITS WG throughout its history: Canada, France, Germany, Japan, Sweden, the United Kingdom and the United States, We have also had participation on occasion from Poland, Australia, and The Netherlands. While most WG members represent national governments some members come from the automotive industry. In certain cases, notably France, Germany and Japan, the national representatives come from industry or government research organizations and participate on behalf of the relevant government agencies.

The ITS working group has had two meetings per year on average. The most recent meetings were in:

November 20-21, 2003, Madrid, Spain
June 24-25, 2004, Paris, France
October 22, 2004, Nagoya, Japan
February 17, 2005, Brussels, Belgium

The following people attended our last meeting in Brussels:

Peter Burns, Chairman, Transport Canada
Christhard Gelau, BASt, Germany
Ruggero Ceci, SRA, Sweden
Åsa Gustafsson, SRA, Sweden
August Burgett, NHTSA, U.S.
Kaneo Hiramatsu, JARI, Japan
Annie Pauzié, INRETS. France
Chris Ward, DfT, UK
Maxime Flament, Ertico, Belgium

The minutes from most of these meetings are posted on the IHRA website: www-nrd.nhtsa.dot.gov/IHRA.

RECENT ACTIVITIES

A group of international ITS safety experts identified priority research areas for the IHRA-ITS group at a workshop in Washington DC in 1999. The working group lead research, exchanges research information and conduct collaborative work on these topics. Some recent activities are described below according to these priorities.

Project 1: Development of a Harmonized Safety Evaluation Methodology Framework

The objective of this project is to develop a Harmonized Safety Evaluation Methodology Framework for in-vehicle information, control, and communication systems with respect to human performance and behaviour. There are several activities that fit under the umbrella of this priority project.

Dr. Pauzié (INRETS) described some European activities relating to this priority. AIDE - adaptive integrated driver–vehicle interface is a European integrated safety project. Integrated projects are a research tool in the European 6th Framework Program. This 4 year research program will include work on developing evaluation tools for assessing the safety if ITS. Volvo Technology is the project leader for AIDE (www.aide-eu.org).

HUMANIST is a European network of excellence concerned with the human-centred design of ITS technologies. These networks are another European research tool. The consortium has 22 partners from 14 difference countries that make up a “virtual research centre” performing a joint program of activities. Task Force E in this network is concerned with the development of methodologies for assessing the safety of ITS. The IHRA-ITS WG was identified as an important contact for the exchange of information with the HUMANIST consortium. Although there are no funds dedicated for research, there is money to support dissemination and integration activities (www.noehumanist.org).

ITS Europe conference in Budapest 2004, had several sessions dedicated to evaluation methodologies (www.itsineurope.com/its_pres.cfm). WG member Dr Burgett (US DOT) presented a basic computational framework for assessing the safety impact of new technologies at this conference. The framework considers the socio-economic benefits which can be obtained by the introduction of ITS. The safety assessment is based on estimates of the impact ITS has on crash prevention and exposure.

INRETS have also drafted a list of evaluation measures. The WG has commented on these measures and the list will be developed further.

This WG has several partners in the European research project HASTE (Sweden, Canada, Netherlands and UK). The aim of HASTE (Human Machine Interface And the Safety of Traffic in Europe) is to develop methodologies and guidelines for the assessment of in-vehicle information systems (www.its.leeds.ac.uk/projects/haste/research.htm). Project HASTE involves the cooperation of eight partners (7 European and 1 Canadian TC) in a concerted effort to address this issue. The final experiments in this 3-year project have been completed. The project will be wrapping up early in 2005 with only some final analyses, meetings and reports remaining. Transport Canada and the other project partners recently assessed two available aftermarket information systems using the HASTE performance measures. A workshop was held in Brussels on March 22, 2005 to present the results of the project and what was learned.

The Collision Avoidance Metrics Partnership (CAMP) in the U.S. has one research project concerned with driver workload metrics. There was a joint research meeting between the U.S. project CAMP and European project HASTE in June 2004 to discuss methods and results.

Data collection in two field operational tests, the heavy vehicle rear-end crash warning system and the light vehicle rear-end crash warning system, has been completed in the U.S. and analysis of the data has begun. Analysis of these data and estimation of the safety impact will be completed by the summer of 2005. Work on development of standardized approaches for predicting safety benefits continues to make progress.

Transport Canada is conducting a series of small studies to follow on from the HASTE research. A study was conducted to build on the efforts of a German consortium in the ADAM (Advanced Driver Attention Metrics) project.[1] ADAM was a German research project funded by DaimlerChrysler and BMW and was looking into similar issues as CAMP and HASTE. A principle deliverable from the ADAM project was the lane change test (LCT), which is a relatively simple and low cost standardized test scenario. The LCT requires drivers to repeatedly perform lane changes when prompted by road signs while driving a simple desktop driving simulator. The amount of distraction due to the additional demands of secondary task performance is evaluated according to lane change quality relative to a normative model. Early results show that the LCT is sensitive to both visual and cognitive distraction.[1]

Early indications of the LCT's potential as a practical and effective measure of driver distraction has raised its profile, particularly within the automotive industry.[2] The procedure is now being further developed as a draft ISO standard.[3] Despite the interest, there is little published research available on the procedure. In addition, the procedure is still under discussion and may be modified.

A Transport Canada study was conducted to learn more about the LCT. The LCT technique was applied to four destination entry tasks on an aftermarket navigation system. The experimental set up included a steering wheel, foot pedals, monitor, computer and navigation system, all off the shelf. The results indicated that the LCT is a sensitive measure of driver distraction. The participants showed greater mean deviation in lane change path when driving while performing a secondary task (i.e., calibration and navigation tasks) than when driving without performing a secondary task (i.e., baseline). The next step will be to compare the results of this study the HASTE project, which ran multiple studies on the same set of navigation tasks using a variety of driving performance metrics. Transport Canada plan to assess the same tasks using the Occlusion test in the next few months.

Project 2: Driver Understanding and Expectation of ITS Systems: Identification and Measurement of The Effects of False Expectation of Driver Performance

The purpose of this project is to identify factors that affect a driver's understanding of ITS system functional characteristics and determine how they develop performance expectations for these systems. In particular, the main objective is to assess the safety consequences of mismatches between driver expectation and system performance.

There is a new U.S. project called " Real World Effectiveness of Advanced Technologies" that started in Sept. 2003. The project will identify and interview "early adopters" who have purchased vehicles equipped with ITS, such as Adaptive Cruise Control, navigation and night vision systems. The project has utilized mail-outs, newspaper advertisements, internet advertisements, magazine advertisements, and incentive mail-outs. Analysis of these data is not yet complete.

Dr. Flament (Ertico), as part of the liaison activities within the European Integrated Project PReVENT, described the EC 6th Framework integrated project on active safety at our last working group meeting. The subproject Response 3 is particularly relevant to this priorty (www.prevent-ip.org).

Project 3: Human Factors Principles Checklist For In-Vehicle Systems

The purpose of this project is to develop a checklist based on human factors principles to be used in the safety evaluation of in-vehicle systems.

C. Patten (SRA) described plans in Sweden to further develop and evaluate the assessment checklist developed by the Transport Research Laboratory (TRL) in the UK. The checklist is also being further developed at TRL as part of the Primary New Car Assessment Program (PNCAP). The EU is now planning to increase the scope of the assessment procedure by incorporating primary safety considerations (braking, lighting, visibility, handling and ergonomics). This may be a potential opportunity for some collaboration.

Project 4: Normative Data On Naturalistic Driving Behavior

The purpose of this project is to characterize driving behaviour in realistic situations by developing a driving performance database which comprises data on normal driving behaviour, in-vehicle ITS system usage, safety critical events, and crash data. Naturalistic driving means unsupervised driving on public roads.

Dr Burgett described progress on NHTSA’s 100 Driver Naturalistic Driving Study. This project collected data from 100 vehicles equipped with data collection systems. Data collection is complete and preliminary analysis has been completed. These data will provide a strong foundation of basic driving behavior and likelihood of various events and types of crash occurring as well as providing data on the level of driver attention before crashes or near-crashes. The relationship between driver workload metrics and level of safety will be one focus of the analyses. Data from this research will generally be available to others for additional analyses.

Project 5: Simulator Reference Test Scenarios

The goal of this project is to develop a catalogue of driving scenarios for use in driving simulator research. The set of scenarios should encompass the breadth of driving possibilities from uneventful everyday situations to safety critical situations.

An IHRA Driving Simulator Scenarios workshop that was held in conjunction with the Driving Simulator Conference - North America (DSC-NA, 2003). The goal of this workshop was to develop a catalogue of driving scenarios for use in driving simulator research. The workshop was considered to be beneficial although it was only a small first step towards achieving the goals of this priority project. Material from the workshop was posted on the IHRA-ITS WG web page.

One recent U.S. project has replicated a test-track experiment using the National Advanced Driving Simulator (NADS). The purpose of this validation study is to provide data from which driver performance in a vehicle can be compared to driver performance in a simulator. The results of this testing show that the level of correlation depends on several factors, including level of braking. For example, simulator steering onsets are not as aggressive as closed-course conditions. Another finding was that there was better correlation for those conditions that produce noticeable looming. The final report of this project is in preparation.

There are an increasing number of initiatives currently underway on this topic. The Canadian Automobile Research Simulation (CARS) network funded by AUTO21 is investigating in-vehicle and related ITS technologies. There was a panel on Critical Issues in Simulation Methods and Measures at the upcoming meeting of the Human Factors and Ergonomics Society. The TRB Simulator Users Group is also very active in this area (www.uiowa.edu/~neuroerg/) and there are routine discussions of test scenarios at the annual International Driving Simulator Conferences (DSC). The next North American meeting will be held in Orlando in November, 2005.

Project 6: Improved Secondary Task Methodology For Evaluating Safety Effects of Driver Workload

The goal of this project is to develop a useful secondary task methodology to calibrate workload effects of combining in-vehicle and out-of-vehicle information.

There are a considerable number of international research projects underway on this topic. Joint research by Japan (JARI), Germany (BASt), and Sweden (SNRA) has been performed on this topic. A report has been completed summarising a portion of this joint research and this will be published in the journal Transportation Research, Part F. National research activities are also underway in Canada, France, Japan, Sweden and the U.S among others.

Project 7: Harmonization and Validation Of Surrogate Safety Measures

The goal of this project is the harmonization and validation of surrogate safety measures. Surrogate safety measures are measures that can be used to estimate numbers of crashes and resulting injuries and deaths.

The U.S. is investigating one method that uses range/rate diagrams to crash prevention boundaries for defining a level of risk. Several field operational tests are also under way.

NATIONAL REPORTS

This section documents other relevant ITS safety research activities from each member's country that may not fit specifically within the priority activities.

Japan

Dr Hiramatsu (JARI) distributed ITS Japan's new journal entitled International Journal of ITS Research. The first issue was published in December 2003 (www.its-jp.org/english/).

There was a recent change in Japan's legislation/ enforcement - "the usage of mobile phone in hands as well as the gaze at display equipment during driving are prohibited and punished. This law was set in 1999, and its strict application has started since 2004 Nov." "the number of traffic accidents with regard to mobile phone increased double in 2003 compared in 2000." www.npa.go.jp

The Japanese Automobile Manufacturers Association recently released a new version of the JAMA guidelines for in-vehicle display systems. Version 3.0 of the JAMA guidelines incorporates performance criteria. The basic intent is that in-vehicle informations systems be designed not to have an adverse effect on safe driving. The new performance criteria set limits on visual distraction. The operation of a display is prohibited if the task requires a total glance time in excess of 8 seconds. Using the Occlusion method, the total shutter open time shall not exceed 7.5 seconds.

France

Dr Pauzié (INRETS) described some relevant French and European activities (www.arcos2004.com). ARCOS is a pre-competitive research project that aims at improving road safety. It considers vehicle, driver and road as a whole system. The project aims at enhancing driving safety on the basis of four safety functions: controlling inter-vehicle distances; avoiding collisions with fixed or slowly moving obstacles; avoiding lane exit; and alerting other vehicles of accidents.

Dr Pauzié described how speed enforcement has gained some support in France and distributed a brochure from the PROSPER project on Intelligent Speed Adaptation (www.prosper-eu.nl).

ECTRI, the European Conference on Transportation Research Institutes, is an association to actively promote the cooperation of surface transport research in European (www.ectri.org).

Sweden

C. Patten described the research work mobile phones and subsequent enquiry. A recent decision was made in Sweden not to ban hand-held cell phones. This was based on the research findings that concluded hands-free phones are no less distracting than hand-held phones.

The Swedish SafeTE project is continuing to look at subjective and objective evaluations of the safety of in-vehicle information systems (IVIS) and advanced driver asssistance systems (ADAS). The techniques of interest include: checklist, peripheral detection task (PDT) and visual performance indicators. The checklist focuses on an expert evaluation of driver-system interaction, for example interface design, system feedback, semantic content and compliance with regulations and standards. The PDT testing, with visual and tactile stimuli, has been completed and analyses are underway.

A Swedish program called IVSS (intelligent vehicle safety systems initiative) started in 2004 to support industry cooperation and promote ITS safety. There are 7 R&D program areas within the Swedish Intelligent Vehicle Safety Systems (IVSS) program, HMI is one of these areas. Further details are available from the following link: http://www.pff.nu/Main.aspx?ObjectID=59d6e9b2-93bf-459e-9b09-b2daaa5c5d6b The SRA is directly involved in two different projects on driver impairment monitoring. One concerns driver drowsiness and the other concerns drugs. Both are focusing on specific sensors to detect impairment, e.g., eye-tracking cameras. The major tasks are to find test regimes and methodologies for evaluation and deployment.

Canada

Transport Canada is conducting an assessment of the Alliance of Automobile Manufacturers (AAM) Statement of Principles. This project aims to evaluate compliance of advanced in-vehicle information and communication systems to the AAM principles. The AAM has been developing principles to address the safety aspects of driver interactions with future telematics systems. Their statement of principles document was developed by consensus with industry stakeholders and continues to evolve. The document outlines principles that must be followed to improve the safety of driver interaction with telematics systems and stipulates performance criteria and verification procedures. The principles from this document were largely based on the European Commission recommendations of December 21, 1999. The results of these voluntary industry principles will apply to vehicles with design freezes after 2006. Although this initiative promises to improve the safety of these systems, there is some uncertainty as to the level of safety and effectiveness of the AAM procedures and criteria. Thus, there is a need to thoroughly evaluate the AAM's 24 principles and to measure the compliance of current in-vehicle devices to these principles as a benchmark for change. Furthermore, there is a need to evaluate whether the verification procedures are explained in sufficient detail to be applied effectively.

In-vehicle information and communication systems, also known as telematics systems, from four leading manufacturers will be evaluated according to the most recent guidelines from the AAM document "Statement of Principles, Criteria and Verification Procedures on Driver Interactions with Advanced In-Vehicle Information and Communication Systems". Results will provide insight into how the current automotive industry standard for telematics systems rate on these new criteria. The project will also independently assess the value of these industry guidelines and use these results as benchmark data on which to assess the safety developments of future telematics systems.

This work will provide essential input into the Memorandum of Understanding (MOU) that is currently being negotiated with the automotive industry (see below). Part of this MOU concerns the AAM principles and we need to know the value of these principles prior to making any endorsement of certain principles. The proposed project is divided into 2 phases, to be carried out over a two-year period. The first phase (to be completed in March 2005) consisted of measuring four in-vehicle systems and assessing their compliance to AAM principles for which verification procedures do not require dynamic testing. The second phase will involve dynamic testing of the same devices used in Phase 1. The dynamic testing of the devices will consist of experiments conducted according to verification procedures outlined in the most recent version of the AAM principles, which is anticipated for Spring 2005. Both phases will also evaluate the validity and reliability of the AAM verification procedures.

Transport Canada consulted with the public and industry stakeholders in 2003-04 to identify potential initiatives for limiting the problem of driver distraction from in-vehicle devices (http://www.tc.gc.ca/roadsafety/tp/tp14133/en/menu.htm). TC investigated public opinions on this issue using a survey and focus group discussions. Stakeholders' comments were received on the discussion document in September 2003 and meetings and workshops were held with industry and provincial stakeholders to discuss strategies. These consultations indicated that a MOU with the automotive industry was widely viewed as the preferred strategy. The purpose of this MoU between TC and the automotive industry would be to set out the general terms and conditions with regard to limiting driver distraction from in-vehicle telematics devices. The parties to Transport Canada's proposed MOU would recognize and acknowledge:

- that distraction is a safety problem and that in-vehicle telematics devices should be designed to minimize their potential to distract drivers.
- that there are currently no performance criteria that have been proven effective in minimizing distraction across a range of technologies

- that there are general guiding principles that can help designers limit distraction
- that the most appropriate approach towards addressing the safety concerns associated with telematics is for manufacturers to develop corporate policy (processes) to ensure that driver-vehicle integration considerations are addressed, consistent with the basic principles

Negotiations on the terms of this MOU are currently underway with the goal of reaching an agreement by early 2006.

Another Transport Canada project is investigating and developing methods for assessing the performance of safety critical in-vehicle warnings. This work will investigate and assimilate the research on measuring the performance of warnings. Although the main focus will be automotive warnings, this project will also provide a survey of what can be learned from other applications (e.g., air) and applied to the automotive realm. Criteria such as conspicuity, perception and reaction time, response type, appropriateness of response, signal detection (false alarms, hits, misses, rejections) and annoyance levels will be considered. Early in 2005, a review of the current state of the literature on warnings was conducted. The next step will be to apply selected to performance measures to a set of automotive warning systems to evaluate the effectiveness of the procedures and criteria.

Lastly, Transport Canada is investigating ITS and speed management. The aim of this project is to develop an understanding and quantify the effects of technical measures to control vehicle speeds in traffic in terms of their potential impact upon collisions and injuries, traffic speeds and congestion, and reductions in greenhouse gases (GHG). Reducing speed could be a practical way to reduce GHG emissions and excess speed is an acknowledged road safety problem. Technology is now available that allows vehicle speeds to be automatically restricted based on current road characteristics, traffic, and even weather data. For example, Intelligent Speed Adaptation (ISA) is an on-board system that regulates the speed of motor vehicles in traffic according to their location on the road network. The potential for ISA and other strategies for improving safety and reducing greenhouse gas emissions in Canada needs to be investigated.

The main activities on this project are: 1) literature review, 2) ISA demonstration and evaluation, 3) fuel consumption tests, 4) fuel consumption display demonstration and evaluation, 5) investigation of speed attitudes & behaviour, 6) modelling & simulation and 7) infrastructure based speed strategies. A demonstration vehicle was built and an international workshop was held in Ottawa on March 8-9, 2005 to plan the Canadian evaluation of ISA in 2005-06. This will eventually be followed by a field operational test of ISA.

Germany

Dr Gelau described some ongoing research at BASt on the measurement of driver workload when driving a motorcycle. They are assessing navigation on motorcycles, and also looking at older drivers needs from ADAS. BASt are also in the process of building a new research facility in Cologne for ergonomics and road safety.

U.S.A.

Among other developments in the U.S., Dr Burgett described the restructuring of the ITS program in the US DOT. The IVI program will cease to exist towards the end of 2004 and will be replaced by these new ITS research initiatives outlined at this link: www.its.dot.gov/press/initiatives4.htm

Harmonization of Vehicle Regulations

The United Nations Economic Commission for Europe's (UNECE) working party 29 is a World Forum for Harmonization of Vehicle Regulations (WP.29). An informal group was established within WP.29 in 2002 to discuss Intelligent Transport Systems and the implications this technology has for automotive safety and regulations. The ITS Informal Group assumes the role of a strategic group for supporting the development of new technologies for enhancing safety, works to expand the knowledge of these technologies, develops a common understanding of them and discusses the course of their handling in the regulatory framework if necessary.

Dr I. Noy (Transport Canada) addressed the AC.2, Administrative Committee, and WP.29 with respect to the work of this WG. The principal objectives were to introduce WP.29 to the challenges posed by ITS and to recommend that WP consider how ITS-related activities might be integrated into its work program. It was also proposed that the IHRA-ITS WG provide research support to WP.29 on ITS safety issues. A recent proposed Terms of Reference from Japan for the WP.29 ITS informal group suggested collaboration between the two groups. IHRA-ITS WG members discussed this proposed collaboration at our last meeting. All members agreed that this WG is well suited to support WP.29.

The IHRA-ITS working group extended an offer to support the WP.29 ITS Informal Group on their proposed short term tasks of: 1) developing a common understanding of driver assistance and 2) information exchange. The chairmen of both groups discussed this proposal at a meeting in Nagoya in October, 2004. Mr Wani (MLIT), Chairman of the WP.29/ITS Informal Group, indicated at this meeting that it would be useful to have two-way communication between the groups. The WP.29/ITS Informal Group would benefit from the views and information about research activities from IHRA/ITS WG. On the other hand, discussions in WP.29/ITS Informal Group are beneficial for IHRA to consider its directions of its research activities.

As a starting point, it was suggested that WG members make presentations to the ITS Informal Group on several leading research issues in ITS. Dr Hiramatsu (JARI), representing IHRA, made a presentation to WP.29 in November 2004 in Geneva explaining our proposed contributions. He explained to the informal group the issues affecting Human-Machine Interaction and provided statistics from Japanese studies demonstrating the effect that Human factors can have on fatal and serious injuries. He demonstrated by means of block diagrams how these fit together and how information overload needs to be considered as part of the development programme (see Figure 1 and Tables 1 & 2). A hierarchical system of warning is needed and should be integrated with the timing and type of system/warning. For vehicles control, then issues such as convenience and severity reduction were important.

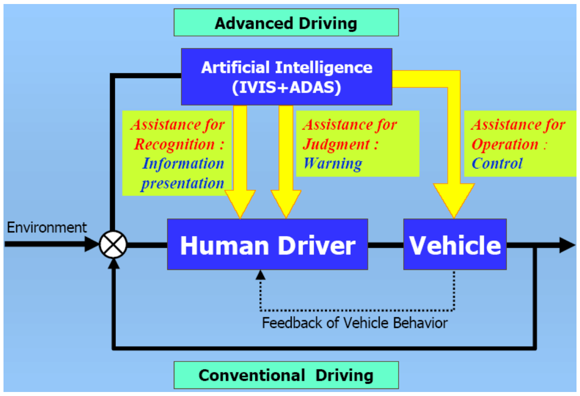
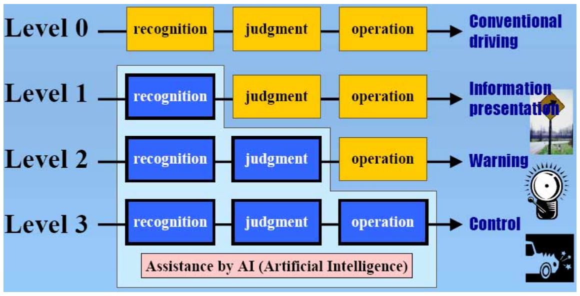


Figure 1. Block Diagram of Driving Behaviour

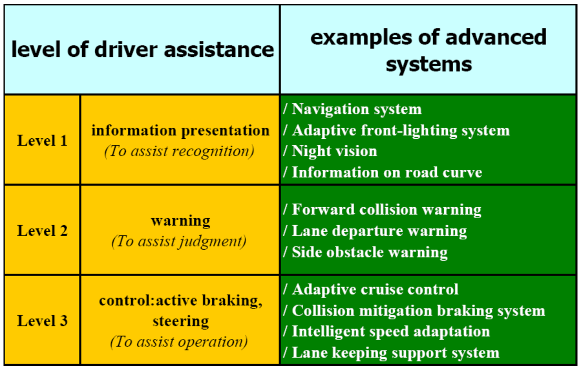
Table 1.
Behavioral Model of a Driver and Level of Driver Assistance.



Level 0	recognition	judgment	operation	Conventional driving
Level 1	recognition	judgment	operation	Information presentation
Level 2	recognition	judgment	operation	Warning
Level 3	recognition	judgment	operation	Control

Assistance by AI (Artificial Intelligence)

Table 2.
Classification of Advanced Systems according to Level of Driver Assistance.



level of driver assistance		examples of advanced systems
Level 1	information presentation *(To assist recognition)*	/ Navigation system / Adaptive front-lighting system / Night vision / Information on road curve
Level 2	warning *(To assist judgment)*	/ Forward collision warning / Lane departure warning / Side obstacle warning
Level 3	control:active braking, steering *(To assist operation)*	/ Adaptive cruise control / Collision mitigation braking system / Intelligent speed adaptation / Lane keeping support system

The following contributions and schedule was agreed at our last WG meeting in Brussels.

1. Dr Christhard Gelau (BAST) and Dr Annie Pauzié (INRETS) will present a comparison of the EU statement of Principles, AAM Guidelines and JAMA requirements to WP.29 at the 136th meeting in Geneva in June, 2005.
2. Dr Peter Burns (Transport Canada) will report on driver distraction research in

North America requirements to WP.29 at the 137th meeting in Geneva in November, 2005.

3. Dr Hiramatsu (JARI) will present the issues on automation and the idea of "Driver in the Loop" to WP.29 at the 138th meeting in Geneva in March, 2006.

Newsletter

IHRA
ITS
SAFETY AND HUMAN FACTORS

INRETS was given some funding from the French Ministry of Transport to support IHRA-ITS activities. This funding has been used to support a newsletter that reviews this WG's activities. The newsletter will be in French and English and will be placed on the WG's and INRETS website. The first issue has been completed and the second issues is now being prepared.

SUMMARY

In sum, the IHRA-ITS working group continues to be an effective forum for international harmonized research on ITS safety. As ITS is becoming more prevalent in the field and is under intensive development, this working group is now conducting a strategic review of its organization and research prioirities.

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SCENE TRIAGE CRITERIA ASSOCIATED WITH FATAL CRASHES AND POTENTIAL FOR USE OF EVENT DATA RECORDER (EDR) DATA

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ABSTRACT

Millions of cars on the road today have Event Data Recorders (EDRs). A small percentage of cars currently have EDR data downloaded, typically hours or days after a motor vehicle crash (MVC). However, real time use of EDR data at the crash scene has the potential to save lives by providing additional quantitative information to emergency medical services (EMS) personnel in order to enhance the decisions they make on how and where to transport seriously injured persons (scene triage).

This paper presents the results of a population-based statewide study of all individuals involved in a specific type of fatal level crash for an entire year. (This paper reports on a subset of crashes from a statewide study of *all* fatal crashes for one year.) Based on the data collected for each victim of the crash, triage criteria were recorded and then compared to the victim's actual type of transport, (ground ambulance vs. air medical), injury severity, outcome, and hospital type (e.g., community hospital or trauma center).

The triage criteria collected for these crashes, including "mechanism of injury" criteria, (e.g., speed of crash), were then compared to data possible to collect from EDRs to determine how often EDR data could potentially be used to complement and potentially enhance triage decision making. A key decision that must be made at the scene of a serious crash is whether or not the severity of the crash or injuries would warrant a request for air medical transport to a trauma center (instead of ground ambulance transport to a community hospital). For the study group 16% were transported to a trauma center by ground, 11% by air.

From the study results, the paper discusses how the statewide use of quantitative real time EDR data could potentially enhance current triage guidelines.

INTRODUCTION

The medical literature shows trauma victims' outcomes are influenced by triage decisions made at the scene of the injury or crash.[1-4] Trauma victims' outcomes, (particularly for the most severely injured victims), have been shown to vary with use of different types of transport (e.g., ground vs. air medical ambulance) and different levels of hospitals (e.g., community hospitals vs. trauma centers).[5-14] In another paper related to this study by the authors, the outcomes of crash victims were found to vary by 2:1 depending on the crash victim's "pathway" through the medical system. [in publication process]

A number of large population-based state and federal crash data bases contain detailed information about various characteristics of crashes, however, the utilization of medical system resources by crash victims is not their focus and therefore, it is not generally documented at all or in detail.[15,16] In addition, these data bases do not attempt to collect any information about what triage criteria may have been used at the scene of a crash to decide how and where to transport a crash victim for emergency medical treatment.

In order to determine what triage criteria may be associated with the type of emergency transport or hospital care crash victims actually received, it is necessary to conduct special studies..[17-20]

This paper reports part of the results from a statewide study of all persons involved in fatal level crashes for one year in Massachusetts. This study provides a population-based "snapshot" of the physiological, anatomical, mechanism of injury and special conditions triage guidelines matched to crash victims. This is one in a series of papers and presentations that present findings from the overall study; two papers have been published to date. [21,22]

In addition, the paper identifies which of the mechanism of injury (MOI) triage criteria, (e.g., “high speed crash”), may be possible to translate into appropriate engineering terms, and capture from existing, (or future), EDRs. At the time of this study, Massachusetts had the lowest MVC death rate in the US (one half the US rate).[16] The Massachusetts’ rate was also one of the lowest in the world. [27]

Real-time use of the crash information from EDRs at the scene has the potential to enhance the triage decisions made by EMS personnel and save lives. In theory, the quantitative information from the EDR, *in combination with assessments of vital signs, level of consciousness and anatomic injuries at the scene,* can assist the decision-making process regarding how, (by ground or air ambulance), and where, (community hospital or trauma center), to send crash victims for optimal care. The authors and their colleagues have made multiple presentations related to this topic to national EDR groups.[23-26]

METHODS

This paper reports on a subset of a statewide, population-based study that tracked all victims (n=940) of fatal level crashes (n=392) through the medical system from the scene of a crash. Fatal crashes were defined as those that had at least one person die from crash-related injuries within 30 days of the crash.

This paper’s study population includes the 729 victims of 338 crashes who were occupants of passenger cars, vans and light trucks because these are the types of passenger vehicles that currently have, or may have in the future, EDRs. Non-occupant crash victims, (i.e., pedestrians, cyclists, motorcyclists, etc.), were excluded from this study. Table 1 shows the relationship of the study population to the state data overall.

Tracking crash victims required linkage of multiple statewide data sources, including crash, air medical, inpatient hospital and vital statistics.[16,28-31] Statewide ground ambulance, emergency department or trauma registry data bases did not exist at the time of the study. Paper records were collected and reviewed, including police and reconstruction reports, ground ambulance runs, and media reports.

All available documentation (electronic and paper) was reviewed to match each of the seriously or fatally injured crash victims involved in the 338 crashes to the appropriate triage criterion included in an air medical transport triage guideline developed by the state of Massachusetts and/or the trauma center triage guidelines developed by the American College of Surgeons (ACS).

The Massachusetts Department of Public Health (MDPH) and statewide Helicopter Utilization Review Committee (HURC) adopted recommended Air Medical Triage Guidelines in 1997. We retrospectively applied these guidelines to 1996 crash victims to try to identify patients who may have qualified for air medical transport from the scene of a crash. A copy of the MDPH air medical triage Guideline is included in a previous paper.[21] All references in this paper to air medical transport mean helicopter emergency medical services (HEMS), rather than fixed wing.

Table 1 Massachusetts Motor Vehicle Crashes, CY 1996

Group	Population	Number of Crashes	Number of Persons
I.	Operator & Police Reported Crashes, All Injury Levels	187,963	217,373
II.	Police Reported Crashes, All Injury Levels	106,359	126,547
III.	Police Reported Crashes, Maximum of Serious Injury	3,286	3,852
IV.	Police Reported Crashes, Maximum of Fatal Injury*	392	940
V	Police Reported Crashes, Maximum of Fatal Injury* for Occupants of Passenger Cars, Vans & Light Trucks	272	729

Notes *Died within 30 days of crash

The ACS developed and published a Field Triage Decision Scheme that is used to help identify patients who may be severely injured enough to require transport to a trauma center. [32]

Both the HURC and ACS guidelines have multiple sections with individual components in each section. These sections and components are described later. In this paper we have shown each of the components separately. Although some of the triage components are designed by MDPH or ACS to be used in combination, the fact that a crash victim met at least one triage criteria component indicates that they may have potentially qualified for a high level of emergency care.

All references in this paper to trauma centers mean American College of Surgeons (ACS) Level I trauma centers. At the time of this study, Massachusetts did not have a statewide trauma system nor did it have any ACS Level II or Level III trauma centers.

In a note accompanying its triage guidelines, the ACS acknowledges that systems of medical triage are inherently imperfect in classifying injured patients and can result in both over-triage (minimally injured patients taken to trauma centers) and under-triage (severely injured patients taken to non-trauma centers). [32] The ACS states: "In most systems, an under-triage rate of 5-10 percent is considered unavoidable and is associated with an over-triage rate of 30-50 percent.

An over-triage rate of up to 50% may be required to maintain a minimum level of under-triage in a community." This was included in the 1993 revision of the ACS book "Resources for Optimal Care of the Injured Patient, (the version in effect at the time of the study), and repeated in the 1999 version, which is still in effect.[32,33]

Although over-triage rates in the range of 30-50% sound large, because they are being applied to the top of the injury pyramid, they result in relatively small numbers to distribute over a statewide trauma system over a year. ACS points out: "It is estimated that because of the small number of patients who really need to be in trauma centers, the impact of patient flow on an individual institution will be minimal, should this degree of over-triage exist." [32]

The seriously or fatally injured crash victims were matched with all applicable triage guideline components. By tracking the pathway of each person through the state's medical system, their transport type and destination hospital were known. From this information it was possible to compare their actual utilization of air medical or trauma center services to the guideline criteria. It was also possible to calculate what numbers of patients would have represented a 30-50% over-triage rate, as noted by the ACS (as a reasonable system-wide goal).

The mechanism of injury (MOI) triage criteria components, for example, "high speed crash", that are included in the triage guidelines were compared to the data that is currently (or potentially) possible to collect from EDRs. This was done to determine if EDR data, collected at the scene of the crash in real time, could provide additional objective, quantitative data that might enhance triage decision making. We also examine the population of study victims that might have potentially benefitted from the EDR data.

RESULTS

Population Characteristics

The injury level distribution of the study population is shown in Table 2. Two hundred and ninety-six or 41% of the crash victims were either uninjured or sustained minor injuries (including a small number of unknowns). Only eight of these lower-severity patients were found to meet any of the triage criteria,

Table 2 Study Population: Persons Involved in Fatal Level
n = 272 Crashes

Injury Level	Persons Number	 Percent
Fatal injury, Dead at Scene	109	15%
Fatal Injury, Transported from Scene	182	25%
Serious Injury (Incapacitating)	142	19%
Subtotal, Serious & Fatally Injured*	**433**	**59%**
Non-incapacitating injury	97	13%
Possible injury	54	7%
No injury	137	19%
Severity unknown, or unknown if injured	8	1%
Subtotal for Less than Seriously Injured	296	41%
Grand Total	**729**	**100%**

Notes
*For the Serious & Fatal Group, 364 (84%) died or became inpat
All persons not dead at the scene were transported by EMS
Totals may not add to 100% due to rounding

or were actually transported to trauma centers. From the data linkage results, none were subsequently admitted as inpatients or died. The remainder of the results therefore pertain to the Serious and Fatally injured group shown in the Table.

The Serious and Fatal Group consists of 272 crashes and 433 victims who were either seriously or fatally injured and were considered to be likely candidates for either air medical transport and/or trauma center care. As noted on the table, a high percentage of these crash victims, (84%), subsequently died or were admitted as inpatients. This group contains all occupants of qualifying vehicles that could possibly be saved in trafficway reported crashes Statewide for the study year.

Table 3 Crash Types and Principal Impacts For Serious and Fatally Injured Persons

Multiple Vehicle Crash Type	**Crashes**		**People**	
Head On	55	20%	118	27%
Angle	43	16%	62	14%
Sideswipe	2	1%	4	1%
Rear End	12	4%	17	4%
Unknown	1	0%	2	0%
Subtotal	113	42%	203	47%
Single Vehicle Principal Impact	**Crashes**		**People**	
Frontal	99	36%	131	30%
Right Side	15	6%	25	6%
Left Side	15	6%	19	4%
Rear	2	1%	2	0%
Undercarriage	4	1%	4	1%
Unknown	8	3%	23	5%
No Impact	16	6%	26	6%
Subtotal	159	58%	230	53%
Total	**272**	**100%**	**433**	**100%**

Note: Totals may not add to 100% due to rounding

Several previous (unpublished) studies by the authors for the State of Massachusetts Governor's Highway Safety Bureau have shown that the use of the rating "serious injury" by the police (for victims of non-fatal, as well as, fatal crashes) was accurately associated with transport to a hospital for care. (As is the case in this study as well.) However, there is variation in how police rate injuries throughout the country and the Massachusetts situation may not be extensible to other states.

Type of Crashes (n= 272)

Table 3 shows the crash aspects and types for the 272 crashes organized by those involving multiple or single vehicles. The majority (58%) of crashes involve one vehicle and an average of 1.4 people per crash.

Multiple vehicle head on (20%) and single vehicle frontal (36%) crashes account for the majority of crashes 56%. The next largest percentage (16%) is multiple vehicle angle contacts and (12%) for single vehicle side impact crashes.

Restraint Use and Air Bag Deployment (n=433 crash victims)

Due to limitations in data entry to its electronic crash file, the state was unable to accurately record belt use and air bag deployment information in its statewide electronic files for 1996. However, the authors were able to review paper documents, and record this information for the 433 crash victims in the study. Table 4 shows that the percentages of unknown/unrecorded values for seat belt use and air bag deployment (at the occupant's seat position) were 29% and 63%, respectively.

Triage Criteria Available and Met by Seriously and Fatally Injured Crash Victims (n=433)

The specific triage criteria used by EMS personnel for each of the 433 persons is not known. Documentation of any type of EMS "triage checklist" was not submitted to the MDPH. However, as a proxy for what information, (at a minimum), may have been possible to use to support the scene triage decision, all of the electronic and paper data for each crash victim was reviewed and matched to the MDPH air medical and ACS trauma center trauma triage guidelines. This approach provided an overview of the information that was available from the existing data sets to support the triage decisions.

Table 5 shows a brief description of each triage criteria component and how often it was judged to have been "met", "not met" or "unknown" for each person. It is important to note that each seriously or fatally injured crash victim could have met zero, one or multiple triage criteria. The triage criteria are organized into sections: Operating Condition (in this case, multiple casualties), Mechanism of Injury (MOI), Physiological measures (first set of vital signs), Anatomic injury measures (not a focus of this study) and Other (age, pre-existing medical condition). "Non-triage criteria" refers to the victims who suffered traumatic cardiac arrest and therefore had a low chance of either surviving transport or reaching a trauma center. Some guidelines recommend these individuals not be transported by air.

Table 4 Belt Use and Air Bag Deployment
For Serious and Fatally Injured Persons n=433

	Belt Restraints Used		Air Bag Deployed at Occupant's Seat Position	
Yes	76	18%	50	12%
No	233	54%	109	25%
Unknown	48	11%	5	1%
Not Recorded	76	18%	269	62%
Total	433	100%	433	100%

Note: Totals may not add to 100% due to rounding

Results for the Anatomic Measures group are not shown in Table 5 because they were very limited. The source of the anatomic injury descriptions generally was the text notes included on the police reports (the vast majority of victims did not have ambulance patient care reports available). Although more information about anatomic injuries was available for the subset of crash victims who were admitted as inpatients, (from their hospital discharge diagnoses), this level of detail would not necessarily have been evident at the scene (prior to hospital diagnostic tests results being available). However, none of the crash victims had an anatomic measure as their only triage criterion; in the few situations where they were documented by the police, other criteria had already been met. Therefore, the overall results are not impacted by the absence of the anatomic components for the study group.

Some triage criteria were interpreted both specifically and broadly, for example, when "high speed crash", (ACS defines this as >40 mph), was judged to be "met", it was a combination of the police at the scene, or police crash reconstructionists documenting a crash speed estimated at >40 mph. However, if no other detail was available, and the police described the fatal crash as "high speed" this was accepted as having "met" criteria, as well.

The most important findings about the 433 seriously and fatally injured crash victims from Table 5 are:

-nearly all, 96%, met at least 1 triage criteria (including 4% of crash victims who suffered traumatic cardiac arrest) - despite limitations in the available data. Given the high percentage, 84%, of this group who either died or were admitted as inpatients, the prediction that nearly the entire group met triage seems reasonable.

- a small proportion, 4%, did not appear to meet any of the triage criteria

- physiological measures were unknown or not available for 74% - these are important measures, but often were not available for this study. However, it is important to note that in the cases when these variables were documented, the crash victim met the triage criteria. In other words, for the subset of these victims who had physiological data available, all of them met the triage guidelines and they all would have been likely to qualify for at least trauma center care, (and possibly air medical, as well, depending on time/distance issues), based on this information alone. This finding is consistent with prior studies.[17,18]

Table 5 Triage Guideline Criteria: Percentage of Group Meeting Criteria n=433

Group	Met	Not Met	Unknown
OPERATING CONDITION			
Multiple Casualties	29%	71%	0%
3 or more Seriously / Fatally Injured in Crash			
MECHANISM OF INJURY			
Vehicle Level - Apply to all persons in a specific vehicle			
Major Auto deformity e.g. >20" ACS	88%	11%	1%
High speed crash e.g. >40 mph ACS	47%	50%	4%
Intrusion into passenger compartment e.g. >12" ACS	32%	63%	6%
Death in same passenger compartment.	21%	79%	0%
Rollover ACS	20%	79%	0%
Person Level - Factors that apply to individuals			
Occupant ejected from vehicle.	17%	82%	1%
Prolonged extrication ACS	6%	92%	2%
pinned or crushed by vehicle	5%	95%	0%
>12" Intrusion at Occupants position	5%	94%	1%
Trapped in burning vehicle	2%	98%	1%
Steering wheel deformed	2%	98%	0%
PHYSIOLOGICAL MEASURES - First Set of Vital Signs			
Blood Pressure <90			
GCS <=12	25%	<1%	74%
Respiration <10 or >30			
ANATOMIC MEASURES - Evident at Scene			
See Text			
OTHER			
Age greater than 55 or less than 10.	27%	73%	0%
Significant Pre-Existing Medical Condition	6%	-	-
For those reaching inpatient status only			
NON TRIAGE CRITERIA - Evident at Scene			
Cardiac arrest subsequent to blunt trauma	4%		
TOTAL PERSONS MEETINGS TRIAGE			
Met at Least 1 Triage Criteria	92%		
Met at Least 1 Criteria, but had blunt trauma cardiac arrest	4%		
Persons not meeting any of the Triage Criteria	4%		

Note: Totals may not add to 100% due to rounding

The top six triage criteria most often met by the seriously and fatally injured crash victims were:

- Major auto deformity	88%
- High speed crash	47%
- Intrusion into passenger compartment (Any location)	32%
- Age >55 or <10 years	27%
- Physiological (BP, GCS, respiration)	25%
- Death in same passenger compartment	21%

The top six mechanism of injury (MOI) triage criteria most often met were:

- Major auto deformity	88%
- High speed crash	47%
- Intrusion into passenger compartment (Any location)	32%
- Death in same passenger compartment	21%
- Rollover	20%
- Ejection	17%

Although the Physiologic measures have the greatest predictive power, the MOI measures have low unknown rates - which makes the idea of using them - via EDR data - to enhance triage attractive.

Medical System Utilization by Seriously and Fatally Injured Crash Victims (n=433)

Table 6 shows the aggregate medical system utilization for the 433 crash victims. One hundred and six (24%) died at the scene and did not receive further medical transport or intervention. Forty-eight (11%) were taken directly from the scene by air medical helicopters to Level I trauma centers. Seventy (16%) were taken directly from the scene by ground ambulances to Level I trauma centers. Therefore, a total of 118 (27%) were taken from the scene to Level I trauma centers, via either ground or air medical transports.

Two hundred and nine crash victims were not taken to a trauma center from the scene. Of this group, 129 subsequently died.

Potential Over- or Under-Triage and Population that May Benefit from Scene EDR Data

Keeping in mind that the State did not have a statewide triage guideline operating in the study year (it's air medical guideline is being retrospectively applied), 96% of the serious and fatal group are candidates for transport to a trauma center, while 27% were actually transported to a trauma center. The difference of 69% - 315 persons- is the group whose transport might be influenced by additional quantitative data.

Table 6 Transports to Trauma Centers

Location	Persons Number	Percent
Dead at Scene	106	24%
Scene Ground to Trauma Center*	70	16%
Air Medical to Trauma Center*	48	11%
Other	209	48%
Total	**433**	**100%**

Notes: *Includes dead on arrival transports
Other group includes 129 deaths
Totals may not add to 100% due to rounding

One might expect to see some of the 30-50% ACS over triage in transports from the 296 persons with injury severities in Table 2 lower than serious. A 30% over triage would be 130 persons. However, as mentioned previously, eight of these 296 lesser injury level victims were transported to a trauma center. There is no indication of any over triage.

Of the persons who were not transported to a trauma center, 129 died. This is the group where a potential exists to save lives; and additional objective information might make a difference. For Massachusetts in the study year, 129 deaths was 31% of all trafficway deaths reported; so it is a substantial fraction.

If EDR data contributed to decisions that resulted in the survival of an additional 20-40 crash victims from this group, that would have the effect of further reducing the (already low) death rate in Massachusetts by 5-10%.

Triage Criteria vs. Possible Output from EDRs

Other than "death in same passenger compartment" many of the MOIs shown in Table 5 can be "translated" into engineering terms that represent variables that could be collected by EDRs.

Table 7 provides examples of EDR variables that might be collected to obtain the key mechanism of injury information in a more objective and quantitative manner.

Key variables used by crash researchers to estimate the severity of a crash and the risk of serious injury include delta V, crash pulse, and principal direction of force. In the past, crash investigators have calculated this information as part of crash reconstructions conducted some period of time (e.g., hours or days) after the crash. EMS personnel currently are only able to "guess" crash speeds and vehicle crush or intrusion as rough proxies for crash severity. With scene access to the vehicle "black box" or EDR data, more objective crash severity information could be used to estimate the risk of serious injury by EMS personnel. Of course, the engineering data downloaded from the EDRs would have to be converted into a format that is easy for EMS personnel to understand, interpret and utilize quickly. A rapid, non-contact download method with passive power would be desirable for this purpose. Similar technology is used in transit system faire cards and car electronic key systems.

Table 7.
Examples of Use of EDR Data for Triage

Mechanism of Injury	Current source	EDR source
High speed	"guess-estimate"	delta V, crash pulse
Crush/intrusion	"guess-estimate"	delta V, crash pulse
Rollover	observation	rollover sensor
Ejection	observation	seat sensors
Multiple casualties	observation	seat sensors
Airbag deploy	observation	deploy trigger
Belt use	observation	belt sensor

Although some of the variables in Table 7 may seem inherently obvious, EMS personnel arrive at some scenes to find victims lying on the ground who either were removed, (on their own or by bystanders) or ejected, from the vehicle. Therefore, their seating position and restraint use would not be possible to directly observe, either. In addition, when EMS personnel arrive at the scene, they may find vehicles at rest in a normal upright position that actually had rolled 360 degrees (or multiples of 320 degrees) during the crash event.

As noted in Table 3, the majority of crashes (58%) involved one vehicle and averaged 1.4 people per crash. This suggests that it generally would not be difficult for EMS personnel to "match" the right victim to the right vehicle and its associated EDR data, even if the victims are discovered outside the vehicle(s). However, for some victims of serious or fatal crashes, prolonged extrication is required to free them from the vehicles - in this study, it was specifically mentioned for 6% of the victims (However, this percentage may be low, because it is not clear if any extrication information would have been recorded for the trapped victims who are dead at the scene).

Risk of injury algorithms could be developed for simple use by EMS personnel at the scene that relied on EDR information for each crash victim, such as, severity of crash variables (crash pulse, delta V, etc.), as well as, seating position, restraint use (seat belts, air bags, etc.), and ejection/rollovers flags, etc. These algorithms could be refined over time as more "real world" crash injury data and outcomes became available. The algorithms would be designed to be used at the scene by EMS personnel to complement their patient assessments of physiological status and anatomic injury, as well as, other important factors.

As noted earlier, restraint use and air bag deployment were often unknown/unrecorded (29% and 63%, respectively), for the seriously and fatally injured crash victims. EDR data could provide an objective source of restraint use and air bag deployment for all occupants, by seating position. Clinicians, and injury severity algorithms, factor in restraint and air bag deployment information when assessing or predicting the risk of particular types of life-threatening injuries.

As noted earlier, 20% of crash victims were occupants of vehicles that rolled over - an EDR sensor potentially could capture this information. 17% of crash victims were ejected; EDR data potentially could help identify (or confirm) this mechanism of injury, as well.

Future studies could also determine if, under certain circumstances in severe crashes, using EDR data from one car in a two vehicle collision is reasonable to support any key triage decisions for injured persons in the other car that did not have an EDR. This would be a potential issue until 100% of the fleet actually had EDRs.

Review of Crashes with Scene Deaths to Identify Possible Delays in EMS Notification (n=99)

To address the question of whether any of the scene deaths possibly may have been related to delays in EMS notification, detailed information on all 99 crashes with scene deaths was reviewed. The scene deaths are those most likely to benefit from technology such as Automatic Crash Notification (ACN). The study scene crashes included, for example, unwitnessed, late night crashes involving a single vehicle running off the road with one or two occupants who may have been too severely injured or isolated to summon help. Table 8 shows 15 crashes where scene deaths possibly may have been related to delays in EMS notification. This represents 4% of the statewide 392 fatal crashes.

This may indicate the potential extent of benefits related to automatic crash notification (ACN). A number of papers discuss the potential benefits of ACN, but the initial focus of ACN generally is on crashes occurring in remote areas that are less likely to be witnessed. [34,35] However, it was not part of this study to determine if a vehicle's ACN system, (e.g., antenna or other components), could have survived and functioned after such severe crashes or if cell phone coverage existed in the areas of the state where the ACN may have been needed.

Also, this study did not try to ascertain how often injured crash victims may have been conscious, and therefore, capable of using a cell phone to summon EMS vs. rely on an ACN system for assistance.

An additional 23 crashes with possible delays in EMS notification were associated with catastrophic injuries likely to cause instantaneous death, so outcomes would not have been changed by earlier EMS notification.

The remaining 61 crashes with deaths at the scene did not include documentation suggesting delays in EMS notification.

DISCUSSION

Based on the available data, many more people appear to qualify for transport to a trauma center than received it. There is no evidence of a pattern of over-triage of crash victims to either air medical transport or trauma centers for the study population.

Table 8 Dead at Scene Crashes with Possible Delayed Disc
Seriously & Fatally Injured Person

Group	Crashes		Persons	
Possible Delayed Discovery, may have affected scene death	15	6%	25	6%
Possible Delayed Discovery, but catastrophic injury*	23	8%	37	9%
Dead at Scene Crash, No Apparen Delay in EMS notification	61	22%	44	10%
All Other Crashes no Deaths at Scene	173	64%	327	76%
Total	**272**	**100%**	**433**	**100%**

Notes *Reasons include killed instantly due to massive trauma;
Trapped in, or under, vehicle which burst into flames,
Airbag did not deploy (no notification event)
Totals may not add to 100% due to roundin

The data indicates that physiological data is important for triage, and that its accurate collection should be the first priority. Nearly 100% of the victims meeting physiological criteria were transported to trauma centers. However, the elevated unknown rate for this information makes the use of MOI data from EDRs look attractive as a possible complement.

The potential appears to exist to use downloaded data from the current generation EDRs at the scene of serious/fatal crashes, *in combination with the patient assessment,* to help EMS personnel triage crash victims. Discussion of how this potentially could be accomplished and technical issues that would need to be addressed for scene use are included in other documents. [23,24,25,26]

Another advantage to EDR data is that it does not require the EMS personnel to "write down" additional data, they would simply download the data and convert it into an appropriate format. Therefore, data completeness on a statewide basis, may be easier to achieve, at least for the fatal level crashes. NHTSA has initiated some efforts to try to collect EDR data for its FARS, SCI and CIREN data bases (but not for real time medical use, at the scene of crashes, on a statewide basis).[36,37].

Additional studies are needed to determine if existing EDR data, if downloaded at the scene of crashes, and coupled with patient assessments, could potentially provide additional objective information about the severity of the crash and occupants' risk of life-threatening injury that would influence triage decisions.

Consistent with this study, others have concluded that physiologic and/or anatomic trauma triage criteria are more powerful predictors of air medical transport and increased hospital resource utilization and/or injury severity than mechanism of injury alone or in combination with these measures [12,17-20]

Based on the literature and this study's findings, it appears it would be extremely difficult to convince a state like Massachusetts to deploy high level EMS services based on mechanism of injury EDR data alone, at this time.

CONCLUSIONS

During the year studied, Massachusetts had the lowest MVC fatality rate in the US.

No "gold standard" exists for the appropriate percentages of victims of fatal level crashes that should receive air medical transport and/or trauma center treatment from the scene of a crash. However, the Massachusetts data showed for a population of the most seriously and fatally injured crash victims, (occupants of passenger cars, vans and light trucks), that 96% retrospectively appear to have met triage criteria, but 11% and 16%, respectively, received air and ground transport from the scene to a trauma center.

The study population contained all the victims whose lives theoretically are possible to save (from the qualifying vehicles) for the study year. Of the 209 persons not transported to a trauma center, 129 expired. This comprised 31% of the statewide trafficway deaths for the study year. On that basis, a potential to save lives by enhancing triage appears to exist. The study results support the rationale for the medical and engineering community to work together to add a "black box" for EDR data to trauma triage decision trees.

The study points out opportunities to use EDR data to enhance triage in two important, but different ways. First, possible "real time medical use" at the scene of a crash, in combination with patient assessments, to help support triage decisions, and second, for statewide evaluations of EMS system response to fatal level crashes in order to enhance response over time.

The study population consists of only very serious crashes. Consequently, it cannot predict the "false positives" that might occur using EDR data to enhance triage in lower severity crashes. This requires further study.

The findings of this study are based on a census of only the most severe crashes and are not extensible to all crashes in the state. In addition, the findings for Massachusetts are not generally extensible to the US overall. Comparative studies of similar data from other states, provinces or countries would be very useful.

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ENHANCEMENT OF ACTIVE & PASSIVE SAFETY BY FUTURE PRE-SAFE® SYSTEMS

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ABSTRACT

Advanced driver assistance systems in combination with new preventive safety systems offer great potential for avoiding accidents, reducing accident severity and increasing occupant protection. This paper presents the activities in this field at the Mercedes Car Group (MCG).

Driver assistance systems can be divided into systems that supply the driver with information during normal driving, systems that warn the driver when the probability of an accident increases, systems that assist the driver actively in avoiding an impending accident, and finally autonomously intervening systems. A special case of an intervention system is PRE-SAFE®: developed and first introduced by the MCG in 2002, PRE-SAFE® is a system that acts in the intervention phase. PRE-SAFE® has opened up new possibilities for vehicle safety by shifting the paradigm from the formerly separate fields of active and passive safety to an integral view of these two fields.

The future task is to enhance the elements of driver assistance systems and to integrate them in a comprehensive system. Since most of the current systems have no or only little information about the vehicle's surrounding, new sensors providing such information (cameras, 24-GHz radar) are especially needed.

How can driver assistance systems be enhanced on the basis of additional and more precise sensor information? Firstly, the driver can be informed and warned much more selectively and accurately. Secondly, systems that act in the assistance phase can be activated more often and provide much more precise support. For instance, BAS activation and support can take objects in front of the vehicle into account to avoid or mitigate a collision.

Thirdly, in the intervention or PRE-SAFE® phase, new occupant protection systems can be activated if an imminent and unavoidable collision is detected. Additionally, it might be possible to apply the brakes automatically in such a case to reduce the collision energy, which is also considered a contributing factor to crash compatibility.

INTRODUCTION

In its white paper on the safety of road users issued on September 12, 2001 the European Union set a 50% reduction in the number of fatalities among European road users by 2010 as its common goal [1].

As a manufacturer of motor vehicles Mercedes-Benz also recognizes its duty to do what it can in this regard, and proposes the following measures for a comprehensive approach to automotive safety:

- ➔ Intensified analysis of the pre-accident phase
- ➔ Further improvement of basic safety
- ➔ Comprehensive safety design of the vehicles
- ➔ Accident avoidance and mitigation through driver assistance systems

IMPROVEMENT OF BASIC SAFETY THROUGH RATING TESTS

Rating and consumer tests in passive safety have gained importance over the past years. These standardized tests evaluate vehicles regarding their protective characteristics in identical crash trials. A clear-cut evaluation system enables even lay people to evaluate the safety levels of different vehicles of the same class.

A five star Euro NCAP result can no longer be disregarded as a developmental goal today. The related basic safety has been optimized by most manufacturers. The development of suitable structural measures and the optimization of restraint systems have contributed to improving crashworthiness across all vehicle categories. Even small vehicles now feature this basic safety level, and yet we must keep in mind that results for different vehicle categories cannot be compared.

Owing to their greatly increased importance, rating tests, and therefore the committees initiating them, also bear a high responsibility for the future development of vehicle safety. Many comments on automotive safety in advertising refer to the safety quality of the vehicles in question in terms of Euro NCAP'S five star system. This concept and the rating as a measuring scale seem to have become established in consumers' minds.

When the EU's deficit analysis speaks of inadequate collision protection, then it is always in reference to the best tested vehicles of the particular category, which traditionally include Mercedes-Benz vehicles. For further developing the safety technology of these top-rated vehicles we had to ask ourselves the following critical questions:

- ➔ Are laboratory crash tests suitable for assessing the comprehensive vehicle safety that goes beyond basic crashworthiness?

- ➔ How can we measure improved crashworthiness if in the near future all vehicles will make the 5-star hurdle?

- ➔ Is further increasing the limits a useful measure?

- ➔ What adjusting levers can make a basic contribution to comprehensive vehicle safety?

Nowadays trials for developing and evaluating crash safety are standardized and performed in laboratories. For reasons of reproducibility and for assessing the progress of development, the same test speeds, vehicle overlap, seat positions, occupant weights and sizes are used. The results are applied in vehicle development and crashworthiness assessment. Specified limits and targets constrain the direction of development, and these standardized tests must always demonstrate the attainment of values.

But how is this related to vehicle safety in real-world accidents? Known variables for subsequent accident severity include the vehicle speed, with the collision configuration (type of collision, angle of collision, overlap, etc.) being a basic parameter. The criteria of New Car Assessment Programs refer only to passive collision protection, and therefore form only a small part of how a vehicle behaves in real-world traffic situations.

For example, standard systems for accident mitigation or accident avoidance, such as antilock brake systems, electronic stability programs and brake assistance systems, are not appreciated at present, although they have a large demonstrated potential for enhancing overall safety.

The interaction between occupants and the vehicle in the important pre-crash phase is also a basic variable in controlling the subsequent severity of injuries. Systems providing active support in this pre-accident phase have also not been evaluated to date, and yet significant reductions of subsequent crash load on real-world situations are possible.

Mercedes-Benz already developed a comprehensive approach to this matter in the mid-1990s and presented it in 1999 [2]. The aim of this approach is to describe the safety of vehicles in all phases of the traffic situation.

COMPREHENSIVE SAFETY DESIGN FOR IMPROVING VEHICLE SAFETY

This comprehensive approach to safety takes into account the individual phases with the potential for avoidance and mitigation, the potential for protecting occupants and other road users, and the potential for aftercare and rescue. This approach can be seamlessly incorporated in the relationships between the driver, the vehicle and the surroundings, and consequently serves as a guideline in the safety design of Mercedes-Benz vehicles [3].

Only this comprehensive consideration of vehicle safety in the normal driving condition, assistance and pre-accident phases, the variously influenced accident phases and finally occupant rescue can disclose further possibilities for reducing injuries and fatalities among road users.

For Mercedes-Benz vehicles we therefore have five areas of action for further enhancing overall vehicle safety:

- ➔ Safe driving and prompt warnings: the vehicle provides the occupants with a permanently safe work environment with the aim of avoiding hazards at their onset. Included are measures for driving safety, stress-reducing safety, operating safety and perceptual safety. The vehicle monitors its own condition, its environment and the interfaces to the driver and warns the latter in or prior to certain critical situations. Possible sensitivity-enhancing measures are implemented on the vehicle.
- ➔ Preventive action: in critical situations the vehicle supports the driver in avoiding danger, or applies measures for mitigating the severity of an accident in unavoidable situations. The vehicle prepares occupant protection systems for possible accidents in the best way possible.
- ➔ Protection: in accident situations the vehicle affords maximum protection to occupants and other involved persons in an adapted way.
- ➔ Aid and rescue: following an accident situation the vehicle automatically notifies rescue workers, supports the occupants and rescuers with information on the vehicle and victims and warns the following traffic to prevent subsequent accidents.

SYSTEMS TODAY: ACCIDENT AVOIDANCE / MITIGATION THROUGH DRIVER ASSISTANCE SYSTEMS

1. ESP®

Over the past two decades, especially electronic driver assistance systems have significantly contributed to enhancing driving safety, without this development being incorporated in New Car Assessment Programs. Here it becomes clear that the best form of accident safety continues to be avoidance, accordingly an essential factor in vehicle safety.

An example [4] of the effective reduction of single-vehicle accidents is the Electronic Stability Program (ESP®) safety system introduced ten years ago.

The ESP® developed by the MCG and BOSCH counteracts oversteering and understeering by applying the wheel brakes separately in order to stabilize the vehicle and maintain its controllability for the driver. Various studies under test conditions indicated the potential benefits for assisting the driver in critical driving situations, especially those with a high risk of loss of control over the vehicle. The MCG consequently made ESP standard in all its passenger cars.

More compelling proof came from four representative, anonymous 50-percent samples of all accidents involving vehicles registered between 1998 and 2002. These samples, purchased from the German Federal Statistical Office, document that the rate of loss of control accidents can be significantly reduced by ESP. A comparison of accident rates for registered vehicles involved in an accident over a period of two years reveals that Mercedes-Benz vehicles have been below average with respect to loss of control accidents since the year 2000 when ESP became standard in all Mercedes-Benz passenger cars (Fig. 1). While within the two-year period of 1998 - 1999 Mercedes-Benz's share of loss of control accidents was close to the average value of 19 percent, the figure dropped to 12 percent in 2000 - 2001 and was much lower than the mean.

The most recent data for 2001 - 2002 again confirms this finding, while the rate also declined for competing passenger cars increasingly using ESP in the meantime.

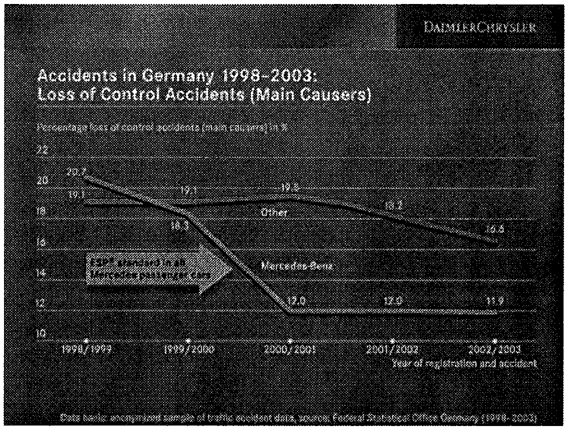

Fig. 1: Accidents in Germany 1998-2002: loss-of-control accidents (main causers)

2. Contributions to Protecting Occupants and Other Road Users: Brake Assist, DISTRONIC and Flashing Brake Lights

BRAKE ASSIST (BAS): While pedestrian accidents are not among the major causes for fatalities and severe injuries in road traffic accidents, they still are responsible for 13 percent of fatalities and 7 percent of injuries in traffic accidents [5]. According to NHTSA, these numbers were 11 percent and 2.4 percent, respectively, for the USA in 2002 [6]. Furthermore, this issue is given high priority within the European Union. Analyses by GIDAS (German In Depth Accident Study) of data collected in the greater Dresden and Hanover areas show that the risk for pedestrians to be killed compared with vehicle passengers is three times higher. A closer look at the different types of pedestrian accidents reveals that in 73 percent of the cases a passenger vehicle collides with a pedestrian and in most cases (65 percent) of pedestrian accidents, the pedestrian is struck by the front of a vehicle [7].

Besides measures of passive safety for reducing accident severity, active safety systems may help even avoid accidents or at least mitigate their severity. MCG research has shown that particularly the Brake Assist has special potential because it can reduce the stopping distance. Developed and first introduced by the MCG in 1996, BAS fully applies the brakes in emergency braking when the driver applies the brake pedal fast but not strongly enough to achieve full brake performance.

Early studies on BAS already demonstrated the benefits for emergency braking. A more recent study carried out by MCG safety engineers, using the DaimlerChrysler Berlin driving simulator, proved effective in the case of pedestrian accidents as well[7]. In this study, test-persons were driving on an urban road at approximately 50 km/h (31 mph) when suddenly a pedestrian (child) entered the road from left. The possibilities for evading the situation were limited (Fig. 3).

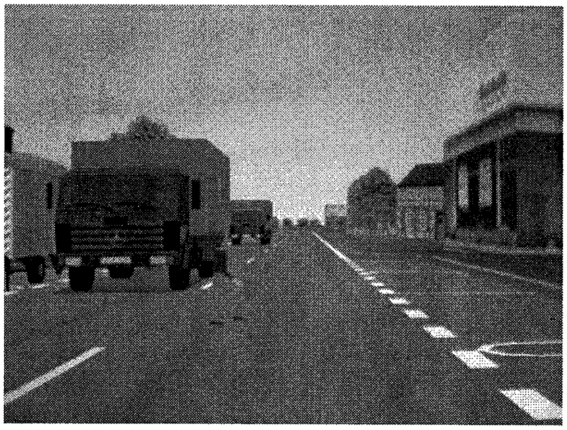

Fig. 2: Critical situation simulated by the DaimlerChrysler Berlin Driving Simulator: child crossing an urban street

In 45 percent of all situations a collision with the pedestrian occurred. Fig. 3 shows that there is a significant difference depending on whether the vehicle was equipped with BAS or not. Drivers with BAS had an accident rate of 32 percent only, whereas drivers without BAS had an accident rate of 58 percent, i.e. almost twice as many accidents. A closer look at the drivers of BAS vehicles reveals that all drivers who managed to activate the BAS also could avoid the accident. In other words, in this simulated situation accidents occurred only when the BAS was not activated by the driver's actions. BAS therefore proves to be very beneficial in this typical kind of pedestrian accident.

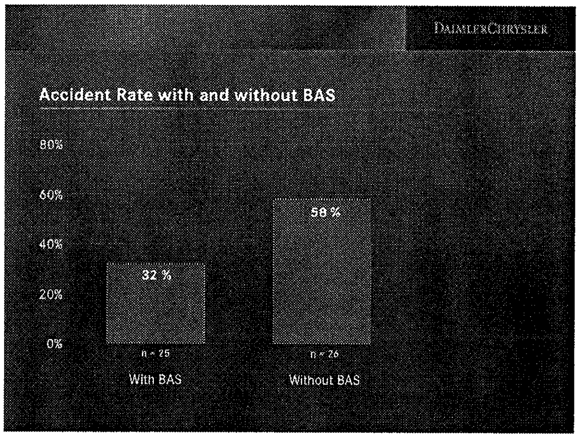

Fig. 3: Accident rates with and without BAS being available

DISTRONIC ACC - In the normal driving phase DISTRONIC maintains a safe inter-vehicle distance and provides the driver with information on the distance to the vehicle in front. In the warning phase DISTRONIC's associated Distance Warning Function signals the driver if the gap to the front vehicle becomes too small, so that (additional) braking by the driver is necessary to reestablish a safe distance. The Distance Warning Function can be used independently of DISTRONIC.

FLASHING BRAKE LIGHTS - Many rear-end collisions are caused by misinterpreting the traffic ahead, especially when the preceding vehicle brakes hard or in an emergency. Although conventional brake lights show the lead vehicle to be braking, they give no further indication about the brake force and the resulting deceleration. Advanced brake light design aims at filling this gap by providing the following vehicles with information about the deceleration of the lead vehicle. Opinions in the automotive industry differ on the best approach, be it additionally activated hazard warning lights (e.g. Peugeot), an enlarged lighted area and/or increased intensity of illumination (e.g. BMW) or flashing brake lights (e.g. Mercedes-Benz).

Mercedes-Benz examined different advanced brake light designs (conventional, additional hazard lights, brake lights flashing at 4 and 7 Hz) [8]. In this study, a group of 39 subjects had to follow a lead vehicle at 80 km/h (50 mph). At random places on the test track the lead vehicle unexpectedly performed an emergency braking maneuver, forcing the drivers of the following vehicles to brake accordingly. The brake reaction times were measured and subtracted from reaction times measured in a static test in order to receive standardized reaction times. The reaction times ranged from 0.31 to 0.74 seconds. It was found that brake lights flashing at 7 Hz provide the greatest benefit, significantly reducing the brake reaction times up to 0.2 seconds compared with conventional brake lights. This translates into a reduction of the stopping distance by 4.44 m. Additional hazard lights did not significantly decrease the reaction times. Subjective ratings gave highest values for flashing brake lights, too.

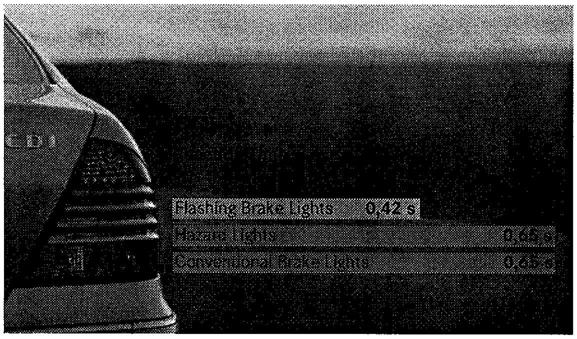

Fig. 4: MCG introduced flashing brake lights into the current S-Class in February 2005

INTERACTION BETWEEN THE OCCUPANTS AND VEHICLE IN THE PRE-ACCIDENT PHASE

3. PRE-SAFE®

The importance of a comprehensive approach for the overall safety of a vehicle is shown by the PRE-SAFE® system introduced in the Mercedes-Benz S-Class in 2002. PRE-SAFE® is a preventive protection system that activates measures for fixing occupants in place and positioning and conditioning them in advance of a collision, by analyzing the driving dynamics or the driver's braking.

For example, if emergency braking occurs prior to a collision, the resulting longitudinal deceleration moves the occupants forward within their seat belt slack.

In a vehicle with PRE-SAFE® this forward displacement is minimized by the activation of reversible emergency tensioning retractors, and the occupants are more coupled to the vehicle deceleration and prepared for a possible collision.

If the front passenger seat is in an unfavorable situation for the collision, for example, PRE-SAFE® automatically changes the seat to a safety position, and thereby improves the occupant's position.

These occupant-vehicle relations in typical emergency braking situations were studied with actual test persons. An average forward displacement of about 15 cm at the chest and about 20 cm at the head were measured.

Trials in which PRE-SAFE® fixed occupants in place minimized these forward displacements at the chest by about 10 cm to 5 cm. Thick clothing and large belt slack were not used on the test subjects, which would have led to even greater differences between PRE-SAFE®-equipped and conventional vehicles. The trials in the pre-accident phase were performed on actual test subjects since at present HIII measurement dummies do not yield results applicable to humans in this low acceleration range.

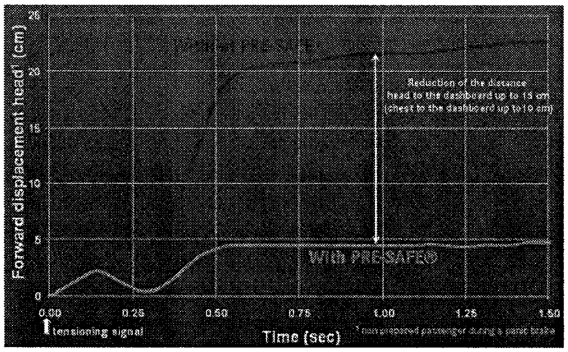

Fig. 5: Forward displacements with/without PRE-SAFE®

As of the start of collision, the results of the test subject studies were transferred to the dummy positions. The corresponding setups for collisions with and without a preceding PRE-SAFE®-supported braking situation were studied on an acceleration slide.

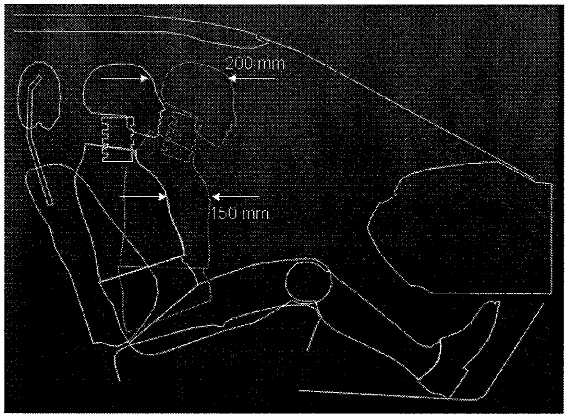

Fig. 6: Recreation of the real-world situation with the measurement dummy

Compared with conventionally equipped vehicles, the study revealed great potential for reducing load on occupants.

Particularly in the head area the loads could be reduced by 30 - 50%, depending on the load criterion, compared with a front passenger not protected by PRE-SAFE®. With a reduction by 20 - 40%, the neck region was also subjected to less stress [Fig. 7].

Particularly in the upper body regions, PRE-SAFE® has good potential for real-world accidents, since it fixes occupants in place very effectively. The measures for repositioning occupants from unfavorable and yet actually occurring seat positions were not considered or assessed; here too we can expect a further reduction of loads.

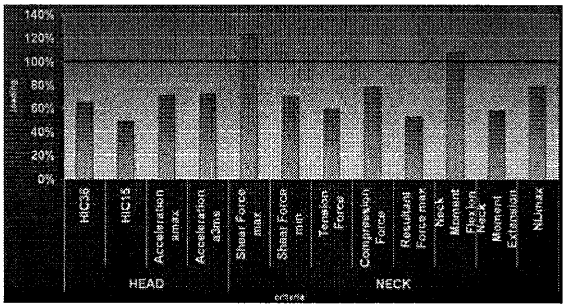

Fig. 7: Load reduction per body region

The aforementioned example of intelligent networking of active and passive safety shows the potential of a coordinated overall vehicle safety.

FUTURE APPLICATIONS

New generations of sensors and the integration of the 24 GHz short-distance radar allows further applications and operating ranges. The next generation of the new S-Class will have a further developed Advanced DISTRONIC.

This assistance system will allow the implementation of additional safety and comfort applications and will be incorporated by Mercedes-Benz in overall vehicle safety.

PRE-SAFE® Brake

In future, information on approaching an object will yield further opportunities. The sensor system and infrastructure of the Advanced DISTRONIC observe and analyze the traffic situation in front of the vehicle by means of long-distance (77 GHz) and short-distance radar (24 GHz).

If the driver brakes while approaching an object, the system uses the object's distance and relative speed to compute the convergence of the two vehicles continuously. PRE-SAFE® Brake compares the actual braking distance based on the adjusted brake pressure with the brake pressure that would be needed to prevent a collision with the preceding vehicle. If the driver incorrectly assesses the situation, or if the relative distance and speed of the two vehicles change, the driver is supported by an automatic and appropriate increase of the brake pressure. The aim of the system is to avoid accidents to the extent allowed by the physical environment parameters.

As of a certain specified braking threshold, the reversible systems of the standard PRE-SAFE® are activated for support and accident prevention at the start of the braking process prior to the possible forward displacement of the occupants, since the specified deceleration is already known from the observation of the environment. The driver can at any time initiate even greater braking pressure within the bounds of the available brake power, and thereby overrule the vehicle's system. The system can fully avoid an accident in many cases, or at least mitigate the severity. In cases where the driver brakes but has incorrectly assessed the longitudinal traffic situation, the system can operate with maximum deceleration up to the current wheel slip limit.

For longitudinal traffic situations in which the driver does not brake, a further application can help mitigate accident severity.

This system will be implemented in a later expansion stage. Here again the preceding traffic is observed by the sensor system. In case of an approach, the driver is visually and audibly warned as of a certain threshold, and thereby requested to perform the appropriate driving task. If the driver reacts by braking, PRE-SAFE® Brake will compute the situation and assist with braking power as required. If the driver does not react, in the next escalation stage the vehicle autonomously initiates partial braking, with the aim again of requesting the driver to act, while the accident severity is being reduced by a decrease in speed.

Parallel to partial braking, at the start of deceleration reversible PRE-SAFE® measures like belt tightening and adjustment of the front passenger seat and rear seats are also activated with the aim of preventive occupant protection.

The system can autonomously mitigate the accident severity in longitudinal traffic situations, as well as prepare the occupants and the vehicle for the subsequent accident in case the driver does not react.

Here the potential lies not only in the reduction of the deceleration energy; the automatically initiated brake application in combination with positioning and fixing the occupants in place also couples the occupants better to the vehicle deceleration following a collision. The result is an increase in the ride-down benefit.

In sudden situations in which the driver can no longer be warned in time or which do not allow longer-term observation, such as accidents in approaching intersections, accidents from cutting in, collisions after lane changes, etc., a collision-proximate situation assessment of the environment can make a short-term contribution to improving occupant protection. In this case only the short-distance radar analyzes the immediate vehicle environment ahead, and triggers sufficiently fast reversible actuators in the range of unavoidable collisions. For example, reversible belt tensioning can minimize actual deficits, such as those related to seat belt slack or thick clothing.

Here too fixing occupants in place and coupling them to the collision deceleration at an early point can reduce possible peak loads during the deceleration. Various constellations are conceivable in which the situation is improved, in some situations no significant improvement can be quantified, but in no situation is the load on occupants increased. Rather, the complex real-world situation cannot be studied in the lab, or only in part.

Information on approaching the object can also be used in making crash-active systems more sensitive. The escalation of the traffic situation is reported to the analyzing algorithm of the crash-active systems as of a certain threshold value. The basic parameter for lowering the triggering thresholds is the relative speed of the vehicle and the collision object. Of course, these systems cannot be triggered by the environment sensor system. Nevertheless, lowering the triggering threshold allows an earlier triggering decision to be made on the basis of the central acceleration sensing. The anticipatory observation of the traffic environment can positively affect conventional protective systems.

Faster and more stable triggering decisions for pyrotechnical emergency tensioning retractors and airbags are the result.

The information on the approaching collision speed can be further applied to predict the possible severity of the collision. Besides the occupant parameters like size, seat position, weight, etc., the expected collision severity is a basic unknown for controlling the energy-absorbing characteristics of the belt and airbag.

The variable of relative speed can at least be used for an energy prediction, for making decisions in controlling the adaptation of restraint systems on a broad informational basis [9].

CONCLUSIONS

In introducing the PRE-SAFE® preventive protection system in the S-Class in 2002, Mercedes-Benz launched a system that for the first time employs the critical assessment of a vehicle's condition prior to a collision for activating reversible safety precautions [10, 11]. In many real-world situations these measures will help improve occupant protection.

The expanded environmental assessment will afford new possibilities in the future for comprehensively enhancing vehicle safety. This comprehensive approach based on real-world accident situations will enable us to mitigate situations that today are responsible for occupant injuries and fatalities. In our view, greater depth of the laboratory assessments of vehicle safety and tightening the limits are not effective approaches, since the high level of collision protection already attained today offers an excellent basis. Consumer pressure and the established rating procedures will also drive those automotive manufacturers forward in their development endeavor who have not yet achieved the previous assessment targets.

In our view, the real potential for reducing loads on the occupants lies only in the full consideration of all accident phases and in networking the systems beyond the present boundaries. An isolated assessment of the collision phase or active safety systems can reflect real-world accident situations only inadequately. Rather, the real-world accident situations must be analyzed to a greater degree in order to assess previous and current traffic safety problems objectively.

These results should guide a broadly coordinated vehicle safety concept. The performance of our products in real-world traffic is the yardstick for achieving our goal.

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STATUS OF NHTSA'S REAR-END CRASH PREVENTION RESEARCH PROGRAM

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ABSTRACT

This paper provides an update on two cooperative research projects being conducted under the National Highway Traffic Safety Administration's (NHTSA) Rear-End Crash Prevention Program. The first project is the General Motors-Ford Crash Avoidance Metrics Partnership (CAMP) Forward Collision Warning (FCW) work. Since 1995, this project has been aimed at defining and developing pre-competitive enabling elements to facilitate FCW system deployment. The second project is the General Motors-led Automotive Collision Avoidance System Field Operational Test (ACAS FOT), which aims to accelerate the deployment of active safety systems by integrating and field-testing vehicles outfitted with Adaptive Cruise Control (ACC) and Forward Collision Warning (FCW) systems.

Results from the first CAMP FCW project played an important role in the development of the SAE J2400 Recommended Practice, "Human Factors in Forward Collision Warning Systems: Operating Characteristics and User Interface Requirements". This paper discusses findings from the second CAMP FCW project, which was focused on evaluating and developing the FCW timing approach and examining drivers' decision-making and avoidance maneuver behavior in rear-end crash scenarios. The closed-course, test track methodology employed allows safely placing naive drivers in realistic rear-end crash scenarios so that driver behavior can be observed. The human factors experimentation and key results from this project will be discussed in this paper.

During the ACAS FOT project, a small fleet of vehicles was built and given to lay drivers for their personal use. Each driver had a vehicle for approximately four weeks, three of which had both the ACC and FCW features enabled. The collected data provided objective information about how the subjects used the system and its impact on their driving behavior. It also includes extensive subjective information collected through questionnaires, interviews, and focus groups. The system design, design and execution of the FOT, and highlights of results will be discussed in this paper.

INTRODUCTION

Forward Collision Warning (FCW) is an emerging automotive safety technology that provides alerts intended to assist drivers in avoiding rear-end crashes. NHTSA 2003 General Estimates System (GES) data indicate that rear-end crashes accounted for about 28% of the total 6,318,000 police-reported crashes in the United States. About 99.5% of these rear-end crashes involved at least one light vehicle (e.g., passenger vehicle, van and minivan, sport utility vehicle, and light truck).

NHTSA's rear-end crash prevention program began in 1991, when research to prevent rear-end crashes through the use of advanced technology was initiated under the U.S. Department of Transportation's (DOT) Intelligent Transportation System (ITS) Program. A brief history of NHTSA's rear-end crash prevention program is summarized below:

1991-1996: Rear-end crash problem definition, identification and assessment of potential countermeasure technologies (NHTSA-Volpe Center-Battelle-Calspan); development and use of a test bed system to develop performance specifications (Frontier Engineering); estimation of preliminary safety benefits (NHTSA-Volpe Center). Preliminary analysis of potential safety benefits showed that rear-end crash avoidance systems could prevent 48% of all rear-end crashes.

1997-2005: Cooperative research with CAMP (GM and Ford) to develop functional requirements, performance guidelines, and objective test procedures for rear-end crash avoidance systems on light vehicles. This activity involved human factors studies on closed-course test tracks to better understand how drivers respond to dynamic scenarios that lead to rear-end crashes. A follow-on research program studying alert algorithm timing and avoidance maneuvers for rear-end crash warning systems was also completed.

1999-2005: Cooperative agreement with General Motors and its partners Delphi Electronics, Hughes Research Labs, and the University of Michigan Transportation Research Institute, to conduct the Automotive Collision Avoidance System Field Operational Test (ACAS FOT) program that developed a state-of-the-art rear-end crash avoidance system with forward crash warning and adaptive cruise control, including a 1-year field operational test employing laypersons driving ACAS-equipped vehicles. An independent evaluation was conducted by the Volpe Center to assess safety benefits, driver acceptance and system performance.

This paper presents background and results from the recent CAMP Forward Crash Warning work and ACAS FOT.

OVERVIEW OF CAMP FCW FINDINGS

The more recent Crash Avoidance Metrics Partnership (CAMP) Forward Collision Warning (FCW) efforts build upon the foundation provided by the human factors work conducted in the previous CAMP FCW system program [9]. This previous work focused on developing FCW timing and interface requirements for closing alerts; that is, alerts intended to warn the driver when they are approaching a vehicle ahead too rapidly (these alerts can be contrasted with tailgating advisories). The follow-on efforts reported here continue this effort, and involved two major lines of research. The interested reader is referred to [7] and [6] for a more detailed discussion of this research.

One line of research is aimed at understanding the relationship between drivers' last-second braking and steering maneuver behavior under closed-course versus National Advanced Driving Simulator (NADS) conditions. The documentation of this effort is in the final stages, and will not be discussed further here. A second line of research, which is the focus of this paper, is primarily aimed at evaluating and potentially refining the preliminary crash alert timing approach developed in the previous CAMP FCW project under a wider range of conditions. Key to driver acceptance of FCW technology is appropriate crash alert timing, which refers to the necessary underlying vehicle-to-vehicle kinematic (or approach) conditions for triggering the onset of crash alerts. The goal of the alert timing approach is to allow the driver enough time to avoid the crash, and yet avoid annoying the driver with alerts perceived as occurring too early or unnecessary.

As in the previous CAMP FCW research, this research was conducted with a surrogate target, test track (or closed-course) methodology, which allows driver behavior to be safely observed under controlled, real approach, rear-end crash scenario conditions. As illustrated in Figure 1, this methodology involves three vehicles— a mock lead vehicle (or surrogate target), a lead vehicle (which tows this mock vehicle), and a subject vehicle that is driven by the test participant. The surrogate target was designed to allow for safe impacts at low impact velocities (up to 10 miles per hour velocity differential) without sustaining permanent damage. The surrogate target consists of a molded composite mock-up of the rear half of a passenger car mounted on an impact-absorbing trailer that is towed via a collapsible beam. The braking level of the lead vehicle, as well as that of the yoked surrogate target, is controlled via an on-board computer operated by the back-seat experimenter in the subject vehicle.

This test track methodology provides a very realistic physical and perceptual representation of what a driver experiences during in-lane approaches to a vehicle. This realistic representation is felt to be of critical importance for ensuring drivers' perception of crash threat under these experimental conditions are, to the extent possible, representative of those obtained during in-traffic, real world driving conditions. Moreover, this approach is intended to increase the likelihood that the experimental results observed will generalize to real world driving conditions.

In order to ensure the safety of the test participant and afford the participant every possible opportunity to perform unassisted last-second maneuvers, a trained test driver accompanies the participant. The test driver rides in the front passenger seat with access to both an override brake pedal and add-on steering wheel to prevent collisions with the surrogate target. In addition, the test driver has access to a "bail out" crash alert via headphones (which signifies to the test driver to take control of the vehicle), and a curtain divider is used to prevent the test participant from observing the foot behavior of the test driver (e.g., the foot hovering above override brake pedal).

The need for obtaining data under these test conditions is dictated by the infrequency of near and actual collisions in the real world (as was evident in the ACAS FOT data), the sparseness of electronic

Figure 1. Surrogate target (lead vehicle) methodology employed at the General Motors Proving Ground (site of the majority of CAMP FCW research).

crash recording data available during these situations, and the inherent safety and logistic issues surrounding gathering driver's last-second maneuver data under in-traffic conditions. Furthermore, attempts to define crash alert timing based on research that places drivers under minimal risk or no crash risk (e.g., driving simulator) conditions has the potential to lead to alerts that occur too late [9, 10].

In developing a FCW timing approach, two fundamental driver behavior parameters should be considered. These parameters serve as input into vehicle-to-vehicle kinematic equations that determine, given a set of assumptions, the alert range necessary to assist the driver to avoid a potential crash. The first driver behavior parameter is the time duration required for the driver to respond to the crash alert and begin braking, referred to as driver brake reaction time (or brake RT). The second driver behavior parameter needed for a crash alert timing approach is the driver deceleration (or braking) behavior in response to the FCW alert under a wide range of vehicle-to-vehicle kinematic conditions.

Both of these fundamental driver behavior parameters were explored in the previous CAMP FCW work by having drivers perform last-second braking judgments under alerted conditions and exposing drivers to an unexpected (surprise) rear-end crash scenario. The CAMP FCW follow-on research reported here is aimed at continuing to develop assumptions for these parameters under a wider range of conditions. This research employed four different types of methodological approaches/research strategies, each of which will now be described with the corresponding key results observed using these strategies. It should be stressed that these research strategies can be adapted in a relatively straightforward fashion to address interface and timing. Indeed, these strategies have already been embraced and adapted in recent research aimed at backing warning systems [12].

Last-Second Braking and Steering Maneuvers

In the earlier CAMP FCW work [9], drivers performed last-second braking maneuvers under various in-lane approaches using two different braking instructions. The first instruction asked drivers to maintain their speed and brake at the last second possible in order to avoid colliding with the surrogate target using "normal" braking intensity or pressure. (Note that this braking instruction is intended to explore the aggressive end of the "normal" braking envelope rather than more nominal, normal braking behavior.) The second instruction asked drivers to maintain their speed and brake at the last second possible to avoid colliding with the target using "hard" braking intensity or pressure. These data were used to identify drivers' perceptions of normal and non-normal braking envelopes, and to generate a brake onset model which estimates the assumed driver deceleration in response to a FCW alert based on prevailing vehicle-to-vehicle kinematic conditions. An underlying assumption of this approach is that alert timing based on rules for judging threatening conditions that are different from those employed by drivers may well be considered unnatural and unacceptable by drivers.

Unlike the earlier CAMP FCW work, the current study examined both last-second braking and last-second steering maneuvers, both normal and long (3-second) following headway conditions, and in-lane approaches to a lead vehicle moving at a slower but constant speed (The previous CAMP work only examined lead vehicle stationary and lead vehicle braking scenarios). This additional last-second steering data was used to examine the extent to which a FCW timing approach based on driver braking

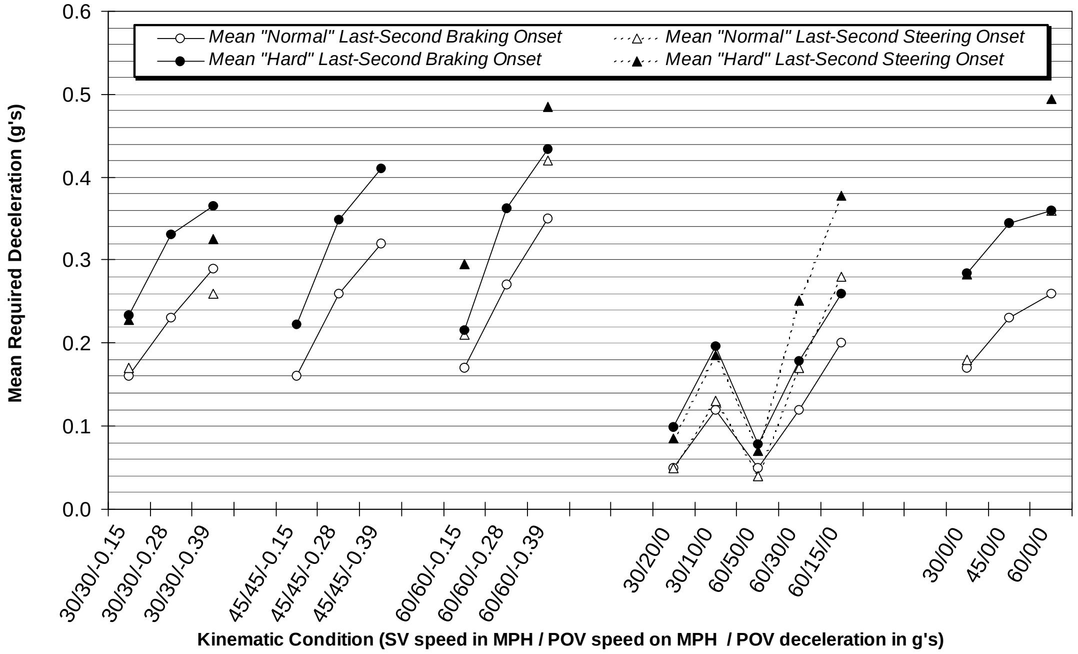

Figure 2. Mean "normal" and "hard" required deceleration values at last-second braking onset and last-second steering onset for each SV speed, POV speed, and POV deceleration profile combination. SV refers to the following, Subject Vehicle, and POV refers to the Principle Other Vehicle (in this case, the lead vehicle).

assumptions could annoy drivers intending to perform a lane-change maneuver around the vehicle ahead. Drivers performed last-second steering maneuvers using two different steering instructions, which parallel the last-second braking (intensity) instructions described above. The first instruction asked drivers to maintain their speed and change lanes at the last second they "normally would to go around the target". The second instruction asked drivers to maintain their speed and change lanes at the last second they "possibly could to avoid colliding with the target". The last-second braking and steering onsets were then characterized in terms of the (constant) required deceleration level to avoid a collision at last-second maneuver onset and the time-to-collision at last-second maneuver onset (i.e., the time before impact if prevailing conditions continue).

There are a number of commonalities between the current and the previous CAMP FCW last-second braking study [9] that enabled the possibility of combining these data sets based on comparable results observed across studies. First, a subset of the Kiefer et al. last-second braking scenarios was included in the current study. Second, identical age and gender requirements were used in both studies. Third, both studies were conducted on a straight, level, smooth, asphalt, dry road under daytime conditions. The previous Kiefer et al. data was gathered at the General Motors Milford Proving Ground test site in Milford, Michigan (shown in Figure 1), and the more recent data was gathered at the Transportation Research Center in East Liberty, Ohio.

Results indicated that the differences observed in last-second braking onset behavior as a function of test site (Milford Proving Ground versus Transportation Research Center), age (20-30, 40-50, and 60-70 year olds), and gender (male, female) were relatively small in magnitude. Hence, the previous and current last-second maneuver datasets were combined for further analyses and modeling. Second, as shown in Figure 2, braking (as well as steering) onsets varied as a function of maneuver speed and lead vehicle deceleration conditions, and the relative timing of last-second braking versus last-second steering onsets was highly dependent on the kinematic conditions. These results provide evidence against a FCW timing approach that assumes a fixed driver deceleration (or fixed time-to-collision) value, and suggests that under some conditions, a FCW timing approach that only assumes a braking response by the driver could result in presenting alerts to drivers performing intentional lane change maneuvers.

However, estimating the potential magnitude/importance of alerts being issued prior to intended lane-change maneuver under real-world conditions is difficult. First, it should be kept in mind that drivers will not always have the opportunity to appropriately execute a steering maneuver. Second, it remains unclear the extent to which drivers would find alerts that occur prior to intentional last-second, normal lane changes annoying. More generally, the annoyance level potentially associated with these alerts, as well as other alerts perceived as too early or unnecessary, will ultimately be weighted against the driver's perception of alert appropriateness and system benefits under a rich set of varied real-world experiences with the FCW system. Consequently, extensive field operational testing was necessary (described shortly), at a minimum, to better understand what types and levels of false alarms are acceptable to drivers.

The last-second braking data from this combined dataset (which includes 3,536 last-second braking judgment trials and 790 last-second steering judgment trials) were then modeled for the purpose of predicting hard braking onset (or driver deceleration behavior in response to the alert). Recall that driver deceleration behavior in response to the alert is one of two driver behavior parameters needed for a crash alert timing approach (the other parameter being driver brake reaction time to the FCW alert).

A wide range of potential time-based and deceleration-based predictors was explored. Inverse time-to-collision (TTC) was found to be the single most important predictor of whether or not a braking onset scenario was a normal or hard, last-second braking onset scenario. The key component of this model is the inverse TTC term, defined as the difference in speed between the lead and following vehicles divided by the range between these two vehicles (or Δ Velocity / Range). It should be noted that although TTC and inverse TTC are mathematically interchangeable, the inverse TTC measure provides a more parsimonious approach for characterizing drivers' perception of normal versus hard braking envelopes [10].

The inverse TTC model was developed using a logistic regression approach that predicts the probability a driver is in a hard braking scenario (and hence, not in a normal braking scenario). This model can be elegantly described as a model that assumes that the driver deceleration response in response to the crash alert is based on an inverse TTC threshold that decreases linearly with driver speed. An examination of the model fit across the approach conditions tested, as well as a domain of validity check across a much wider range of approach conditions, provided support for the robustness of this approach.

It is important to note that TTC can also be perceptually defined as the angular size of the approaching object divided by its angular speed [11,17], and hence, inverse TTC is directly tied to the visual looming properties or angular expansion of the lead vehicle. Furthermore, inverse TTC has been found to be a robust measure for describing drivers' ability to perceive relative motion under near threshold relative speed conditions [3]. Note that just as the visual angle subtended by the lead vehicle becomes "optically explosive" immediately prior to a collision [4, 16], changes in the inverse TTC measure (unlike the TTC measure) become more prominent as TTC diminishes to low TTC values.

The inverse TTC model has several potential advantages over the previous CAMP FCW required deceleration model of last-second braking [9], although it should be noted that both models provide comparable predictions. First, the current model offers greater flexibility by operating in the "probability of hard braking" domain, which allows the designer to modulate the "probability of hard braking onset" assumption based on inputs that may be available to the FCW system (e.g., driver age, driver eye movement location, driver attentional state, road/weather conditions, suspected lane change conditions). Second, the current brake onset model does not require accurate knowledge of lead vehicle deceleration, and instead merely requires knowledge of whether or not the lead vehicle is stationary, moving and braking, or moving and not braking. This is of some practical importance since obtaining real-time, accurate knowledge of lead vehicle deceleration behavior is technically challenging.

The performance of the inverse TTC model suggests that drivers do not use detailed knowledge of lead vehicle deceleration when making hard braking decisions. However, accurate knowledge of lead vehicle deceleration is still desirable for FCW timing purposes, since this knowledge can be used to improve predictions associated with calculating the assumed Delay Time Range, which, along with the assumed Braking Onset Range, is used to calculate FCW Warning Range [9]. The Delay Time Range is calculated based on the projected change in range to the vehicle ahead, given prevailing speed and deceleration levels of the lead and following vehicles, during an interval which is composed of the summation of various system delay times. These system delay times include driver brake RT, the time between when the alert criterion is violated and the onset of the crash alert, and the time between brake onset and actual vehicle slowing as a result of braking. The Braking Onset Range corresponds to the assumed range at which the vehicle begins to actually slow as a result of braking.

In conclusion, these results suggest that the inverse TTC model of braking onset provides a promising component for a FCW timing approach. Furthermore, inverse TTC appears to be a key element of the underlying mental process drivers use in deciding when they are in their normal versus hard braking envelope.

Surprise Lead Vehicle Braking Trials

The surprise (unexpected) lead vehicle braking technique has been used rather extensively in previous and recent CAMP FCW efforts to address the extent to which a wide range of factors impact the effectiveness of the CAMP FCW timing approach developed in the initial CAMP FCW project [9]. This more recent surprise trial work [6] examined the extent to which alert effectiveness is impacted by driver characteristics, environmental factors, interface design, distraction task/activity, kinematic conditions, and training/false alarms. Seventeen distinct surprise trials conditions were examined involving a total of 260 drivers. The alert timing approach employed was based on the required deceleration approach described in [7], coupled with a 1.52 second brake RT (or 95th percentile brake RT) assumption [9]. In addition, this work examined the degree to which knowledge of the factors examined would be useful for modifying the alert timing approach, as well as the benefits of a FCW alert (or alert presence). To investigate these issues, a surprise trial technique (illustrated in Figure 3) was employed in which the driver is distracted intentionally by the on-board experimenter immediately prior to the unexpected lead vehicle braking (or closing) event, which inevitably leads to a FCW alert presentation. Distraction techniques included both eyes-forward tasks (e.g., interacting with a voice recognition system to obtain navigation directions) and tasks involving head-down activity (e.g., dialing an unfamiliar set of numbers on a cellular phone mounted on the center console). In addition, much of the current and previous CAMP FCW surprise trials efforts have focused on evaluating a single-stage, dual-modality (auditory plus high head-down visual) FCW alert, in part because this interface is considered favorable from an industry-wide, production-friendly perspective.

Overall, results strongly support the effectiveness of the CAMP FCW alert timing/interface approach evaluated. First, based on test driver intervention rates, this approach was found to be robust, effective, and rated by drivers as appropriate across the wide range of conditions evaluated. Overall, intervention rates in the FCW alert and no-FCW alert conditions were 6.8% and 13.2%, respectively, which provides support for the overall utility of FCW alerts. The former intervention rate may be reduced if drivers received "valid" FCW alert experience/training, which was not provided here.

Second, these test driver interventions were restricted to tasks involving head-down glance activity, and never occurred for the eyes-forward distraction tasks examined. Furthermore, interventions occurred when the driver was looking down at the phone at FCW alert onset. Hence, a promising means of improving the CAMP FCW alert timing approach appears to involve sensing driver eye movement location, and more precisely, sensing when the driver is looking down (or away from the forward scene) instead of looking forward at the scene ahead. This sensing capability would not only improve alert timeliness for valid alerts issued when the driver is looking down, but just as importantly, such a capability would reduce the number of alerts perceived as occurring too early or unnecessary by the driver because they were already looking at the forward scene and purportedly aware of the vehicle ahead. Such a capability is highly desirable based on the ACAS FOT results that will be discussed below.

Third, 85th percentile driver brake RT values to the FCW alert under these surprise trial conditions have remained remarkably stable across the seven driver distraction tasks which have been examined (which includes previous CAMP FCW surprise trial work), ranging between 1.03 and 1.22 seconds. As might be expected, the 95th percentile brake RT values across these tasks tend to vary more widely, ranging from 1.10 to 1.73 seconds. These upper percentile values correspond well to other relevant sources of surprise driver brake RT data [5, 14, 15], and hence, are viable candidates for driver brake RT assumptions employed in FCW timing approaches, which is one of two driver behavior parameters desired for a crash alert timing approach.

Fourth, although both negative and positive effects of "cry wolf" false alarms were observed under these experimental conditions, it is somewhat tenuous to generalize these results to the rich and

Figure 3. Surprise trial method (Unexpected lead vehicle braking).

varied nature of drivers' experiences under day-to-day, naturalistic driving conditions with both valid FCW alerts and alerts perceived as too early or unnecessary by the driver. Indeed, gaining a deeper understanding of drivers' tolerances of false alarms provides an important underlying rationale for conducting the ACAS FOT project described below.

Time-to-Collision Judgments

The last-second braking data reported above suggests that the inverse TTC measure provides a parsimonious approach for characterizing driver's perception of normal versus hard braking envelopes. Hence, drivers' perception of the instant they feel that they would have collided with the vehicle ahead, and the relationship between perceived and actual TTC are of inherent interest. The perceived TTC measure was obtained here by occluding the driver's vision using liquid-crystal glasses (as shown in Figure 4) during the last phase of an in-lane approach to a lead vehicle. (See [13] for a more detailed description of these occlusion glasses.) After vision was occluded (at which point the test driver took control of the vehicle), the driver was to press a button the instant they felt that they would have collided with the vehicle ahead (assuming prevailing vehicle-to-vehicle kinematic conditions and existing collision course trajectories continue).

Nearly all previous TTC judgment studies intended for automotive application have been gathered with scenes presented under laboratory or driving simulator conditions [4, 18]. These scenes have distinctly different visual properties than real-world scenes that may impact TTC judgments (e.g., reduced peripheral vision, degraded binocular distance cues, and artificial scene texture gradients), and hence, drivers' perception of crash threat. (Indeed, this issue underlies the motivation for the current CAMP FCW NADS research briefly mentioned earlier in the paper.)

This study provides the most extensive set (known to the authors) of TTC judgment data ever gathered under realistic driving conditions. The current study examined TTC estimation under 12 combinations of driver speed and relative velocity, with driver speeds ranging between 30 and 60 MPH (48 and 97 km/h) and relative speeds ranging between 10 and 30 MPH (16 and 48 km/h). Results indicated that TTC was consistently underestimated. The TTC ratio (perceived TTC/actual TTC) increased as driver speed decreased and as relative speed increased. These ratios were largely unaffected by age, gender, actual TTC (3.6 or 5.6 seconds), viewing time (1-second versus continuous), and the presence of an eyes-forward, mental addition distraction task. It is of importance to note that the experimental manipulations of limiting viewing time (to 1 seconds) and/or introducing a concurrent (mental addition) distraction task were explicitly intended to represent distracted driver conditions. The elevated importance of TTC estimation coupled with the extreme salience of the lead vehicle looming behavior under the low TTC conditions examined appears to mitigate any effects of the independent variables examined on TTC estimation. In an analysis aimed at examining extreme TTC judgments, which may play an

Figure 4. Time-to-collision judgment technique using occlusion glasses (1-second glimpse condition shown).

underlying role in rear-end accident causation, increases in age and relative velocity were found to lead to higher probabilities of TTC overestimation (i.e., when perceived TTC exceeds actual TTC). With an eye toward developing an alert timing approach, these results suggest that under these low TTC conditions drivers estimate TTC in a relatively uniform fashion and that they are capable of providing this estimate based on a brief glimpse to the vehicle ahead after a period of losing visual and/or cognitive contact to the lead vehicle. Such a glimpse may occur following a FCW alert issued to a driver looking down, which is intended to trigger the driver to look toward the forward scene.

From a more theoretical perspective, these results tend to support for the view that drivers employ a direct, efficient, and automatic optic flow heuristic for making TTC estimations (at least under these low TTC conditions), which may be modified based on speed and relative velocity conditions [8]. Under this heuristic, drivers estimate TTC by operating directly on the visual scene and associated looming properties of the lead vehicle.

"First Look" Maneuvers

The "first look" technique, like the TTC estimation technique described above, is a visual occlusion technique being employed to further understand drivers' decision-making and avoidance maneuver behavior in rear-end crash scenarios. (It should be briefly noted that the data generated from these CAMP FCW occlusion techniques may provide a useful tool for validating/calibrating similar data gathered under simulator and laboratory approach conditions.) This technique is aimed at quantifying a surprised driver's reaction to a collision alert, and assessing the adequacy of a FCW timing approach under a wider range of approach conditions than can be practically attained using the "1 trial per subject" surprise trial technique described above.

After receiving a FCW alert, the surprised driver must quickly decide upon and execute a crash avoidance maneuver. In order to create what is considered an extreme form of driver distraction (i.e., a surprised driver) in which the driver has lost all visual and/or cognitive contact with the vehicle ahead, this first look technique (illustrated in Figure 5) involves blocking a portion of the driver's central vision with a CAMP-designed (liquid-crystal) occlusion window during the entire initial phase of an in-lane approach such that the driver could not see the lead vehicle. (Note that drivers still received visual information available through the side windows and portions of the front windshield, which is important since non-central visual information plays an important role in speed perception.) During the last phase of this in-lane approach, the driver's vision is suddenly "opened" at a point in time intended (based on the surprise trial dataset described above) to correspond to when a driver caught looking down would get their "first look" at the vehicle ahead after receiving a FCW alert. A driver is presumed to be in an alerted state shortly after a FCW alert is issued, which in this case corresponds to the timing of the window opening. Upon vision opening, the driver's task was to avoid colliding with the lead vehicle.

Drivers were encouraged to brake if at all possible unless they were not closing on the vehicle ahead (referred to as catch trials), in which case they are instructed to refrain from either braking or steering. If the driver is closing in on the vehicle ahead after vision opening, two steps are taken to prevent the driver from adopting a strategy of either always braking or always steering. To discourage the driver from an "always braking" strategy, trials are included with very late window opening timing, where a last-second steering avoidance response is predicted to be favored over braking (based on the CAMP FCW last-second steering data reported in [7]). To discourage the driver from adopting an "always steering" strategy, a trailing vehicle is present which passes in and out of the

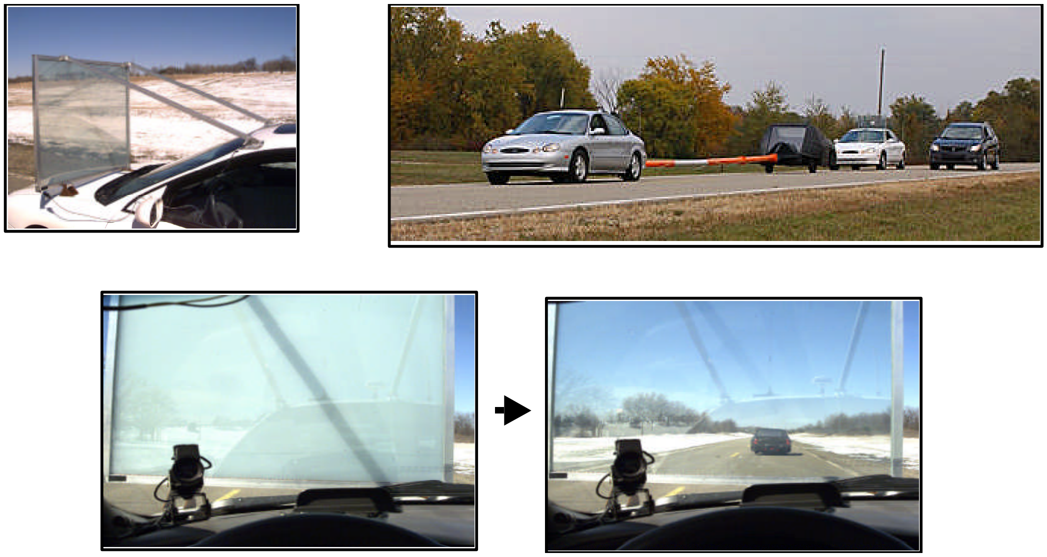

Figure 5. "First look" (extreme distraction) technique using the window occlusion method.

driver's blind spot in the adjacent lane and effectively discourages the driver from reflexively making a steering response.

Results from this study indicated that drivers were able to execute an unassisted, successful braking maneuver for over 85% of the trials. These results were obtained across a much wider range of vehicle-to-vehicle (kinematic) approach conditions than have been examined under surprise trial conditions. Hence, these results suggest that drivers can execute an appropriate crash avoidance maneuver under the alert timing assumptions evaluated, and under conditions that may have increased decision-making complexity relative to what drivers experienced in the previously reported surprise trial (unexpected lead vehicle braking) studies. These results, along with the TTC estimation results reported above, suggest that the driver can quickly assess TTC and make the appropriate crash avoidance maneuver under CAMP FCW alert timing assumptions.

Furthermore, a comparison of driver behavior under these "first look" conditions relative to the surprise trial conditions discussed above indicates the first look method appears to be a valid, efficient, and promising method for exploring the consequences of FCW alert timing. These comparison results indicate that required decelerations at brake onset and peak decelerations throughout the braking maneuver were somewhat higher under the current conditions relative to the matched surprise trial data set. These results suggest that this first look method represents a rather extreme form of driver distraction, and hence, this method may provide a conservative estimate of FCW alert effectiveness from a crash avoidance perspective. In addition, it is felt that this method provides a promising technique for generating decision-making and maneuver behavior representative of that which would be obtained from drivers under real world, rear-end crash scenarios.

This method could be used to explore the consequences of later FCW alert timing, which may serve to reduce false alarms, and hence, potentially increase the overall "credibility", acceptability, and safety effectiveness of the FCW alert system. Indeed, as will be discussed in the next section, reducing the number of false alarms drivers experience to a level that is considered acceptable by drivers while still maintaining effective valid alert timing remains a formidable challenge for FCW deployment and effectiveness.

More generally, it should be noted that there is a general lack of both age and gender effects under the actual FCW alert (i.e., surprise trial) and simulated FCW alert (i.e., visual occlusion) conditions examined in previous and current CAMP FCW efforts. This suggests that the FCW alert information may be an effective means of equalizing (or neutralizing) drivers in their ability to avoid rear-end crashes, and that a "one-size-fits all" FCW alert timing approach for closing alerts may be feasible.

OVERVIEW OF ACAS FOT FINDINGS

The goal of the Automotive Collision Avoidance System Field Operational Test (or ACAS FOT) project was to further the science and understanding of Forward Collision Warning (FCW) and Adaptive Cruise Control (ACC) systems by conducting an extensive FOT with lay drivers. The FOT was designed to address numerous issues dealing with the use and deployment of FCW and ACC systems. These issues revolved around examining the potential implications of these systems from both a traffic safety and driver acceptance perspective. The following is a summary derived from [1] and [2].

As the team leader for this project, General Motors was responsible for program management, overall integration of the various subcomponents and their associated software, threat assessment functions, and activities associated with predictions of vehicle location and road geometry. Delco Electronics & Safety was responsible for the Forward Looking Radar system, the ACC system, the Vision and Scene tracking systems, the Target Selection system and the Driver Vehicle Interface system that included a head-up display (HUD) which was used to display ACC- and FCW-related information. Hughes Research Laboratories was responsible for the Data Fusion system designed for the purpose of accurately determining forward road geometry. Delphi Chassis was responsible for developing the Intelligent Brake Control subsystem for the ACC system. Finally, the University of Michigan Transportation Research Institute (UMTRI) was responsible for the design and implementation of the Data Acquisition system, as well as the design and conduct of the formal FOT. Both UMTRI and General Motors were responsible for conducting the analysis of the FOT data.

The ACAS FOT program began in June of 1999 and was completed in November of 2004. It was organized into two phases. Phase I ran from June 1999 to December 2001. In this phase, the various ACAS subsystems were selected and developed using five Engineering Development vehicles. Once satisfactory performance was achieved, these subsystems were then integrated into a single Prototype Vehicle.

Phase II of the ACAS FOT program began in January of 2002 and was completed in November of 2004. In this phase, lessons learned from the Prototype Vehicle were used to install the ACAS system into two Pilot Phase Vehicles with FOT-deployment-level packaging. Further improvements were then made to the system and these two vehicles along with the 11 Deployment Vehicles were then built-up for a total of 13 Deployment Vehicles available for the FOT.

The FCW and ACC systems were developed, integrated and ultimately packaged in the 13 Buick LeSabre (2002 model year) Deployment Vehicles. Both FCW tailgating advisories and closing alerts were provided to the driver on a HUD via a graded looming approach shown in Figure 6. A small blue-green "vehicle ahead" display is provided when the system determines a vehicle is in the path of the driver's vehicle. For tailgating advisories and closing alerts, as the potential for a rear-end conflict increases, the icon turns to an amber color (referred to as a cautionary alert) and grows in size with the icon size dependent on the degree of predicted conflict. A final flashing alert (referred to as an imminent alert) consists of both a red/yellow flashing visual display and a series of warning beeps. Whereas the timing of the cautionary alerts was adjustable by the driver, imminent alert timing was not adjustable.

The ACC system evaluated is an enhancement to traditional cruise control. This feature allows the driver to keep cruise control engaged in moderate traffic conditions without having to constantly reset their cruise control. The system could apply limited braking or acceleration of the vehicle automatically to maintain a driver-selected follow distance to the vehicle ahead (which ranged from 1-2 second time headway). ACC braking was limited to about 0.3 g's (2.94 m/sec^2) of deceleration, which is comparable to moderate application of the vehicle's brakes.

These Deployment Vehicles were then given to 96 test subjects who, after receiving training on the ACAS system, drove these vehicles as their own personal cars for three or four weeks. The 96 lay drivers chosen for this experiment were randomly selected from three age groups (20-30, 40-50, and 60-70 years old) balanced for gender. During the first week of each subject's use, the ACAS features were not available to the drivers. During the subsequent weeks, the ACAS features were available. A robust data acquisition system was employed to capture a wealth of data from each driver's use of the ACAS cars. This data included a myriad of signals from the host car's J1939 data bus as well as visual images of the road ahead, and the driver's face. Radar tracks of cars, stationary objects, and other "targets" ahead were detected by the radar. Altogether some 1.4 terabytes of information were collected for analyses.

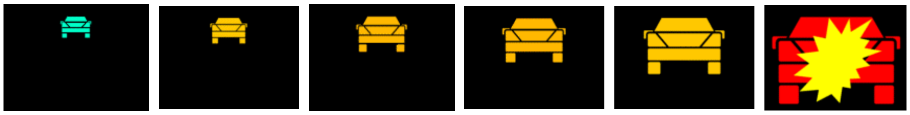

Figure 6. ACAS FOT graded, looming visual alert approach.

Table 1.
Overview of ACAS FOT safety and acceptance findings for Forward Collision Warning and Adaptive Cruise Control.

	Safety	*Acceptance*
Forward Collision Warning	- Reduced tailgating behavior - "Valuable" alerts identified - No broad "closing conflict" effect - No unintended safety consequences	- Purchase interest low - Too many alerts perceived as unnecessary
Adaptive Cruise Control	- Reduced tailgating behavior - Increased lane dwelling - Perceived as having more safety value than FCW - No unintended safety consequences	- Purchase interest high (without price target)

Interviews, questionnaires, and focus groups were also employed to capture the test participants' subjective evaluations.

When the FOT began in March 2003, the initial acceptance response of the ACAS system was much less positive than was reported by participants during earlier pilot testing. This dissatisfaction was based on what drivers considered to be false alarms (i.e., alerts perceived as too early or unnecessary). About half of the alerts were due to stationary objects along the roadside being detected by the radar and erroneously classified as "threats". Many other alerts occurred under conditions that drivers simply felt did not warrant an alert.

To address this situation, a 3-phased approach was implemented. First, in order to ensure sufficient information was garnered from the original algorithm (called Algorithm A), a total of 15 drivers drove with this original set of software. While this testing was underway, an improved algorithm was quickly developed and installed on the ACAS vehicles for a second set of 15 drivers (called Algorithm B). This software included several improvements over Algorithm A and also eliminated all alerts from stationary objects that the radar had never before seen moving during the approach (e.g., a roadside sign). Algorithm B still issued alerts to stationary objects that the radar had previously seen moving during an approach, such as when a lead vehicle came to a stop. Finally, a very ambitious set of software was developed (called Algorithm C) which restored alerts from "never before seen moving" stationary objects and added a host of features to further reduce the number of false alarms. The remaining 66 test subjects drove their vehicles with Algorithm C as the operating software. Overall, the efforts made to reduce false alarms produced approximately an order of magnitude reduction in these alarms from the first algorithm implemented in the Prototype vehicle to the most advanced algorithm that was ultimately employed in the formal ACAS FOT.

It is important to emphasize that the FCW and ACC sub-systems examined could potentially reduce the incidence of rear-end crashes, as well as the harm caused by such crashes, in primarily two different ways. First, these systems could reduce the amount of tailgating behavior, that is, the amount of time drivers spend following a vehicle ahead at short time headways under "steady state" driving conditions. A lengthening of headway times under these conditions can provide the driver with additional time to respond should an unexpected rear-end crash scenario unfold. Secondly, the FCW system may at times (e.g., when the driver is distracted) alert the driver to an approach (or closing) conflict earlier than the driver would have detected such a conflict. These approach conflicts, as well as tailgating behavior, can ultimately lead to a rear-end crash.

A high-level overview of the ACC and FCW safety- and acceptance-related results are shown in Table 1. Results indicated that both the FCW and ACC sub-systems reduced the incidence of tailgating behavior relative to manual driving without the support of these systems. Overall, as can be seen in Figure 7, the incidence of less than 1-second time headways were 26% with FCW system support, and

30% without FCW system support. This overall FCW headway lengthening effect was also observed at 0.1 second headway steps starting from cumulative time headway at less than 1.6 second headways all the way down to cumulative time headway at less than 0.5 second headways. A more detailed examination indicated that this effect was restricted to daytime driving and freeway driving conditions.

Perhaps more notably, as can be seen in Figure 8 (which shows headways under heavy traffic conditions), the incidence of less than 1-second time headways was three times lower during ACC relative to manual driving. This may in part explain why drivers' ratings of whether the system increased their driving safety were more positive for ACC than corresponding ratings for FCW. It should be pointed out that although this lengthening of headway times caused by ACC will naturally lead to increased cut-in behavior by other drivers, the warm driver acceptance of ACC suggests that the perceived ACC benefits clearly outweigh this potential annoyance.

The more dramatic effects of ACC on tailgating behavior are in all likelihood a direct result of the system preventing the driver from selecting an ACC gap (or time headway) setting of less than 1-second following time. The exact source of the FCW headway lengthening effect on tailgating is less clear, but can be potentially attributed to either the FCW tailgating advisory display (or possibly a transfer of training from the ACC system) increasing the driver's general awareness of their car following behavior.

On the other hand, evidence that the FCW and ACC systems reduced approach conflict behavior was mixed. Approach conflict metrics examined included the frequency of imminent alerts (where "silent" or "virtual" alerts were examined when the ACAS system was not activated), required deceleration to avoid impact and time-to-collision at brake onset, as well as peak conflict measures during approach events to a lead vehicle. Results indicated that the FCW system did not have a broad effect on reducing approach conflict behavior. Nevertheless, a small number of FCW imminent alert incidents were identified that were judged to have increased drivers' awareness of a potential rear-end crash and/or encouraged the driver to brake. Hence, the potential for the FCW system to help the driver avoid rear-end crashes and reduce the harm caused by such crashes was demonstrated.

With respect to ACC, it can be hypothesized that this system has at least the potential to increase approach conflict behavior, either because of the manner in which ACC controls the vehicle in approach situations and/or due to the choices drivers make in allowing ACC control in their assumed supervisory role. Results indicated that ACC did not negatively impact approach conflict behavior. On the contrary, it appears that ACC may reduce risks associated with lane changes by decreasing passing behavior (thereby increasing lane dwelling) and increasing the range at which drivers initiate certain lane-change-and-passing maneuvers on freeways (presumably to avoid ACC braking during passing).

Results did not indicate any unintended safety consequences of these systems (e.g., no notable increases were observed in secondary task behavior such as cell phone conversation, passenger conversation, eating, grooming, smoking). However, it should be noted that the increased percent driving time with ACC relative to conventional cruise control (overall, 37% versus 20% usage) was evident across all driving conditions, with the most notable increase of ACC usage occurring under heavy traffic conditions.

In addition, the rare occurrence of events in which the ACC system provided the maximum level of ACC braking was observed almost exclusively under surface street conditions. The rate of these rare events dropped substantially over the course of the three weeks of driving with ACAS enabled. Overall, there is a clear suggestion that drivers strongly preferred intervening with manual braking before the ACC applied its maximum braking authority, suggesting that drivers were not being overly reliant on ACC braking. Finally, a search for drivers who may have been experimenting with ACC and FCW systems failed to yield a single ACC maximum braking incident caused by driver experimentation, and suggested that the heightened level of driver attentiveness during this experimentation may serve to mitigate the risks associated with this activity. Driver acceptance of the FCW system was clearly mixed, and uniformly high for the ACC system. Overall, the older drivers tended to be more accepting of these systems. Without a hypothetical system cost, 45% and 75% of drivers indicated positive purchase interest toward the FCW and ACC systems, respectively. With a $1000 system cost for each system individually or a $1,600 combined (ACC plus FCW) system cost, positive purchase interest dropped to between 30% and 35%. The higher purchase interest in ACC may in large part be due to the fact that ACC profoundly reduces the workload and stress associated with the everyday task of car following (e.g., brake apply rates were 25 times lower under freeway conditions than with manual driving), along with the lack of FCW alert "credibility".

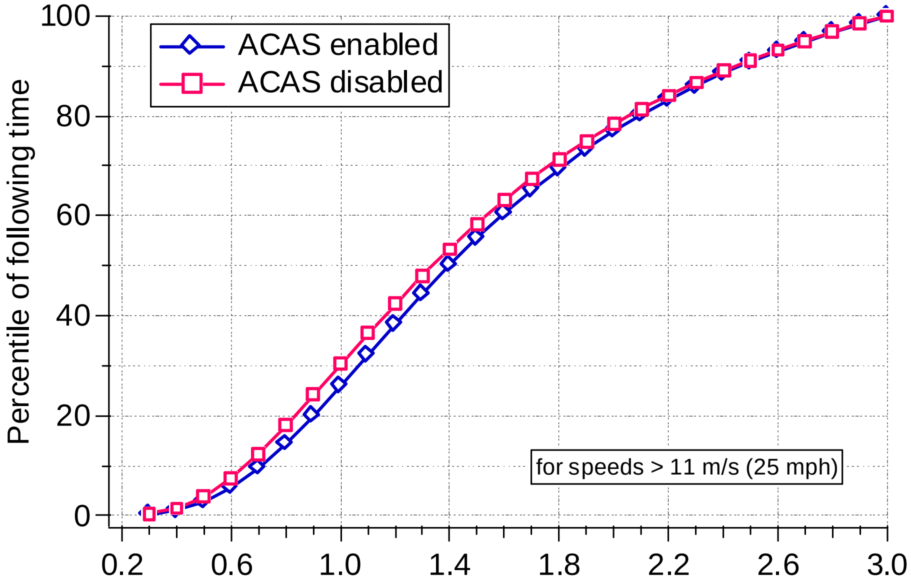

Figure 7. Cumulative distribution of headway times with and without ACAS Forward Collision Warning (FCW) system support.

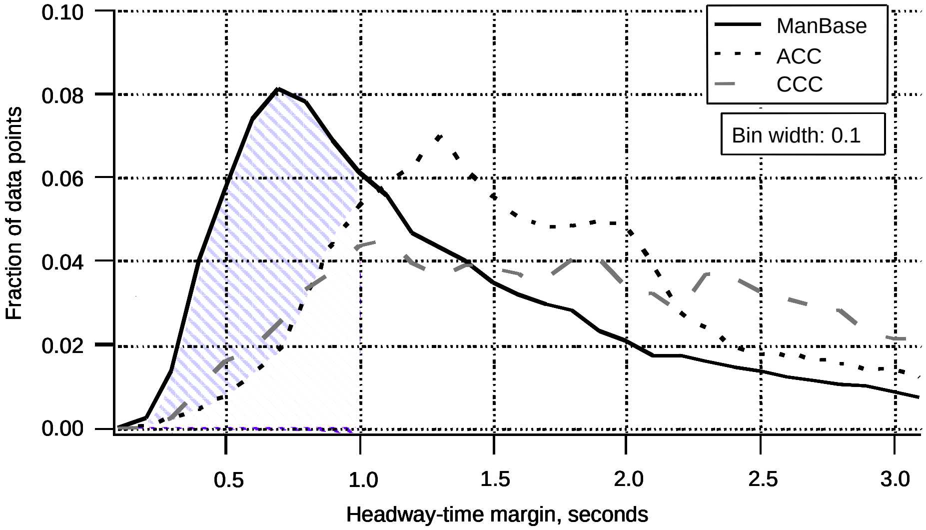

Figure 8. Cumulative distribution of headway times without cruise control, with Adaptive Cruise Control (ACC), and with Conventional Cruise Control (CCC) under heavy traffic conditions.

Although the ACAS test participants may not be fully representative (e.g., from an income level or vehicle ownership perspective) of likely buyers for initial ACC- and FCW-equipped production vehicles, these data clearly illustrate the importance of ensuring FCW and ACC systems can be offered to consumers at affordable costs in order to foster deployment of these features.

With respect to FCW, results clearly suggest that further reductions in false alarms (resulting in a higher proportion of "credible" FCW alerts) are needed to ensure widespread FCW system acceptance. Overall, the vast majority of imminent alerts occurred during non-ACC driving. Under these manual driving conditions, imminent alerts occurred at an average rate of 1.44 per 100 miles for drivers using Algorithm C (with alerts occurring primarily on surface streets). In addition, average imminent alert rates varied from 0.08 to 4.34 per 100 miles across drivers.

Roughly one-third of the imminent alerts were issued in response to each of the following three general alert categories: to vehicles that remained in the same lane as the driver during the approach, to roadside out-of-path stationary objects (such as signs and mailboxes), and to vehicles which transitioned in and out of the lane sometime during the approach (e.g., when the lead vehicle was turning or during driver-initiated lane changes). Consequently, it is not surprising that drivers were not observed to brake reflexively to the imminent alert.

The overall impression is that a formidable technical challenge lies ahead in fielding a widely accepted FCW system. Unfortunately, a comparison of subjective results across algorithms investigated, as well as within the 66 drivers experiencing the final algorithm, failed to provide clear direction as to the extent to which false alarms must be reduced in order to ensure widespread acceptance of the FCW system. Nonetheless, the lessons learned in this project have suggested numerous improvements that have the potential to lead to this broader customer acceptability by reducing false alarms. For example, at least for the current state-of-the-art capability, it appears that the requirement levied on the ACAS system to detect "always stationary" vehicles (i.e., vehicles that have never been seen moving by the FCW system) may be ill-advised, based on the high frequency of false alarms to "always stationary" objects (such as signs and mailboxes) relative to the extremely rare occurrence of credible imminent alerts to "always stationary" vehicles.

From the perspective of executing an FOT, this effort demonstrates the value of conducting multiple preliminary mini-FOTs (prior to the formal FOT) to ensure system performance is commensurate with driver expectations. Furthermore, it should be stressed that drivers' acceptance of systems based on short-term exposures can be very misleading.

CONCLUSIONS

In summary, the CAMP FCW and ACAS FOT program have produced pioneering knowledge which can be used to address the rear-end crash problem, as well as other types of crashes. The CAMP FCW project has provided important information with respect to characterizing and modeling drivers' normal and non-normal last-second braking and steering maneuvers (or envelopes), FCW timing and interface approach recommendations, and innovative test-track methodologies which can be used to examine crash avoidance systems under controlled, realistic conditions.

The ACAS FOT augments this information with an immense set of in-traffic, naturalistic data which has provided much needed information on FCW system alert rates and false alarm issues, the immense variation of driver's alert experiences, driver potential acceptance of an FCW system, and FCW system performance requirements. In addition, the ACAS FOT provides an equally rich set of data to understand how drivers choose to use and behave with an ACC system with moderate levels of braking authority.

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A REAR END COLLISION WARNING SYSTEM FOR TRANSIT BUSES

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Paper Number 05-0275

ABSTRACT

Rear impact crashes are the most frequent type of bus accidents. Transit buses are particularly susceptible to rear impact collisions because of their frequent stops, which often occur in traffic lanes. The majority of bus collisions occur while the bus is decelerating or stopped. The preponderance of crashes occur with buses stopped during daylight hours, in good weather conditions, while traversing a straight path, and with the striking vehicle attempting no avoidance or corrective action.

To respond to this surprising set of crash conditions, General Dynamics, in partnership with the Ann Arbor Transit Authority (AATA), developed a Rear-Impact Collision Warning System (RICWS) based on our premise that following drivers were either being distracted or simply not paying attention. To determine the following drivers' behaviors behind transit buses, General Dynamics first conducted a series of field collections using a recording system, digital video, and a laser front-end sensor mounted on the rear of an AATA bus in service. These "behaviors" were then used to build decision logic to determine when a dangerous situation required mitigation or countermeasures.

General Dynamics then developed a visual warning system. Tests concluded that a light bar with a specific moving light pattern was effective in attracting a distracted driver's attention. This light bar was added to the RICWS and was turned on once a following vehicle committed dangerously aggressive closing behavior toward the rear of the test bus. Three warning algorithms were field tested, each with different parameters defining 'aggressive closing behavior.'

Both Phase II and Phase III of this program produced informative results regarding typical following driver behavior behind buses. The light bar proved effective in modifying following drivers' behavior (with all three algorithms). A set of comprehensive RICWS specifications were generated as well as future commercialization steps for the system.

INTRODUCTION

The RICWS report (which is the basis for this paper) was prepared for the U.S. Department of Transportation, Federal Transit Administration for the development of performance specifications for Rear Impact Collision Warning Systems (RICWS) for transit buses. The actual specifications are not listed in this paper, but may be found in the original report. This research was conducted in this area since one of the most frequent accidents in transit bus operation is when a vehicle collides with a bus from behind: a "rear impact." This type of collision is responsible for significant costs including damage to the bus, injuries to the occupants, and disruption of the operation of the transit agency. In addition, damage to following vehicles (FVs) and injury to their drivers is usually significantly greater than to the bus or its occupants.

In 1994, transit buses were involved in 3,119 rear-end collisions, nationwide. By 1996, that number increased 56 percent. For the same period, the number of injuries increased 161 percent.

Table 1.
Crashes and Injuries for Transit Bus Rear-end Collisions

Year	1994	1995	1996
Crashes	3,119	3,668	4,868
Injuries	1,403	3,262	3,661

Data courtesy of Volpe National Transportation Systems Center, N. Burke, 2/99

Transit buses are particularly susceptible to rear impact collisions because of their frequent stops. Adding to the problem, some bus stops do not allow the bus to pull out of a lane of moving traffic. The DOT Draft Transit IVI Baseline Statistics Study (personal communication, N. Burke, February 2, 1999) indicates that the majority of collisions occur when the bus is decelerating or stopped.

This type accident is common with transit companies all over the country. Nationally, rear-end crashes account for 21.5 percent of all collisions involving buses for 1994 to 1996 (personal communication, N. Burke, February 2, 1999).

According to the 1998 Transit Fact Book, although casualty and liability costs comprise only an average of 2.9 percent of transit companies operating budgets, efforts to reduce the risk exposure, and therefore premiums and claims, by operating fewer miles, having fewer accidents, and/or fewer employees are "often overwhelmed by litigation awards, inflation and state- or region-wide premium increases to cover insurer losses elsewhere." In rear impact crashes, due to the mass of the bus, the resulting collision can be severe for the occupants in the following vehicle, but not necessarily for the bus. Although, there is usually little cost associated with physical damage to the bus, there are costs associated with workman compensation, rider injury, litigation against the following vehicle driver, lost time of bus and driver, and possible drug testing of the driver.

Table 2.
Rear-end Transit Bus Crash Summary

Feature	**Most common (%)**	**Second most common (%)**
Number of lanes	Two (41.7%)	More than two (39.1%)
Relation to junction	Non-junction (62.7%)	Approach to intersection (22.2%)
Grade	Level (59.6%)	Grade (15.4%)
Alignment	Straight (89.1%)	Curve (7.6%)
Speed limit	30-45 (55.3%)	50-75 (15.8%)
Following Vehicle speed	<=25 mph (47.3%)	26-40 mph (34.4%) [Largest single 5 mph bin is 31-35, 15.1%)
Lighting	Daylight (85.5%)	Dark but lighted (6.7%)
Weather	Clear (77.3%)	Rain or snow (18.7%)
Bus motion	Stopped (67.2%)	Slowing in lane (13.5%)
Following Vehicle movement prior to critical event	Going straight (82.1%)	Slowing or starting (6.6%)
Corrective action attempted by striking vehicle	None (67.3%)	>2 vehicles involved (15.4%)

From Table 2 it can be seen that this type of collision happens most often with clear weather, daylight, straight road, bus stopped, striking vehicle approaches in same lane at constant 31–35 mph with no corrective action.

Research Approach

The research approach was to divide the effort into three major phases. The first phase was an initial causation study and technology demonstration. Overall the Phase II effort provided a detailed accident profile report, an initial system specification for a RICWS system, and field data collection effort to establish the baseline parameters for a RICWS system. Phase III of this contract provides for outfitting two buses with similar systems which include algorithms and warning lights to study and assess the reactions of following vehicle drivers in response to ignition of the warning light. Phase III also updated the system specifications for a rear impact collision warning system.

The detailed approach in each of the two phases is identified below.

The approach and efforts for Phase II:

- Conduct an assessment of available crash data to characterize rear-end crashes involving buses.
- Completed a warning indicator study to arrive at an "optimal" design of a warning indicator.
- Establish requirements for a baseline data collection.
- Build two testbed Data Collection Systems (DCS) to be used on AATA buses to collect baseline data.
- Generate a "baseline" of on-the-road data to use in assessing the efficacy of the data collection system and to use in building and testing a warning algorithm.
- Build tools with which to analyze the collected baseline data.
- Assess and analyze following vehicle driver behavior as exposed in the baseline data collected.
- Evaluate crash scenarios and possible benefits of the warning system, refine performance specifications, and define evaluation strategies.

The approach and efforts for Phase III:

- Implementation of the code necessary to add the capability to the DCS system to provide ignition of a warning light at appropriate times.
- Algorithm development and validation testing.
- Light bar field testing.
- Replacement of degraded laser IR sensors.

- Human factors testing of drivers approaching the back of a bus under “normal” conditions.
- Collection of data from two buses fitted with the system with warning lights.
- Analysis of collected data.
- Update algorithms to signal the warning light based on field testing.
- Update system specifications.
- Complete the final report and recommendations for next steps.

FINDINGS

Findings in this paper encompass only the Phase II and Phase III efforts. The Phase II findings are identified below and are more comprehensive than the Phase III findings; however the Phase III findings encapsulate the overall results of this program. The Phase II effort is the basic R&D needed to support the Phase III effort. In Phase II, we identified key system parameters and established the plan for the Phase III effort. The Phase III findings are more abbreviated and to the point since they focus on the results of the system performance in an operational environment. Essentially Phase III findings are the “icing on the cake”. They are the operational conclusions from RICWS testing in a real environment.

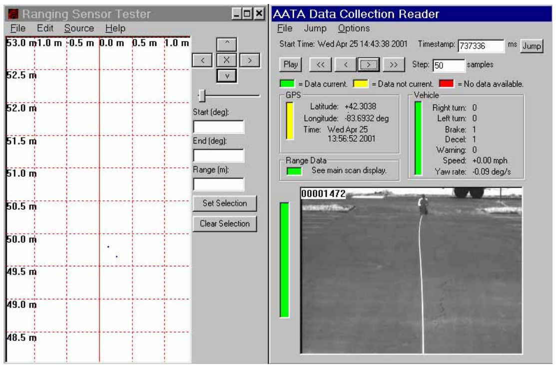
Phase II Findings

Conclusions derived from the Phase II baseline data collection have been developed by manual examination of data from two particular days of collections, the very first (4/25/01) and a day near the end of collections (8/17/01). Algorithms have been run extensively on these two days’ data.

Range Sensor Performance did not receive a rigorous or detailed evaluation in a laboratory setting; however a reasonable set of outdoor measurements were made to validate the nominal performance of the sensor. In addition to the outdoor measurements, examination of the baseline data collected helped to characterize the sensor performance. An important note, however, is that the selected sensor for our testbed DCS system may not be the ideal sensor for deployment in transit bus fleets across the nation. In fact, our selection process was driven by a sensor that was a reasonable cost and was commercially available (with no development costs) that would be adequate for this program. As will be identified later in the report, we recommend a different type of sensor for a deployed commercial system. The detailed information provided below is included here since it was instrumental in providing guidance, evaluation and insight into the recommended sensor requirements for a commercialized system suitable for nation-wide deployment. The recommended sensor for commercialization is included in the Phase III findings.

The range sensor’s resolution is 15 cm and spec sheet accuracy is listed as + or – 1 percent at 100 meters. Empirical observations of the returns from stationary targets at various ranges tend to support this specification and, in fact, suggest that the absolute accuracy may be better at distances in excess of 25 meters. At closer range this sensor appears to suffer from saturation and possibly cross-talk problems with highly reflective targets, and range measurement accuracy degrades. In fact, the sensor functions quite poorly at distances below 8 meters. In almost any instance, the following vehicle warnings were signaled at distances greater than 15 meters, so the lower range limit was not a significant issue for our testing.

On 4/25/01, the day the bus was put into service, a number of specific range measurements were taken utilizing boards coated with retro-reflective material (see Figure 1). A table of these measurements and the range sensor outputs is shown below (see Table 3).



Start Time: Wed Apr 25 14:43:38 2001 Timestamp: 737336 ms

Step: 50 samples

Latitude: +42.3038
Longitude: -83.6932 deg
Time: Wed Apr 25 13:56:52 2001

See main scan display.

Right turn: 0
Left turn: 0
Brake: 1
Decel: 1
Warning: 0
Speed: +0.00 mph
Yaw rate: -0.09 deg/s

Figure 1. Measuring Range Detection Performance of Range Sensor.

Table 3
Sensor Range Accuracy and Repeatability Observations

Measured Range (meters)	Observed Sensor Range Mean (meters)	Diff. (meters)	Percent Accuracy	Observed Sensor Range Repeatability (meters)
5	2.85	2.15	43	+0.15, –0.3 or more
10	11.4	1.4	14	±0.15
15	14.55	0.45	3	±0.15
20	19.65	0.35	1.75	±0.15
30	29.85	0.15	0.5	±0.15
40	39.75	0.25	0.625	±0.15
50	49.8	0.2	0.4	±0.15
60	59.85	0.15	0.25	±0.30

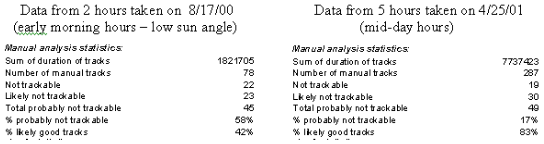
The table above indicates accuracy in essentially a static environment, and those accuracies are adequate for the calculations needed to calculate when to signal the warning light. However, we found that in the dynamic environment of buses and following vehicles moving, that the specular returns from the following vehicle could jump from one region on following vehicle to another causing an error input to our tracking algorithms. This effect of dynamic jumping of the return from the following vehicle and affecting our tracking algorithms will be addressed in the Phase II findings.

The following factors have been identified and observed in normal operations data that serve to reduce the quality and availability of range returns for objects that are clearly visible in the video record and which, based on their position in the video should have produced a range return. The factors include:

- Intermittent or no returns off some vehicles with no apparent environmental cause (due to vehicle characteristics such as profile, surface materials, angle of presentation).
- Intermittent or no returns off some vehicles due to environmental conditions impairing the range sensor's performance (ambient light energy entering the sensor—such as at low sun angles, rain, fog, smoke/dust, dirt on the sensor face, etc.).
- Intermittent returns off vehicles caused by bus movements (primarily vertical bounce due to bumps or potholes).

Unfortunately, these conditions are difficult to identify automatically, and it is impractical to manually review all the video data to correlate poor range sensor performance with these types of factors (as opposed to the default explanation: no following vehicles present). However, portions of two days of data have been examined manually with the following results (see Table 4).

Table 4.
Manual Assessment of "Interesting Tracks"



Data from 2 hours taken on 8/17/00
(early morning hours – low sun angle)

Manual analysis statistics:	
Sum of duration of tracks	1821705
Number of manual tracks	78
Not trackable	22
Likely not trackable	23
Total probably not trackable	45
% probably not trackable	58%
% likely good tracks	42%

Data from 5 hours taken on 4/25/01
(mid-day hours)

Manual analysis statistics:	
Sum of duration of tracks	7737423
Number of manual tracks	287
Not trackable	19
Likely not trackable	30
Total probably not trackable	49
% probably not trackable	17%
% likely good tracks	83%

Direct low angle sun impinging on the sensor seemed to be the primary environmental factor affecting the sensor's ability to detect returns in the 8/17/01 data (note: table erroneously labels this date as 8/17/00). No other environmental factors (e.g., rain) were observed in these sets of data. Both days examined can be expected to have the same percentage of range return problems due to vehicle profiles. A more "normal" range return behavior is evident in the data from 4/25/01. Making a gross estimate of the percentage of hours with rain and low sun angles (and other effects that similarly compromise optimal sensor performance) as 25 percent, then a weighted average of "percent likely good tracks" as determined by this direct visual examination of the video and range data yields an expected sensor performance of 73 percent. That is, the range sensor produces, on average, good, usable range returns for 73 percent of vehicles that approach the bus on a potential collision course due to environmental conditions.

However, a very significant reduction in probability of detection of an approaching vehicle is not associated with environmental conditions. As indicated above, a number of instances of the system not being able to detect and track a closing vehicle was due to vehicle characteristics such as profile, surface materials, angle of presentation, etc. For example, with an infrared (IR) sensor and eye safe illumination, it is very difficult to get an adequate return from some vehicles, such as a Corvette. This situation is far from limited to Corvettes. Most any small "sleek" vehicle, especially with retractable headlights is not very visible to this type of sensor. Our data analysts estimated that 30 percent of the following vehicles were not identified by the laser sensor. For our field testing this sensor performance issue just removed these types of vehicles from our test set. Though not ideal, we were still able to evaluate algorithms and effectiveness of the light bar over the data set of the vehicles our system could detect and track. However, for a commercially deployed system, it is probably not acceptable to not track 30 percent of the following vehicles, therefore a more robust sensor is needed which can detect almost all vehicles which would be encountered in a transit bus environment.

Ranges to Targets at First Detection were determined by calculations to quantify the desired minimum detection range for approaching vehicles. The following chart (Figure 2) provides guidance on the required distance for first detection of approaching vehicles to allow enough time to flash a warning and expect the vehicle to stop before hitting the bus. The different curves show the results of different braking effort and reaction time assumptions. Common assumptions embedded in these curves are that the detection system has a sampling interval of 0.1 seconds, and that a minimum of five samples are required before signaling of the warning light can occur.

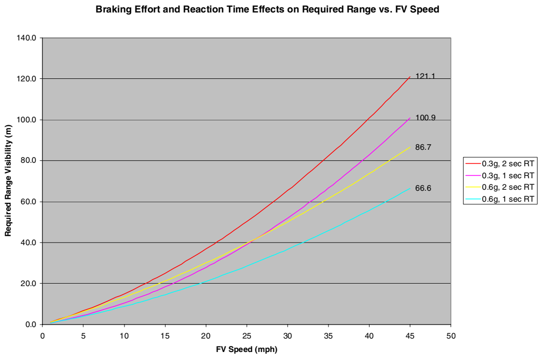


Figure 2. Chart of Required Range of First Detection to Avoid Collision.

The 0.3 G braking curves (labeled as 0.6 G) indicate that first detections must occur between about 45 and 61 meters at 35 mph.

Examination of the collected baseline data for one day's worth (8/17/01) of approaching targets yielded the following distribution (see Figure 3) of first detection distances for a group of 112 vehicle tracks, all of which exceeded (at some point during the track) the following measures of relevance for collision warning purposes (as determined automatically by a tracking algorithm):

- Range rate exceeded 10 m/s closing.
- Time to collision fell below 3 seconds.
- Braking required exceeded 0.25 G.

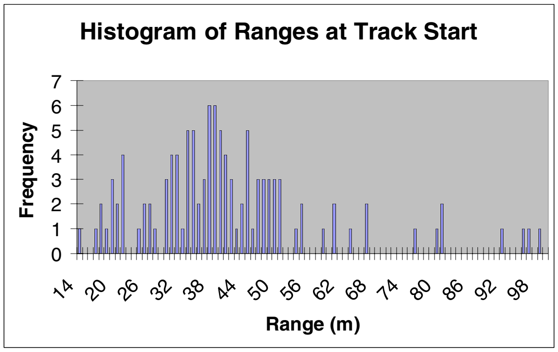


Figure 3. Ranges at Track Start (112 selected tracks).

The mean of this distribution is 41.2 meters, standard deviation 17.1 meters, and median of 38.6 meters.

All approaching tracks for a single day were examined and yielded the following distribution of first detection distances (see Figure 4).

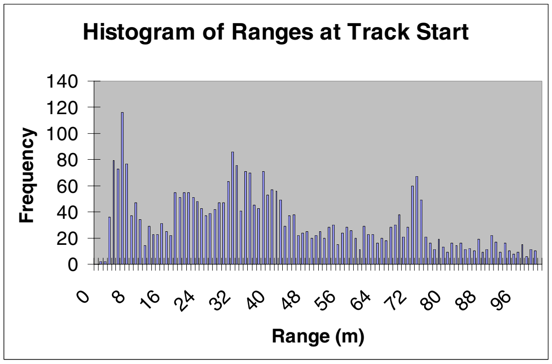
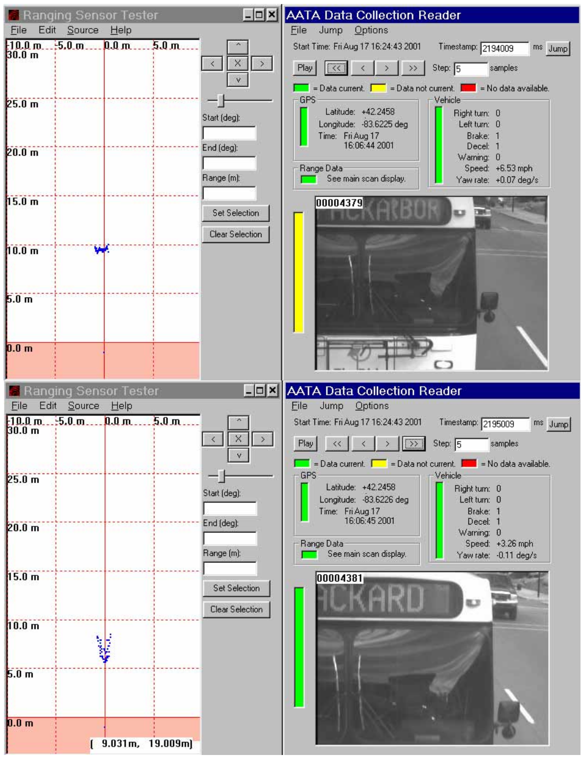


Figure 4. Ranges at Track Start (3255 total approaching tracks, 8/17/01).

The mean of this distribution is 39.3 meters, standard deviation of 25.3 meters, and median of 34.6. The multiple peaks showing in this second histogram deserve further discussion.

The large number of tracks starting within a 10-meter range are due to an observed "spreading" of the range returns from a single vehicle at close range which results in track splitting and spawning within the cloud of range returns (due to the current clustering algorithm utilized to establish the association of range returns to single targets). This origin of the range spreading phenomenon is as yet undetermined, but is likely due to overloading (saturation) of the range sensor detector at close ranges (see Figure 5). Since many of these ranges at track start are due to multiple tracks on the same vehicle, this peak is erroneous.



Start Time: Fri Aug 17 16:24:43 2001
Timestamp: 2194009 ms
Step: 5 samples
Latitude: +42.2458
Longitude: -83.6225 deg
Time: Fri Aug 17 16:06:44 2001
Right turn: 0
Left turn: 0
Brake: 1
Decel: 1
Warning: 0
Speed: +6.53 mph
Yaw rate: +0.07 deg/s
00004379

Start Time: Fri Aug 17 16:24:43 2001
Timestamp: 2195009 ms
Step: 5 samples
Latitude: +42.2458
Longitude: -83.6226 deg
Time: Fri Aug 17 16:06:45 2001
Right turn: 0
Left turn: 0
Brake: 1
Decel: 1
Warning: 0
Speed: +3.26 mph
Yaw rate: -0.11 deg/s
00004381

Figure 5. Range Spread Phenomenon at Close Range (within 10 m)
(Note: Lower display is 1 second later than upper display)

The peak at about 76 meters range in Figure 4 indicates that there is a certain class of vehicles that tend to become visible to the range sensor at this range. This class of vehicles includes other buses and large truck tractors – basically anything presenting larger-than-normal perpendicular surfaces to the range sensor.

The remaining middle peak corresponds to the average distance at which the typical following vehicle (a sedan, SUV, or pickup truck) becomes visible. This distance, approximately 40 meters, corresponds to a speed of 32 mph on the 0.6 (0.3) G, 1 second reaction time curve of Figure 2. While not optimal (ideally, ALL following vehicles would become visible to the range sensor at least 66 meters to allow for warning and a complete stop before crash at up to 45 mph) this sensor still provides an adequate range of detection for the majority of vehicles transit buses may encounter in city driving.

In the Derived Parameter Assessment, timing relationships among the data elements are established by construction in the loop sequencing in the data collection system, but detailed timing relationships can vary depending on the instantaneous computational load in the DCS system. These relationships and variations have not been fully quantified, but have been observed in plots to be reasonably accurate. This effect is embodied in selection of a CPU with sufficient power to perform the calculations in the required time.

Analysis of the of the database data (both video and stored parameters) and manual examination of dozens of plots of velocities, accelerations, range-rate, headway time margin, time to collision, and braking required indicate that computations of these parameters are being done correctly.

Crash Scenarios, Performance Specifications, and Evaluation Strategies developed as expected. Based on the extensive manual review of data to date and processing results it would appear that the vast majority of potential rear-end collision incidents occur under the conditions as indicated in our analysis of crash history data—and this is not an unexpected conclusion. Virtually all incidents of “excessive” braking required parameters occur in tracks of following vehicles in the lane of the bus (generally straight and level) that are approaching the bus and ultimately stop behind the bus. The remaining incidents are vehicles approaching in the same lane but which execute a lane change to pass, typically on the left, but sometimes on the right.

Phase III Findings

The Phase III effort was the primary data collection with RICWS systems on two buses over an assortment of AATA routes. This collection was the first test with the warning lights being activated in a field operational environment where drivers would be exposed to the warning system and hopefully modify their driving behavior immediately following the warning light illumination. This Phase III collection was divided into three major sub-collections, each one utilizing a different collision warning criteria; 0.3 G fixed threshold, 0.225 G fixed threshold, and the CAMP algorithm. Though this program was not funded to do a major evaluation or optimization of warning algorithms in Phase III, we elected to evaluate three different criteria in an effort to better characterize the motorists reaction to the system and either select the best approach or at least establish a trend. The original plan was to analyze the Phase II data collection data where baseline driving behavior was collected. However in this scenario, though excellent baseline data was collected, it of course did not include driver’s response to the warning because the lights were not illuminated. Our original plan was to develop the algorithm from this baseline data with no need to implement secondary modifications or conduct multiple algorithm studies during the Phase III collection where motorist response to the warning was included. However, with the questions initiated by the combination of the initial 0.225 G threshold results, the results of our human factors testing, and the importance of the CAMP algorithm and the respect for that research, it was deemed most appropriate to evaluate multiple scenarios in the operational field test. The downside of this approach was that for any given warning algorithm there would not be a sufficient number of incidents to statistically prove it was effective in mitigating risky driving behavior behind transit buses. If we would have gone down the path of selecting and utilizing only one algorithm, then we would have had the potential to prove that that one algorithm was or was not effective in this transit bus scenario, however we would not have developed the understanding of how effective that algorithm was with respect to other potential algorithms. It would just be a single point analysis.

The Warning Light Design and Effectiveness Evaluation was one of the key challenges of this program. General Dynamics was to design, build, and evaluate the warning lights that were to be mounted on the back of the bus. These warning lights are the interface from the RICWS to the following vehicle driver. The goal for the light bar is to capture the following vehicle driver's attention and elicit a response as quickly as possible.

The Vision Detection Laboratory at the University of California, Berkeley, led by Professor Theodore E. Cohn, provided the necessary design, build, and human factors testing to evaluate and select the system that provided the highest performance. The result of their warning light research is shown in Figure 6. The light bar is mounted horizontally on the back of the bus. It is an LED 8-segment light bar system (50 inches long by 4 inches high), where the segments are grouped in pairs. Each pair, starting from the middle pair and working outwards to the left and right sides of the bus, are illuminated. These sequence pairs are a symmetric set of segments centered about the centerline. So the middle two segments are a pair. The next adjacent segments are a pair, and so on. As can be seen in Figure 6, the segments are amber, and the intensity was set to the same light intensity as a brake light.

The human factors performed at the Vision Detection Laboratory indicated this configuration to elicit the fastest response from the test subjects.

Figure 6. Warning Light Bar on AATA Bus.

Following Vehicle Driver Behavior was recorded without any public education being provided. Two buses at AATA were equipped with the RICWS. So all following vehicle drivers who encountered warnings from the yellow warning light bar reacted totally on intuition and basic understanding as to what the flashing yellow warning lights were trying to tell them. In the future, if RICWS systems are widely deployed, it can be conjectured that the driving public will have been educated somewhat to the intention and goals of RICWS systems, and as such might react even more favorably.

The video recording of the data acquisition system was critical in evaluating driving behavior. Our analyst soon discovered that as soon as most drivers see the bus in front of them they start making plans to get out from behind it. Whether their actions are to immediately pull into an open adjacent lane, or start to jockey for position to pull into an adjacent lane opening, or even to force an opening in the adjacent lane, their goal is predominantly to get out from behind the bus. And one of the very common maneuvers is to jockey for an open position in the adjacent lane while approaching the back of the bus on a collision course. They pull into the adjacent lane at the last second, all totally planned and fully aware of the situation. In this scenario, the following vehicle driver probably does not need to be warned about the impending collision with the bus, because in most instances he seems to be fully cognizant of the closing velocities and the opportunity he is generating to swerve around the bus.

Our RICWS system, unfortunately, is not robust enough at processing the collected data to understand the driver's plans. The RICWS can only look at closing velocity and lateral velocity (and of course position with respect to the bus). From our video analysis we identified that there is not some typical following vehicle velocity behavior that is a high predictor of what the intentions of following vehicle driver is planning on doing. So the best a RICWS system can do is signal its warning when the closing velocity and distance of the following vehicle's "Braking Required" exceed the algorithms threshold in a driving scenario where there are no lateral velocity changes to indicate an impending lane change.

For this common swerve scenario, all a RICWS system can do is activate its warning lights. However, there may be a dilemma here: if the warning lights are activated, how will the driver react in the midst of his planned risky behavior? Additional human factors research is needed to validate that drivers would not react adversely to a rear impact collision warning in this situation.

Determining Effectiveness of the RICWS in Transit Bus Field Operations requires several evaluation parameters. Various choices exist for definition of the specific warning criteria for signaling of the warning light. Making this choice is a complicated process that involves simultaneous balancing of trade-offs having to do with:

- Sensor capabilities and characteristics:
  - Lateral distance/velocity accuracy, resolution and dynamic range.
  - Longitudinal distance/velocity accuracy, resolution and dynamic range.
  - Contrast ratio between targets (following vehicles) and background clutter.
- Striking a balance between false alarms and missed threats.
- Timing of warning with respect to need (early enough to prevent crash, but not too early so as to represent a nuisance alert).

We have looked at using three possible scenarios for driving the warning indicator:

- An alert based on simple braking required threshold of 0.3 Gs.
- An alert based on simple braking required threshold of 0.225 Gs.
- The CAMP forward collision warning alert equation.

For the fixed threshold approach, we collected data and provide warnings at both the 0.3 G and 0.225 G thresholds. We also collected data utilizing the CAMP algorithms.

In the overall analysis of the performance of the three thresholds, we primarily compare two data plots. The first graph is a plot of the braking required history for all incidents where the following vehicle exceeded the threshold and the warning light was signaled. The second comparison graph is the plot of the braking required histories for all following vehicle pseudo-incidences. These pseudo-incidences are situations where the following vehicle met all requirements to signal the warning (both threshold and parameters), however the warning was not signaled because it was not enabled. Pseudo-incidences are very intentional, they occur in time periods when the system is fully operational except for the final signaling of the warning light. Their purpose is to provide the reference or ground truth for the field operational test.

The key comparison that is made between the incidents and the pseudo-incidents is comparison of peak values of braking required. For following vehicle incidences where the light is signaled, if the system is effective, the driver will respond to the RICWS warning light and slow down. In the following vehicle pseudo-incidences, the warning is inhibited from being signaled, and it is expected that the drivers would continue to drive at the bus for a time period, and as such their path histories would have higher braking required. In fact, it is this single parameter comparison that we use as the metric for evaluation of the effectiveness of the system.

As any of the charts below are analyzed, it should be noted that only two seconds of data was plotted before the threshold warning point. In many cases data preceded this point, but was truncated for convenience of plotting. After the threshold warning point, not all data returns to 0 Gs braking required, which seems a little odd at first glance, but the selected IR laser sensor does not reliably work below 8 meters distance behind the bus, so data is truncated at this point. In all cases, there were no collisions into the back of the bus, so all vehicles did stop behind the bus, pulled out of the threat zone behind the bus, or the bus started pulling away after the following vehicle entered the 8-meter zone.

Another aspect of the plots for each of the data sets is the number of traces on each graph. For the two fixed threshold sets (0.3 G and 0.225 G), there are few more traces (braking required incidents) for the non light activation scenario than on the activation scenario. In both cases, the data analyzed was based on a 50 percent duty cycle between activation and non activation, so the different number in the plots was just a matter of statistics. However, for the CAMP algorithm, there were 13 CAMP warnings with the light activated, and 183 without. This apparent discrepancy is due to processing a much larger set of data where the light was not activated. Any of the data which was collected where the light was not activated is potential data for reprocessing to evaluate any algorithm. We took advantage of this for the CAMP evaluation. Even though the CAMP light activation data was collected in September, the data set for CAMP with no light activation was a time period over March and April.

The 0.3 G Fixed Threshold Data Collection is the least conservative warning criteria used in our data collection. From an intuitive standpoint, this is the value of braking required which most people in our human factors testing felt was the maximum braking required level that could be done while still feeling "comfortable". It should be noted that the evaluations were done by the subjects deliberately driving towards the back of the bus and braking at the last instance where they felt comfortable. As mentioned elsewhere in this report, at 0.3 Gs, items start sliding off of seats (if they are not restrained).

The first plot which is shown in Figure 7 is the plot of the braking required histories with the warning light enabled at 0.3 Gs. There are two major observations. First, there were only two such incidences while the light bar was enabled. And second, and most important for our analysis, the peak braking required was only 0.306 Gs, just slightly higher than the 0.3 G threshold for signaling the warning. It also should be pointed out that this peak occurred within tenths of a second after the warning light came on, almost too fast for a driver to react, unless he had his foot on the brake and was starting to stop anyway.

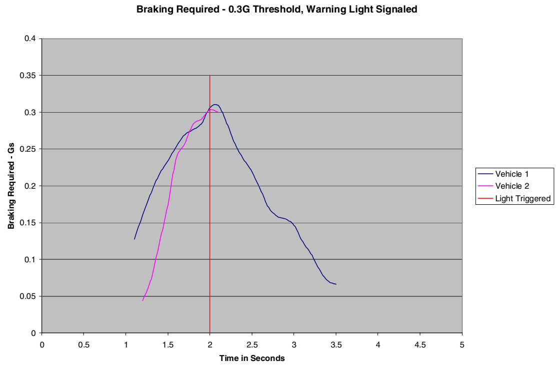


Figure 7. Braking Required, 0.3 G Threshold, Warning Signaled.

The Figure 8 is the second plot of the pair of analysis plots. It is the plot of the pseudo-incidences for the following vehicle. In this case, even though the data was collected, the warning signal was not activated. As shown in the plot, after the warning light should have been activated, the motorists kept proceeding towards the bus and the braking required values continued to increase to average peak value of 0.33123 Gs. Comparing the average peak braking required of these two plots, it can be conjectured that the RIWCS system was effective (7.62 percent reduction in braking required) in getting the drivers' attention and they responded positively and slowed down.

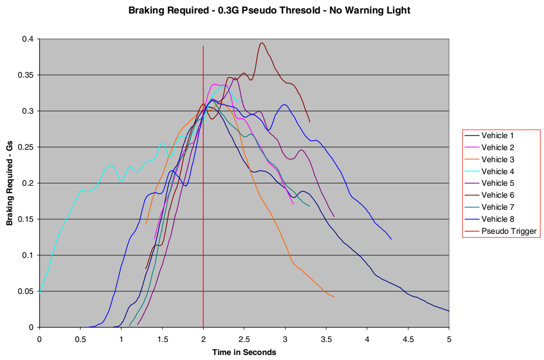


Figure 8. Braking Required, 0.3 G Threshold, Warning NOT Signaled.

The comparison of these two plots shows a trend, but does not prove the results statistically. In addition, considering how few plots are generated, it can be conjectured that different warning threshold might be appropriate that would warn more drivers more of the time.

Related to potentially picking a more conservative warning, analysis from the human factors perspective may shed some light on the issue. In our human factors testing, if the driver was aware of (looking at) the bus while approaching, 90 percent of our drivers felt comfortable with this 0.3 G braking required regime. If a driver were not paying attention (not a condition evaluated in our human factors testing) and it took our RICWS warning to get their attention, then the CAMP research indicated that it would take the driver approximately 1.38 seconds to respond, which would subtract from the time to impact, which in turn would require a higher braking required value. At 30 mph, this new braking required value is 0.422 Gs due to time lost during driver response, assuming the driver immediately sees the RICWS warning lights. As shown in our human factors testing, none of our test drivers felt "comfortable" braking at this level; therefore the team concluded a more conservative approach was needed to warn the driver earlier.

Two approaches for this were evaluated. The first is a lower fixed threshold, and the second is the CAMP algorithm that takes into account time delay and modulates effective braking with closing velocity.

Despite the decision of the research team to look at more conservative approaches, the comparison of braking required with and without activating the warning light utilizing an algorithm with a fixed threshold of 0.3 Gs indicates that the RICWS was effective in modifying the following vehicle's driver behavior by lowering the braking required by 7.62 percent (for this data set) when the light was activated.

The 0.225 G Fixed Threshold Data Collection is the next more conservative warning criteria we implemented. The first of the two graphs (Figure 9) shows the time histories of the following vehicle incidents where the warning threshold was triggered at 0.225 Gs.

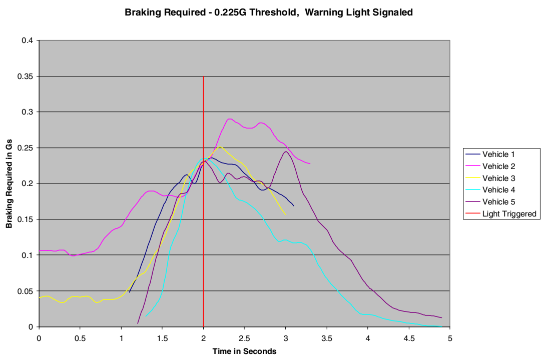


Figure 9. Braking Required, 0.225 G Threshold, Warning Light Signaled.

As can be seen in Figure 9, we had five incidents where the warning was signaled and the drivers responded. The average peak braking required value for this set of following vehicle incidents is 0.2496 Gs. The comparison set is in Figure 10, where we had 36 incidents (note the legend only had enough space to display Vehicles 1 through Vehicle 31, but there are actually 36 traces) where the light bar would have been signaled if it was enabled. The average peak braking required value for this set was 0.2723 Gs. This showed a reduced braking required of 8.3 percent.

Therefore, the comparison of braking required with and without activating the warning light utilizing an algorithm with a fixed threshold of 0.225 Gs indicates that the RICWS was effective in modifying the following vehicle's driver behavior by lowering the braking required by 8.34 percent (for this data set) when the light was activated.

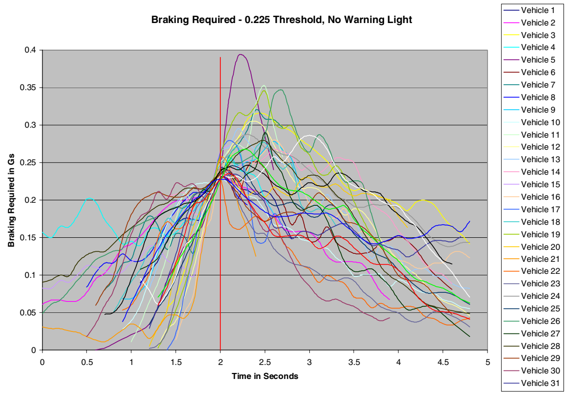


Figure 10. Braking Required 0.225 G Threshold, No Light.

The CAMP Warning Algorithm Data Collection takes into account a 1.38 second driver response time and the braking required threshold is modulated by the speed of the following vehicle closing rate. At higher speeds, the braking required threshold is increased. For example at a closing velocity of 15 mph, the braking required threshold utilized is 0.309 Gs (this does not include the 1.38 second time delay), and at 60 mph, the braking required threshold is 0.455 Gs. And of course, these values are effectively modified by the inclusion of the 1.38 seconds delay time.

The utilization of the CAMP algorithm to signal the warning light is presented in Figure 11. The vertical line at the two second point is the point when the warning light was activated. As can be seen comparing Figure 11 and Figure 9, the CAMP approach is more conservative than the 0.225 G fixed threshold. In fact, some of the following vehicle braking required histories are incredibly conservative (see vehicle 10 and vehicle 12 traces in Figure 11) where the CAMP threshold is down to almost 0.1 G. At this type of level (almost coasting to a stop) we would expect many drivers to consider this a false positive. Upon examining the velocity data, range data, and video associated with these braking required histories, it became apparent that these cars were going slow at short range and were just following the bus. However, their mild driving behavior at this short range triggered the CAMP algorithm. We cannot automatically jump to the conclusion that these following scenarios should be considered false positives, since in the real driving world; there are many low speed short range collisions in stop-and-go traffic. However, intuition tells us that there are many more situations where a less than 5 mph activation of the warning light would be considered a false positive by the following vehicle driver, especially if the driver is just following the bus slowly, and not in a major slowing down mode. By studying the tracks histories of the following vehicle, and looking at the change in braking required, the closing velocities and the distance to the bus, etc., we believe the low speed warning could be significantly improved by appropriate examination of the available data by an enhanced algorithm. Therefore we recommend that this low speed area needs more research. It may also drive the sensor parameters specifications to work at a shorter range.

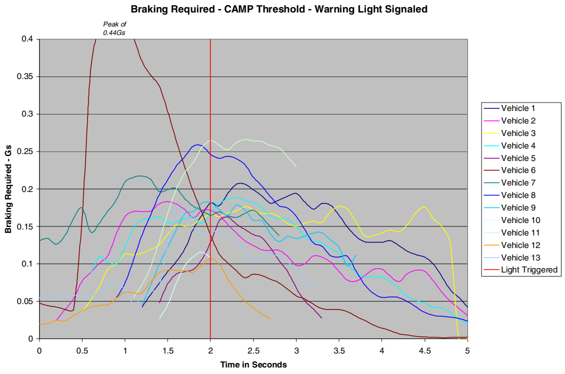


Figure 11. Braking Required CAMP Warning.

The comparison plots for the CAMP algorithm, with and without the warning lights are shown in Figure 11 and Figure 12. The comparison shows that there are many more vehicle braking required histories without the light activation. The data for the CAMP braking required with light activation was collected during September, and unfortunately one of the AATA buses was out of commission for garage work, so we only had a small set of data to base our results on. The reference set in Figure 12 without the warning light activation was from a much larger set of data during March and April. As such we had 183 pseudo warning incidents without the warning light and only 12 incidents with the warning light.

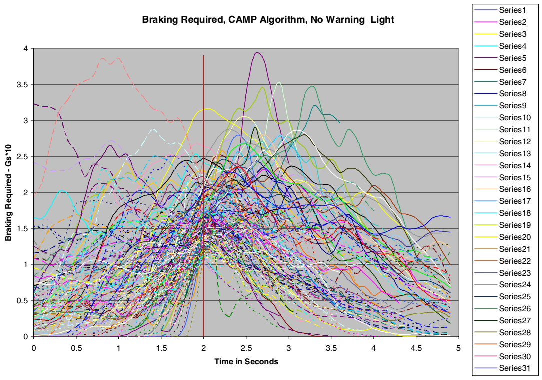


Figure 12. CAMP Braking Required – No Light Activation.

In as mentioned above, there are many very low speed (less than 5 mph) incidents that are potentially false positives in both figures. As such, to improve the quality of the analysis, we manually went through the data sets and eliminated the tracks at less than 5 mph. The results of this culling of the slow speed incidents where there was not an appreciable rate of change of braking required (following vehicle not stopping aggressively) are shown in Figure 13. As can be seen in Figure 13, vehicle traces 6, 10, and 12 have been eliminated. Also, vehicle 6 was slowing down significantly from 0.44 Gs braking required down to 0.138 Gs braking required at the warning point, which probably means the following vehicle driver was well aware of the bus before the warning, and the warning was a false positive. So this culling significantly affected the statistics of this small set.

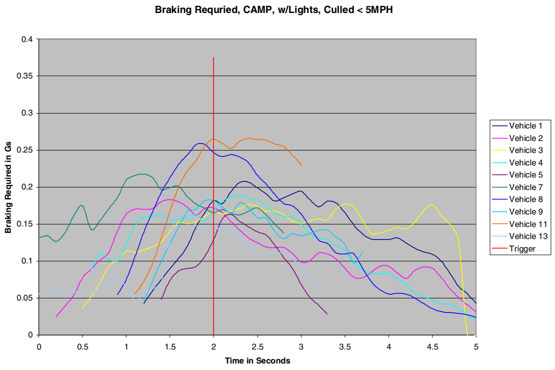


Figure 13. CAMP Braking Required, w/Lights, Culled < 5 mph.

In the same vein we have eliminated the less than 5 mph vehicle histories from the data set in Figur where the light was not activated. This reference set is shown in Figure 14. This culling out the less than 5 mph incidents reduced the number of pseudo-incidents from 183 down to 134. As a side note, if we would have culled out the incidents where the speed was less than 10 mph, the number of incidents would have been reduced to 74. For our analysis of the CAMP algorithm, we will use the data sets in Figure 13 and Figure 14. As in the fixed warning thresholds, we looked at the average peak braking required, however in the CAMP plots, we will specifically only will look at peaks that occur after the warning has been signaled. It does not make sense to look at peaks before the warning, since the warning light could not have influenced the driver's behavior before it was activated. For the fixed threshold algorithms we did not need to worry about this effect, since in the worst case situation, the trigger point would be the peak value.

For the data set where the CAMP algorithm triggered the warning lights, the average peak braking required that occurred after the warning was activated was 0.1917 Gs. In the reference data set where we did potentially modify the driving behavior (and hence the data) with activating the light, the average of the peak braking required that occurred after the warning would have been signaled was 0.1968 Gs, only 2.6 percent higher than the where the light was activated to encourage the following vehicle to slow down. Though this does show the trend, the margin of difference is small. One of the issues that might be related to this is the fact that the set with no light is reasonably statistically significant, and the set with the light activation is not.

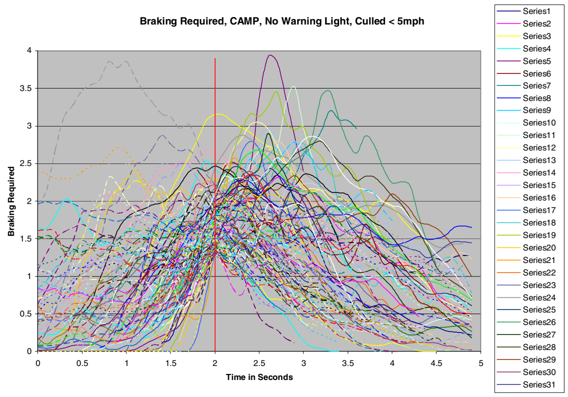


Figure 14. CAMP Braking Required, No Warning Light, Culled < 5mph.

And maybe even more importantly, with the CAMP algorithm the braking required value for triggering the light is modulated by the following vehicle's closing velocity. So, since we do not have a statistically significant set of data for the CAMP algorithm where the light was activated, it would be nice to have a metric that eliminated this variation. From analysis of the data, it was determined that such a potential metric was the "average difference between the peak braking required (after the warning light activation) and the braking required at the CAMP warning threshold." Intuitively this makes sense. This metric looks at how much higher the braking required value went after the light was activated. If in general this delta value is higher with no warning light, then we can conclude the drive reacted and slowed down sooner. For our two data sets, this delta peak value for the set with the warning light was 0.0102 Gs and the delta peak value for the CAMP set without the warning light was 0.0302 Gs, or almost 3 times higher. These acceleration values are not large values in themselves, but they do support the trend that shows the lights do cause the following vehicle drivers to modify their behavior to a more conservative regime. And we should not just discount this trend just because it is based on a small number. For example, at a 0.25 G threshold braking required value, there is one incident every 19 hours. At a threshold that is 0.05 Gs higher 0.3 Gs, an incident occurs approximately every 83 hours. So even though these are small numbers, when considered as differences, they can represent a significant difference in a driving trend.

CONCLUSIONS AND RECOMMENDATIONS

The result of this research lays much of the foundation for implementing/commercialization of RICWS for transit buses, however there is more work to be done. This proof of concept effort has developed a working testbed system that has been installed on two Ann Arbor Transportation Authority (AATA) buses and run in their normal operations. Results of the testing have shown the trend of the RICWS system causing the following vehicle drivers to modify their driving behavior to be more conservative. The following drivers stop sooner with less braking required, which is a less risky driving behavior.

This research paves the way to establish standards and/or potential regulations for RICWS systems. A standard that identifies requirements should encompass the light bar warning system and the algorithm for activating the warning to provide a consistent warning environment to the driving public. The remainder of the RICWS specifications should be specified as a recommended practice (such as an SAE recommended practice). Any particular implementation with a given sensor may require tradeoffs between the specifications. As a recommended practice, the manufacture is allowed to perform engineering tradeoffs for their particular sensor selection. If it were an absolute requirement or regulation down to the level identified in the final specifications, then there would be almost no latitude for switching sensors. For example, a millimeter wave radar sensor might not be able to track lateral velocity as accurately at the laser sensor, however the target (following vehicle) cross section (reflectivity) might be better behaved for millimeter wave, and therefore the overall lateral performance of a millimeter wave system could be better. So it is important to separate and apply absolute requirements and recommended practices appropriately.

The RICWS system as demonstrated in our field testing successfully caused the following vehicle driver to modify his driving behavior behind transit buses in a positive manner. Though more confirmation is needed, such a concept could easily be considered for other vehicle segments. There is no reason to believe applying such a system to other vehicle segments would not mitigate those rear-end collisions. A RICWS system should be able to be applied to trucks which also suffer from a relatively high rate of rear end collisions. And in the largest segment, passenger cars, again rear impacts are a significant issue and such a system might provide significant mitigation. If other segments are addressed, from a public education perspective and the desire to elicit a similar positive response from following vehicle drivers, similar warning devices should be considered for all vehicles. Applying RICWS to these multiple vehicle segments will entail a compromise for packaging of the warning light system. Of all the vehicle segments, the transit bus is probably the easiest to package our rather large warning system evaluated in this report. However, if RICWS systems are to be considered for other vehicle segments, the salient features of the warning lights (color, brightness, pattern, rate, etc.) should be same for all vehicle segments. Packaging will be one of the key issues, and as such light size, mounting location, across the various segments will need to be tailored to the configuration of vehicles in each segment. The ultimate goal in the multi-vehicle segment would be for the driving public to recognize that sequence pairs of amber light blinking outwards means that the motorist is approaching the leading vehicle too fast and corrective action is needed.

There is significant potential for improving the safety for the driving public with RICWS systems, and the technology is well within the grasp of the industry. There are no new technology breakthroughs that are required for commercialization, and the basic concept is sound. We have demonstrated the following positive aspects from this program to support commercialization of RICWS:

- That a relatively low cost IR Laser sensor was accurate enough to provide the range and angle data necessary to demonstrate the functionality of RICWS (for the vehicles that the sensor could see).
- A medium scale on-board microprocessor (333MHz Pentium II) was adequate to perform the calculations necessary to track incoming vehicles and perform the warning calculations. No optimization was made for computational efficiency.
- That the light bar warning design was effective in conveying the state of warning to the following vehicle drivers.
- The RICWS proof-of-concept system was effective at causing the following vehicle drivers to modify their driving behavior a positive manner.

This program has also identified the following near term areas that need to be addressed before the final steps of commercialization can be undertaken:

- A more robust sensor needs to be demonstrated and evaluated. The sensor needs to be able to acquire and track almost all vehicles on the road that could be in a position to follow transit buses.
- Establishment of an accepted protection range behind transit buses.
- Determination of how to handle following vehicles swerving around buses.
- Enhancement of the qualifying parameters of when to activate the warning system.
- Enhancement of the CAMP algorithm for low speed operations directly behind the bus to eliminate nuisance warnings.
- Enhancement of the CAMP algorithm for near-range operation behind the bus to eliminate nuisance warnings.
- A larger Field Operational Test (FOT) to characterize crash mitigation performance of RICWS systems applied to transit bus fleets.
- Financial and return on investment (ROI) analysis of RICWS. This would involve working with a potential RICWS manufacturer to estimate system prices for range of manufacturing volumes. The product cost of RICWS systems should be less than the cost of forward collision warning systems due to many reduced requirements. The RICWS does not need to integrate other systems to estimate roadway geometry, the vehicle velocities should be lower, and the RICWS has a less severe task in assessing

targets with collision potential (it does not have to worry about separating out stationary targets within and outside of the vehicles pathway). The ROI analysis would take into account system costs, installation and operations costs, accident costs, insurance aspects (if applicable) and the probability of the RICWS mitigating rear-end collisions.

- Present the salient features of RICWS and ROI analysis to transit bus fleet operators.

Though the list of next steps is longer than the accomplishments list, the concept and the fundamentals of the technology have been demonstrated. There are no major technological hurdles to overcome in the next steps, however there is engineering and sensor work listed above which must be completed to support deployment of a robust RICWS product.

SUGGESTED RESEARCH AND NEXT STEPS

There a few areas or issues that were not fully resolved that should be resolved before RICWS systems are commercialized. This section will identify on them. The following research steps are not in any order of priority.

Protection Range – Following Vehicle Speeds

The maximum operating range of a RICWS system is dependent on the maximum speed of the following vehicle that is desired to protect from. For instance, at 60 mph utilizing the CAMP warning criteria, the following vehicle needs to be warned at 118 meters. At 35 mph the safe warning distance is only 55 meters. This may be a regulatory issue, however; it is recommended that a study be performed to establish a statistical distribution of driving speeds over transit bus routes across the nation. From this distribution, a recommendation can be derived as to the maximum speed and associated range for a following vehicle that the system must protect from. We feel the industry needs a well-founded agreed upon value for range of operation.

Determination of How to Handle Swerves

As identified in this report, following vehicle swerves around the bus are a very common occurrence, in fact it is much more common an incident than where the following vehicle comes to a stop behind the bus. Many of these swerving following vehicles wait to the last minute to swerve, so the RICWS sees a driving scenario which is defined as an incident and will trigger the warning system to alert the following driver, but the following drive is well aware of the bus and in fact is concentrating on getting around it. However there is an unanswered question as to how the swerving motorist will react to the warning lights being signaled as the swerve is being initiated. A human factors study needs to be performed, with the desired goal to show there is no deleterious affect. If it is a problem, then more research is needed into a much more robust approach to identifying a planned swerve.

Millimeter Wave Sensor

Some of our previous conclusions identified that an IR sensor is not the ideal sensor for a RICWS system, and it was conjectured that a millimeter-wave radar sensor would perform better. A system demonstration utilizing a millimeter-wave radar sensor instead of the IR sensor is needed. If the demonstration is successful, then in analyzing the RICWS data, it is expected that many fewer incidents would be considered false positives due to the tracking of well behaved reflections from following vehicles.

Parameters for Qualifying Potential Incidents

Two major events must occur before the warning light is signaled. First, the following vehicle must exhibit a certain behavior before the warning system is enabled. The second event that must occur is that the following vehicle must exhibit a closing velocity and distance that triggers the CAMP algorithm. We believe the CAMP algorithm is reasonably adequate (see Section 4.2.7); however we believe the parameters that characterize the following vehicle driving behavior need improvement. Presently the parameters include such criteria as: 1.) the following vehicle must have been in the alert zone behind the bus during some time in its trajectory history, 2.) the vehicle must have crossed the centerline of the alert zone, 3.) at the time to activate the warning, the following vehicle must be within + or – 2 meter corridor of the center line of the bus, etc. These parameters and approach need at least a second pass on their development to improve the robustness of the performance of the system. The upgraded parameters should be tested in a field operational environment.

Statistically Prove Performance

One of the major short comings of this program is we did not successfully prove (statistically) that a RICWS was effective. We showed trends that made sense, but did not collect enough data on any particular configuration statistically prove effectiveness. In hindsight, a better characterization of this effort is that it was an extensive proof-of-concept program. Therefore, it is recommended that after some or all the improvements to the system (as recommended in this section) are made, that another field operational test be conducted to prove the effectiveness of a RICWS in operations.

Data Mining of Evaluation Data

Our analysis focused on braking required as the key metric for evaluating the performance of the system. The database of at least 200 gigabytes of data is a rich resource of information that has not been fully tapped. In addition to the key evaluations we performed, other studies could be performed that would help understand the drivers behavior, understand more about the required RICWS performance specifications, and more about the effect of the warning system. For example, analysis could be performed on the time averages of following vehicle path histories, evaluation of stopping distances from the bus, detailed analysis of lateral position and velocities of following vehicles both with and without the activating the warning lights (may provide insight into following vehicle swerves), regression analysis of following vehicle behavior with initial velocity of the following vehicle, and regression studies of following vehicle maneuvers with respect to the position the bus is with respect to the normal lane traffic. The database is a rich source of information that when analyzed will probably provide greater insight to driving behavior.

Near-Range CAMP Algorithm Performance

The CAMP algorithm seemed to provide the most reasonable approach as to when to warn the following vehicle driver. It takes into consideration the delay time of the driver response and it compensated for drivers wanting a less conservative warning at higher speeds. One of the trends we noticed in the analysis of the data with the warning light activated was that most drivers reacted much more quickly than the expected 1.38 seconds identified in the CAMP algorithm. It is postulated that driver typically were already planning to stop and had their foot on the brake, and when our warning light was activated, almost immediately pressed on the brake pedal initiating braking quicker than expected. More study to confirm this trend would benefit the decision analysis needed to help decide what a false positive is and what is not. After the algorithm is enhanced, some roadside surveys of drivers or a public web site to acquire following vehicle driver feedback for such situations maybe helpful in understanding the driving public's reaction to the light system.

CAMP Algorithm Performance at Low Speed and Short Range

The CAMP algorithm performed as expected in most situations. However, at short range and low speed in both data sets (with and without light activation), there were many identified incidents where the CAMP algorithm activated the warning signal with the braking required and following speed at very low levels. Of the 184 identified CAMP incidents, 49 incidents (almost 27 percent) were at 0.126 Gs or less, with associated closing velocity less than 5 mph. In viewing the video for many such incidents, it was readily apparent that the drivers were following the bus at a slow speed, and were very much aware of the bus in front of them when the CAMP algorithm indicates the warning lights should be activated. These situations have a very low braking required associated with them, under 0.126 Gs. This is a short coming of the CAMP algorithm as applied to RICWS systems. Development to improve slow speed following warning is very much needed. This region of performance is a little suspect, and potentially could be considered a false positive. A more in-depth study is desired to confirm the performance of the CAMP algorithm at low speed and short range. If the study indicated that for a RICWS application on transit buses that the CAMP algorithm was too conservative (tending towards false positive), another parameter in the CAMP equation could be added to compensate for these scenarios.

ACKNOWLEDGEMENTS

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Effect of Auditory Intersection Collision Avoidance Warnings on Driving Behaviors in Different Distracted Driving Conditions

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ABSTRACT

In-vehicle information systems (IVIS) have become popular; IVIS could be used to provide drivers with a variety of information (e.g., en-route guidance information and collision warning information) via different in-vehicle devices. In Taiwan, some aggressive driving behaviors are observed such as tailgating and violating traffic signals. Intersection collision warning system (ICWS) provided by IVIS could be used for avoiding the accidents due to violating traffic signals. This study employed a driving simulator to investigate the influence of auditory collision warning messages on drivers' perception-reaction times and workload when the drivers were visually or audibly distracted by secondary tasks via different IVIS devices. The secondary task was to solve simple mathematical problems displayed to the driver three different formats: voice, numbers shown on a liquid crystal display (LCD) panel, and number shown on a heads-up display (HUD). The most important finding of the study was that the auditory collision warning message was capable of decreasing drivers' perception-reaction times when the drivers were visually distracted by the mathematical problems shown on the LCD panel or the HUD. However, when the drivers were distracted by an auditory task (i.e., hearing mathematical problems), the auditory collision warning message increased drivers' perception-reaction times.

INTRODUCTION

The traffic conditions in Taiwan are very congested, and some aggressive driving behaviors such as tailgating, speeding and violating traffic signals are observed. A collision avoidance warning system may help a driver to avoid a crash, but it could also contribute to an increase in driver distraction. Since driver distraction is always an important issue in driving safety, and analysis of accident reports shows that drivers violating traffic signals at intersections is the third leading cause of traffic accidents, this study focuses on whether or not an auditory ICWS could assist a driver in avoiding an imminent crash while he or she is visually and/or aurally and/or mentally distracted.

ICWS messages can be displayed in different formats via in-vehicle devices, such as auditory information and text or figure information shown on a heads-up display (HUD) or a liquid crystal display (LCD). An auditory display is a common means for providing collision warning messages. Several studies have found that an auditory display or multimodal display with auditory and visual warning information has positive effects on driving performance [1-4]. The major objective of this study was to investigate how auditory collision warning messages affect driving performance in the presence of other visual and auditory IVIS devices (i.e., distractions). A six-degree-of-freedom motion-base driving simulator was used for the experiment. The secondary task was to solve mathematical problems displayed using three different types of IVIS devices: (1) auditory voice from a speaker, (2) numbers shown on a LCD screen, and (3) numbers shown on a HUD. Driving performance was measured by measuring driver perception-reaction time. Additionally, heart rate variability was used as a measure of driver workload, and eye movements were used as a measure of driver eye distraction.

EXPERIMENT DESCRIPTION

The participants were asked to drive the simulator, which depicted scenes from an urban area. The road conditions were as follows: there were two lanes in each direction; the lanes were 3.50 meters wide; the traffic flow on the roads was 700 vehicles per hour per lane, and the speed limit was 50 km/hour. The participants were told before the formal experiment that the car (i.e., the host vehicle) was equipped with an auditory collision avoidance warning system (CAWS), and in case of urgent situations, such as a driver cutting in, the system would provide a short audio message, such as 'watch your left-hand side'. In addition, they were told that sometimes the CAWS system malfunctions, and thus, the system may not be able to sense all urgent situations. The purpose for telling the participants that the car was equipped with CAWS instead of

ICWS was to avoid participants' expectations of dangerous situations occurring at intersections. An urgent situation was defined as one in which a collision was likely to occur in less than 4 seconds. The short female prerecorded voice message, 'watch your right-hand side' or 'watch your left-hand side', was 1 second in Chinese. Therefore, the driver had 3 seconds left to respond to the urgent situation. Drivers' perception-reaction times were of interest to measure driving performance, and heart rate variability was used to determine driving workload. Heart rate variability was defined as the difference of average heart rate (x_2 - x_1) 10 seconds after the urgent situation (x_2) and 10 seconds prior to the urgent situation (x_1). In addition, glance frequencies and glance durations at a LCD display were analyzed to determine the effects of different types of mathematical problems on drivers' eye movements. The following factors were considered in the experiment: the provision of auditory ICWS, IVIS display formats, and complexity of mathematical problems (see Table 1).

Table 1.
Experimental Factors

Factor	Provision of auditory ICWS	Display format	Complexity of mathematical problem
Factor Level	yes	auditory	simple addition (e.g., 5+9)
	No	LCD	medium difficult addition (e.g., 24+35)
		HUD	repeating 3-digit number (e.g., 168)

For the secondary task, participants were asked to solve mathematical problems. The tasks included solving one-digit mathematical addition (e.g., 5 + 7), adding two-digit numbers less than 40 (e.g., 32 + 15), and repeating three-digit numbers (e.g., 254). Before a problem was presented by auditory display (voice), or shown on a LCD screen or a HUD, different short beeping sounds were presented to notify the subjects that a problem was going to be displayed. These three short sounds were easily distinguishable from each other. The locations of the 6-inch LCD and HUD are illustrated in Figure 1 and Figure 2, respectively, and the view angle from the eye to the center of the LCD display was 24.3 degrees to the right of center. There were three blocks in the experiment design representing the three display formats, and the sequence of the three display formats was random. The height of the numbers shown on the 6-inch LCD display was 6.5 cm, and the height of the letters shown on the HUD display was 31.5 cm.

Each subject had ten trials to become familiar with the driving simulator (e.g., using the steering wheel, the accelerator and the brakes). Then the subjects were asked to practice with the IVIS devices three times to become familiar with the devices and to make sure they could easily distinguish between the three short beeping sounds before a mathematical problem was displayed.

Young drivers were the focus of this study. The participants had to be licensed drivers between 20 and 30 years of age with at least three years of driving experience. Nineteen undergraduate and graduate students (10 male, 9 female) participated in this experiment.

Figure 1. Heads-Up Display of a Mathematical problem

Figure 2. LCD Location

EXPERIMENTAL DATA ANALYSIS

This study aimed to explore the effect of different IVIS interfaces as well as with/without ICWS voice messages on driving behavior, including the drivers' perception-reaction times and the increase in hart rate while some unexpected imminent incident occurred such as a vehicle violating the traffic signal. Besides, this study also explored the drivers' glance frequencies and glance durations while viewing LCD. Duncan multiple comparison and t test methods were used to determine the significant factors.

Drivers' Perception-Reaction Times

Table 2 and Figure 3 show the effects of IVIS interfaces and provision of auditory warning messages on drivers' perception-reaction times, and there is an interaction between these two factors. When drivers were engaged in solving mathematical problems displayed on a LCD or a HUD, their perception-reaction times were shorter if an auditory collision warning message alerted them to an urgent situation at the intersection. If drivers were watching the LCD, the perception-reaction times of drivers with an auditory collision warning message were 0.08 seconds shorter than the perception-reaction times of drivers without the auditory collision warning message. If drivers were watching the HUD, the perception-reaction times of drivers with an auditory collision warning message were 0.54 seconds shorter than the perception-reaction times of drivers without an auditory collision warning message. However, if the driver's were distracted by an auditory mathematical problems via voice interface, the perception-reaction times with an auditory collision warning message were 0.73 seconds longer than perception-reaction times without an auditory collision warning message. This is possibly due to drivers' sensory overload with two different voice messages (i.e., the collision warning message and the mathematical problem). Therefore, if ICWS warning messages are provided via voice interface, it is important to consider any other auditory distractions such as music or cellular phones. Drivers' perception-reaction times by sex are shown in Table 3. There was no significant difference between the perception-reaction times of the male and the female participants (p = 0.54111).

Table 2.
Effects of IVIS Interfaces and Provision of Auditory Warning Messages on Drivers' Perception- Reaction Times

Provision of warning message and types of IVIS interfaces	Mean (sec)	Std Dev	Multiple comparison[1] (Duncan, α=0.05)
Voice warning & voice Interface	1.77	0.81	A
Without voice warning & HUD interface	1.25	0.54	A B
Without voice warning & LCD interface	1.20	0.55	A B
Voice warning & LCD interface	1.12	0.83	B
Without voice warning & voice interface	1.04	0.64	B
Voice warning & HUD interface	0.71	0.39	B

Note: [1] The results in multiple comparisons with the same symbol indicate that the differences among the corresponding groups are not significantly different.

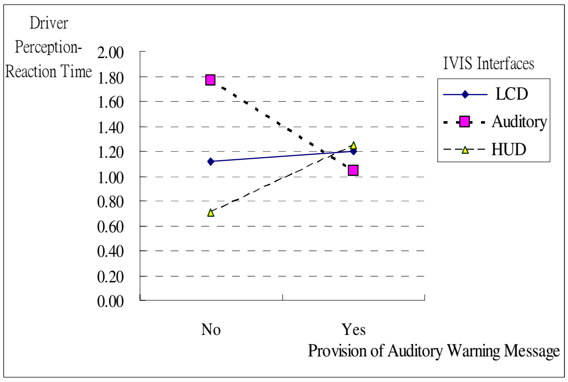

Figure 3. Interaction Effects of IVIS Interfaces and Provision of Auditory Warning Messages on Drivers' Perception- Reaction Times

Table 3.
Drivers' Perception-Reaction Times by Sex

Sex	Mean (sec)	Std Dev
Male	0.87	0.73
Female	1.01	0.59
t-value=-0.61	df =73	p-value =0.5411

Increase in Heart Rate

Table 4 summarizes the effect of IVIS interfaces (i.e., distractions) and auditory collision warnings on the drivers' heart rate variability (i.e., difference of average heart rate (x_2-x_1) between 10 seconds after an urgent situation (x_2) and 10 seconds prior to (x1) an urgent situation. Although the multiple comparisons show that there was no significant influence of the IVIS interfaces or auditory warnings on heart rate variability, the table indicates that the increase in heart rate was the highest (6.08 beats/minute) when the driver was distracted by auditory mathematical problems and received an auditory collision warning message at the same time. The effect of heart rate by sex is shown in Table 5. There was no significant difference in increase heart rate between the male and the female participants (p = 0.1286).

Table 4.
IVIS Interfaces & Provision of Auditory Collision Warning Message on Increase in Heart Rate

Provision of warning message and types of IVIS interfaces	Mean (beats/ min)	Std Dev	Multiple comparison (Duncan, α=0.05)
Voice warning message & voice interface	6.08	5.46	A
Without warning message & HUD interface	4.79	3.89	A
Without warning message & LCD interface	4.47	4.59	A
Voice warning message & LCD interface	4.29	5.25	A
Without warning message & voice interface	3.31	4.95	A
Voice warning message & HUD interface	3.25	3.42	A

Table 5.
Increase in Heart Rate by Sex

Sex	Mean (beats/min)	Std Dev
Male	4.60	3.79
Female	6.24	4.94
t-value=-1.53 df =88 p-value =0.1286		

Eye Movements While Viewing LCD

Drivers' eye movements were recorded by a video-camera during the experiment in order to examine drivers' glance frequencies and glance durations when different types of mathematical problems were posed on the LCD. As shown in Table 6, the subjects glanced more frequently when required to repeat a 3-digit number or to solve more complicated mathematical problems than when posed with simple mathematical problems. In addition, the subjects took longer to repeat 3-digit numbers (1.87 sec) than to solve more complicated mathematical problems (1.40 sec) or simple mathematical problems (1.21 sec) (Table 7). Based on these results, the complexity of mathematical problems displayed on the LCD influenced drivers' glance frequencies and glance durations. The simple task of memorizing 3-digit numbers caused the most driver visual distraction (i.e., largest mean glance frequency and longest mean glance duration). A similar situation could occur when a driver views and memorized the route guidance information displayed on a LCD panel. However, more research is required with respect to drivers' information load and its effect on safety. Tables 8 and 9 show the results by sex in terms of glance frequency and glance duration, respectively. There was no significant difference between glance frequencies or glance durations by the male and the female participants (p = 0.8438 and p = 0.2514, respectively).

Table 6.
Drivers' Glance Frequencies by Mathematical Problems in Various Types

Complexity of mathematical problem	Mean (Frequency)	Std Dev	Multiple comparison (Duncan, α=0.05)
repeating 3-digit number	1.47	0.51	A
Medium-difficulty addition	1.42	0.72	A
Simple addition	1.06	0.24	B

Table 7.
Drivers' Glance Durations by Mathematical problems in Various Types

Complexity of mathematical problem	Mean (min/one time)	Std Dev	Multiple comparison (Duncan, α=0.05)
repeating 3-digit number	1.87	1.30	A
Medium-difficulty addition	1.40	0.44	A B
Simple addition	1.21	0.42	B

Table 8.
Drivers' Glance Frequencies by Sex.

Sex	Mean (Frequency)	Std Dev
Male	1.36	0.64
Female	1.33	0.58
t-value=0.20 df=73 p-value =0.8438		

Table 9.
Drivers' Glance Durations by Sex.

Sex	Mean (min/one time)	Std Dev
Male	1.74	1.33
Female	1.46	0.54
t-value=1.16 df =45.6 p-value=0.2514		

CONCLUSIONS

This study aimed to explore how the presence of IVIS information in a vehicle impacted driver workload (e.g., heart rate variability) and drivers' perception-reaction times with auditory ICWS information in a simulated urban driving environment. The experimental data analysis results revealed that the auditory collision warning messages were capable of decreasing drivers' perception-reaction times when drivers were visually distracted by mathematical problems shown on a LCD panel or a HUD. However, when drivers were distracted by auditory mathematical problems, an auditory collision warning message increased perception-reaction times by 0.73 second. In addition, increases in heart rate were highest in this situation (although not significantly different from the other situations).

It was found in this study that the complexity of questions displayed on the LCD influenced drivers' glance frequencies and glance durations. The simple task of memorizing 3-digit numbers increased drivers' visual workload. This type of secondary task is similar to viewing and memorizing route guidance information from an IVIS. Further research is required with respect to drivers' information load and its effect on safety.

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Study of Driver Behavior as Motorcycles Mixed in Traffic Flow

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ABSTRACT

The population density in Taiwan is very high, especially in the metropolitan areas. The huge amount of motorcycles (532 motorcycles/1000 people) results in complicated traffic conditions and safety problems such as cars and motorcycles competing for lanes. Moreover, in-vehicle multimedia systems have become popular in Taiwan. A driver's workload increases when he or she watches or listens to a multimedia program.

The analysis of official accident reports shows that, among various types of crashes in which motorcycles involved, side collisions and side-swipe collisions account for about 50% of all collisions. Normally, drivers tend to look forward while driving. Therefore, car crashed could easily happen if drivers fail to notice their surroundings when motorcycles suddenly approach. In this context, Side-Collision Avoidance Systems (SCAS) could be capable of alerting drivers and enhancing safety. However, few studies and systems reflect on traffic conditions where motorcycles are mixed in the traffic. This study employed a driving simulator to assess the effects of using SCAS and in-vehicle multimedia on drivers' workload and driving performance (i.e., drivers' perception reaction times, the change in heart rate and eye blinks) while moving in traffic mixed with cars and motorcycles.

A primary finding of this study was that cars equipped with SCAS could decrease drivers' perception-reaction times effectively. The type of vehicle cutting in (car or motorcycle) had a significant influence on drivers' perception-reaction times—drivers displayed longer perception-reaction times when a car cut in than when a motorcycle cut in. This result indicates that drivers were more attentive in the traffic flow mixed with motorcycles. In addition, the change in drivers' eye blinks (from before a vehicle cut to after a vehicle cut in) were all negative--drivers blinked less frequently after a vehicle cut in. This finding indicates that drivers were more alert after vehicles cut in than before vehicles cut in.

INTRODUCTION

According to the traffic accident reports in Taiwan, side collisions, intersection collisions, side-swipe collisions and head-on collisions are the major types of crashes. Driver distraction and lack of caution are typical causes of crashes. In this context, Collision Avoidance Warning System (CAWS) shall be the focus of ITS development in Taiwan. The system is designed to alert drivers and therefore to prevent accidents. The population density in Taiwan is very high, especially in the metropolitan areas. The huge amount of motorcycles (532 motorcycles/1000 people) results in complicated traffic conditions and safety problems. Motorcycles mixing with cars in the traffic flow and competing for lanes are particular traffic conditions in Taiwan. Among various types of crashed in which motorcycles are involved, side collisions and side-swipe collisions account for about 50% of all crashes. Normally, drivers tend to look forward in the course of driving. Therefore, car crashed could easily happen if drivers fail to notice their surroundings when motorcycles suddenly approach. In this case, cars equipped with Side-Collision Avoidance Systems (SCAS) will be able to alert drivers and prevent accidents such as side collisions or side-swipe collisions. In particular, motorcycles relative to cars are small in size and aggressive in motion. The effect of motorcyclists on car drivers' driving performance may be quite distinct from that of other car drivers. However, few studies and systems reflect on traffic conditions where motorcycles are mixed in the traffic flow. This study aimed to assess the effects of using in-vehicle multimedia on drivers' workload and driving performance (i.e., drivers' perception reaction times, the change in heart rate and eye blinks). In addition, we also explored the volume of CAWS warning signals on drivers' perception-reaction times when an in-vehicle multimedia was used during driving.

In this study, a driving simulator was used to perform the driving simulation experiments in order to measure the following situations:

1. The effect on drivers' perception-reaction times and the change in heart rate with/without CAWS while moving in traffic flow of cars only and when moving

in traffic mixed with motorcycles;
2. The effect of collision warning sounds in various dB on drivers' perception-reaction times.
3. Drivers' eye blinks while watching a news program played by the in-vehicle multimedia device;

EXPERIMENTAL DESCRIPTION

Simulator and Tasks

The Institute of Transportation in Taiwan started developing a driving simulator in 1997. It is a six-degree-of-freedom hydraulically driven Stewart platform simulator. The horizontal front field-of-view is 135 degrees and vertical field-of-view is 36 degrees in the experimental scene. The simulated setting for this study was daytime roadways in downtown. There were three lanes in each direction, and each lane was 3.5 meter wide. The driver was asked to drive in the middle lane at normal speed (speed limit 50 km/hour). The driver was listening to a TV news program played by the in-vehicle multimedia device while driving. The participants were young men between the ages of 21 to 30. Totally, 12 men participated in this study. Accordingly, the selected programs played by the in-vehicle multimedia were those contents in which young men are interested, such as sports, informative or fantastic stories, entertaining information, etc. This was designed to measure the drivers' eye blinks when something interested him as well as his perception-reaction time when an unexpected incident (i.e., a car or motorcycle cutting in) arose.

Experimental Design

This study aims to explore the effect of SCAS on driver behavior while moving in the mixed traffic flow where cars are mingled with motorcycles. In the experimental setting, motorcycles would compete with cars for lanes. Pursuant to Australia statute [1], motorcycles have to keep at least 1 meter away from motorcars while driving. In this study, the alert range defined for the warning system was one-meter (see Figure 1 as the dotted line shows). When any motorcycle or car approached the alert range, the warning system would send a collision-warning signal to the driver. The speed limit of the downtown roadway was set to 50 km/hr. A traffic "incident" occurred when a motorcycle or a car would travel 60 km/hr, appear in either direction on the right side or left side of the subject vehicle, and then cut in and overtake the subject vehicle.

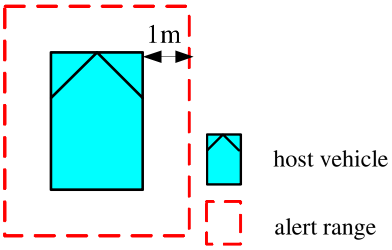

Figure 1. Alert Range

Pursuant to SAE J2400 [2], the Default Warning Intensity of audio signals should be less than 75 dB. Cheng [3] studied how the loudness of warning signals influenced driver behavior. Cheng used two different levels of loudness (68 dB and 78 dB) to sound the warning signals. The difference between the two volume levels was 10 dB. In respect of the audio frequency, Cho [4] and Cheng [3] in their findings concluded that 2000 Hz had better efficacy in the driving performance. The measured value that sounded from the driving simulator developed by IOT is 63 dB. Consequently, we set the loudness of warning signals in this study as 65 dB and 75 dB respectively. The sound frequency was set to 2000 Hz. The news program that drivers heard from in-vehicle multimedia was set to 65 dB.

In addition to a beep sound, the warning system also presented warning symbols on a Heads-Up Display (HUD). The driver could determine from which direction the vehicle (car or motorcycle) was approaching based on the diagram shown on the HUD. This study employed collision avoidance/warning symbols that Campbell [5] used in his study. For instance, the warning symbol shown in Figure 2 represents a danger on the right side of the vehicle, Figure 3 on the left side of the vehicle, and Figure 4 up front. The position of HUD makes reference to the research outcome of Green [6]. The ideal location to mount the HUD is 5 degree laterally to the right of the driver's horizontal vision.

Figure 2. A danger on the right side

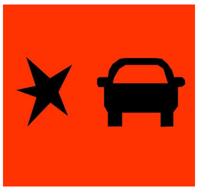

Figure 3. A danger on the left side

Figure 4. A danger up front

According to AAM [7] regulations, the display of any in-vehicle multimedia device shall be mounted in a position where the viewing angle is less than 30 degrees downward and up to 40 degrees laterally. The LCD used in this study was mounted 16 degrees downward and 21 degrees laterally to the right of the driver's vision (see Figure 5). Another position was placed 30 degrees downward and 27 degrees laterally to the right of the driver's vision (see Figure 6).

Figure 5. The LCD position (high)

Figure 6. The LCD position (middle)

The experiment designed in this study employed two blocks by the factors of "LCD position". The experimental factors and corresponding levels are shown in Table 1. When traffic flow consisted only of cars, only cars cut in front of the subject vehicle. In the mixed traffic flow (including motorcycles), two types of incidents occurred as both cars and motorcycles cut in from of the subject vehicle. Consequently, there were 9 simulative combinations of factor levels in each block.

Table 1.
Experimental Factors and Corresponding Levels

Factor	With/Without CAWS	Type of Traffic Flow	Type of Vehicle Cutting in
Level	Yes (Beeps - 65 dB)	Cars Alone	Car
	Yes (Beeps -75 dB)	Cars Mixed with Motorcycles	Motorcycle
	No		

Experimental Procedure

Each subject had eight trials to become familiar with the driving simulator in terms of operating the accelerator, the brake and so on. After a short break, the subjects were asked to perform the experiment and then to complete a questionnaire regarding the content of the news program played by the in-vehicle multimedia. On average, the subjects would take one hour to finish the whole experiment.

EXPERIMENTAL DATA ANALYSIS RESULTS

This study aims to explore the effect of SCAS on drivers' perception-reaction times. The SCAS used in the experiment is set to produce 3 kinds of auditory signals: (1) without any signal; (2) a warning signal in 65 dB; and (3) a warning signal in 75 dB. The experiment designed in this study employed two blocks by two positions to mount the LCD. News programs were played by the in-vehicle multimedia during the experiment. We examined drivers' perception-reaction times as well as the change in heart rate by variables such as the type of vehicle cutting in accidentally, the position of LCD, and the SCAS with/without auditory warning signals. In addition, we also examined the effect of the above variables on drivers' eye blinks.

Drivers' Perception-Reaction Times

Table 2 shows that, drivers' average perception-reaction time was 1.47 sec without any warning signal; 0.94 sec with a warning signal in 65 dB; and 0.74 sec with a warning signal in 75 dB. According to the Duncan multiple comparisons method, drivers displayed significantly longer perception-reaction times when no SCAS was provided than when warning signals appeared. There was no significant difference between the two levels of dB with respect to drivers' perception-reaction times. The volume of news program played by in-vehicle multimedia was 65 dB. Even though the volume of warning signal was the same as the volume of the news program (65 dB), the beep sound of the warning signal was effective at alerting drivers to be more attentive. Table 3 shows the results of a t-test for drivers' perception-reaction times by the type of vehicle cutting in. The type of vehicle cutting in had a significant influence on drivers' perception-reaction times (p = 0.05). On average, drivers displayed longer perception-reaction times when a car cut in suddenly (1.18 second) than when a motorcycle cut in (.72 second)—the former took 0.46 seconds longer than the latter. The findings suggest that drivers were more mindful in the traffic flow mixed with motorcycles and were more alert to unexpected motorcycles cutting in. Table 4 shows the results of a t-test for drivers' perception-reaction times by the position of LCD. The LCD used in the experiment was mounted 16 degrees downward and 21 degrees laterally to the right of the driver's vision. Another position was placed 30 degrees downward and 27 degrees laterally to the right. There was no significant difference between the two positions with respect to drivers' perception-reaction times (p = 0.6851).

Table 2.
Effect of SCAS on Perception-Reaction Time

SCAS Warning Signals	**Mean (sec)**	**Std Dev**	**Multiple comparison (Duncan, α=0.05)**
No	1.47	0.9	A
Yes (Beeps in 65 dB)	0.94	0.8	B
Yes (Beeps in 75 dB)	0.74	0.9	B

Table 3.
Perception-Reaction Time by the Type of Vehicle Cutting in

Type of Vehicle Cutting in	Mean (sec)	Std Dev
Car	1.19	1.03
Motorcycle	0.75	0.53
t-value=2.34 df =64.8 p-value =0.05		

Table 4.
Perception-Reaction Time by LCD Positions

LCD Position*	Mean (sec)	Std Dev
A	1.08	0.71
B	0.99	1.04
t-value=0.41 df =64.4 p-value =0.6851		

Note: * Position A is 16 degrees downward and 21 degrees laterally to the right. Position B is 30 degrees downward and 27 degrees laterally to the right.

Change in Heart Rate

The change in heart rate defined in this study refers to the difference of average heart rate (x_2 - x_1) 10 seconds after a vehicle cuts in (x_2) and 10 seconds before a vehicle cuts in (x_1). Table 5 shows the effect of SCAS on the change in heart rate by multiple comparisons. According to the findings, there is no significant difference in the change in heart rate between vehicles with and without SCAS. Table 6 and 7 show the results of t-tests for the change in heart rate by the LCD positions and by type of vehicle cutting in, respectively. There was no significant difference in change in heart rate with respect to the two positions (high/middle) (p = 0.3916) or with respect to the two types of vehicles cutting in (car/motorcycle) (p = 0.5205).

Table 5.
Effect of SCAS on the Change in Heart Rate

SCAS Warning Signals	Mean (beats/sec)	Std Dev	Multiple comparison (Duncan, α=0.05)
No	0.89	2.3	A
Yes (Beeps in 65 dB)	0.44	2.1	A
Yes (Beeps in 75 dB)	0.24	1.7	A

Table 6.
Change in Heart Rate by LCD Positions

LCD Position	Mean (beats/sec)	Std Dev
A	0.36	2.10
B	0.79	1.91
t-value=-0.86 df =68 p-value =0.3916		

Table 7.
Change in Heart Rate by the Type of Vehicle Cutting in

Type of Vehicle Cutting in	Mean (beats/sec)	Std Dev

Car	0.40	1.98
Motorcycle	0.73	2.14
t-value=-0.65 df =68 p-value =0.5205		

Eye Blinks

We also recorded drivers' eye blinks during the experiment. This is designed to measure drivers' eye blinks under the circumstance of different types of vehicles cutting in, the position of the LCD, and SCAS warning signals provided. The change in eye blinks defined in this study refers to the change in average blink frequency 10 seconds after a vehicle cuts in and 10 seconds before a vehicle cuts in. Table 8 shows the effect of SCAS on the change in eye blinks by multiple comparisons. There was no significant difference in the change in eye blinks among the three set-ups of warning signals. According to the findings in Table 9 and 10, the changes in drivers' eye blinks were all negative for all experimental conditions. This result indicates that drivers blinked less frequently after a vehicle cut in and were therefore more alert after this occurred (however, the changes in eye blinks from before the incident to after the incident were not significant (p = 0.38 and p = 0.61 for LCD position and for type of vehicle cutting in, respectively)).

Table 8.
Effect of SCAS on the Change in Eye Blinks

SCAS Warning Signals	Mean (times/sec)	Std Dev	Multiple comparison (Duncan, α=0.05)
No	-0.04	0.2	A
Yes （Beeps in 65 dB）	-0.06	0.2	A
Yes （Beeps in 75 dB）	-0.07	0.2	A

Table 9.
Change in Eye Blinks by LCD Positions

LCD Position	Mean (times/sec)	Std Dev
A	-0.08	0.21
B	-0.04	0.16
t-value=-0.88 df =52.4 p-value =0.38		

Table 10.
Change in Eye Blinks by the Type of Vehicle Cutting in

Type of Vehicle Cutting in	Mean (times/sec)	Std Dev
Car	-0.05	0.18
Motorcycle	-0.07	0.17
t-value=0.51 df =81 p-value =0.61		

V. CONCLUSIONS AND SUGGESTIONS

The huge amount of motorcycles in Taiwan has resulted in complicated traffic conditions and safety problems. Moreover, in-vehicle multimedia systems have become popular. This study employed a driving simulator to assess drivers' perception-reaction times as well as the change in heart rate and eye blinks as a result of the set-up of SCAS warning signals, the position of in-vehicle multimedia LCD and the type of vehicle that cut in suddenly. The conclusions and suggestions of this study are as follows:

1. Drivers in a car equipped with SCAS displayed shorter perception-reaction times than those without warnings. Even though the volume of the news program was the same as that of the warning signal (65 dB), the beep sound of the warning signal was effective at alerting drivers to be more attentive. In addition, according to our findings, there was no significant difference in the change in heart rate before and after a vehicle cut in between vehicles equipped with or without SCAS.
2. This study explored the effect of warning beeps only. It deserves further study of various auditory warnings such as voice messages and examination of their influence on driver behavior under circumstances of sound interference produced in the vehicle.
3. The type of vehicle cutting in had a significant influence on drivers' perception-reaction times. Drivers displayed longer perception-reaction time when a car cut in than when a motorcycle cut in. This result indicates that drivers were more attentive in the traffic flow mixed with motorcycles.
4. As for the relationship between the type of vehicle cutting and the change in heart rate, there was no significant difference in the change in heart rate with respect to the two types of vehicles cutting in (car/ motorcycle).
5. The LCD used in this study was mounted in two positions: 16 degrees downward and 21 degrees laterally to the right and 30 degrees downward and 27 degrees laterally to the right. There was no significant difference between the two positions with respect to drivers' perception-reaction times or with respect to the change in heart rate and eye blinks.
6. The change in drivers' eye blinks were all negatives with respect to the set-up of the warning signals, the position of the LCD (high/middle), and the type of vehicle cutting in (car/motorcycle). Based on the analysis results, drivers blinked less frequently after a vehicle cut in, indicating that drivers were more alert after a vehicle cut in than before (however, the changes in drivers' eye blinks were not significant).

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A STUDY ON WARNING TIMING FOR LANE CHANGE DECISION AID SYSTEMS BASED ON DRIVER'S LANE CHANGE MANEUVER

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ABSTRACT

The purpose of this paper is to clarify the suitable warning timing of "Lane Change Decision Aid Systems (LCDAS)" for a driver's lane change maneuver. The relationship between lane-change tasks and closing vehicles in the passing lane was investigated by field experiments on the Chuo expressway in Japan. The driver's steering during the lane change was simulated using a linear prediction model. Based on these results, the system requirements of warning timing and sensing area for LCDAS are proposed.

INTRODACTION

Several warning systems, including Forward Vehicle Collision Warning Systems (FVCWS) and Lane Departure Warning Systems (LDWS) have been proposed as advanced vehicle safety devices using ITS technologies. A Lane Change Decision Aid Systems (LCDAS) is one of such devices that warns the subject vehicle driver of potential collisions with other vehicles in the adjacent lane during lane change maneuvers. The warning can be one of two categories: a blind spot warning that informs the driver of other vehicles on the side of the subject vehicle and a closing vehicle warning that informs of a faster vehicle closing from the rear.

For application to large trucks, several blind spot warnings using ultrasonic sensors were introduced into the market in the 1990s [1,2]. However, the obstacle detection accuracy was insufficient and there were many unnecessary or false alarms that made the warning system unsatisfactory. With the advance of sensing technologies, such as image processing and laser radar, interest in practical application of LCDAS has been rekindled [3,4], and LCDAS standardization has begun as an ITS device at ISO/TC204/WG14 [5].

The design of the warning timing is discussed in the development and standardization stage of a warning system like LCDAS. To ensure effectiveness, warnings must be presented to the driver in a timely manner. Although the warnings should be presented early when considering the driver's safety as the first priority, if warning timing is set too early, the driver may consider it unnecessary or a false alarm, reducing the effectiveness of the warning system. Therefore, it is important that the contradicting issues of establishing safety and reducing nuisance be resolved.

The purpose of this study is to clarify the suitable warning timing of the LCDAS based on the driver's lane change maneuver. The relationship between lane change tasks and closing vehicles in the right-side lane (i.e., passing lane) was investigated by field experiments on the Chuo expressway in Japan. The driver's steering when reversing a lane change based on the output warning was simulated using the driver's linear prediction model. Based on these results, the system requirements of warning timing and sensing area for LCDAS are proposed.

INVESTIGATION OF LANE CHANGE MANEUVER

Test Method

Ten male and five female subjects, ages 23 to 56, with valid driving licenses and normal visual and auditory senses, participated in this test. The subject drivers drove the a test vehicle that installed with four CCD cameras installed for recording of the driver’s face and the traffic conditions as shown in Figure 1.

The subjects drove on the left-side lane (i.e., cruising lane) of a four-lane road, overtaking slower vehicles by changing to the right-side lane (i.e., passing lane) as shown in Figure 2. The subjects could stop the lane change task if they judged it risky based on closing vehicles in the adjacent lane. The rear-view image of the right-side lane in Figure 1 was also recorded (on different tapes) to calculate the headway distance from the subject vehicle to the target vehicle by image analysis.

The experiment was conducted using the Chuo expressway between Chofu interchange and Hachioji interchange, a distance of about 17 km. The subjects made three round trips in this section for a total distance of 100 km, and total time of 70 minutes per subject.

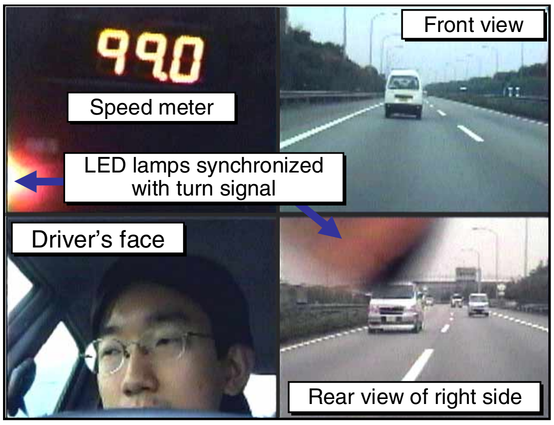

Figure 1. Example of recorded scene using four CCD cameras.

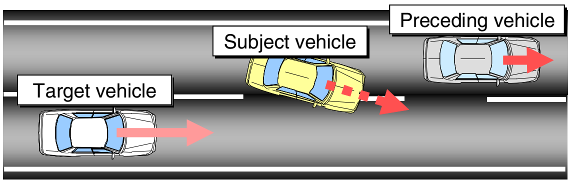

Figure 2. Image of driving task.

Calculation of Headway Distance

By analyzing the rear view image of the right side, the headway distance from subject vehicle to target vehicle in the adjacent lane was obtained for both the lane change execution and the lane change cancellation. The headway distance was measured as the drivers checked the adjacent lane from the moment the driver begins to return the viewpoint from the rear view mirror to the front. To calculate the relative velocity with respect to a target vehicle, the headway distance before one second was also measured.

A personal computer mounted to a video capture board (resolution 640×480 pixels) was used for the analysis. The corresponding tread width of the target vehicle and pixel number on the screen were used to calculate the headway distance. The accuracy of the image analysis was verified using the test vehicle placed 3.5 m to the right side of the subject vehicle with a 1.48 m tread width. Figure 3 shows that the method used to calculate headway distance using the image analysis was appropriate (full-scale error is ±3% or less).

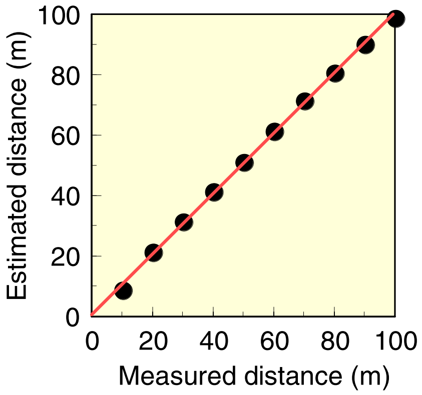

Figure 3. Verification of headway distance calculated from video analysis.

TEST RESULTS

Number of Acquisition Data

Table 1 presents the total amount of data acquired for each subject, divided into the number of lane changes and lane-change cancellations. A headway distance of 100 m was the criterion for judging a target vehicle in the adjacent lane.

The field experiment totaled 1500 km driven by fifteen subjects, with 1097 data points obtained. There were 538 lane changes with an adjacent vehicle present, which meant that headway distance was less than 100 m. Furthermore, there were 266 instances of lane change cancellation influenced by adjacent vehicles. The average speed of all vehicles was 91.3 km/h.

Table 1.
Number of experimental data

Subject number	Execute lane change		Cancel lane change	Total	Average speed （km/h）
	No target vehicles (Dist.≧100m)	With target vehicles (Dist.＜100m)			
1	15	46	14	75	94.3
2	33	40	10	83	97.2
3	9	41	16	66	88.9
4	16	52	27	95	94.3
5	14	25	20	59	88.0
6	25	30	14	69	94.4
7	25	30	8	63	95.0
8	22	46	21	89	89.3
9	7	46	32	85	86.9
10	33	37	8	78	95.3
11	21	30	8	59	92.7
12	0	41	23	64	86.2
13	18	22	17	57	88.1
14	27	21	17	65	88.3
15	28	31	31	90	91.1
Total	293	538	266	1097	–
AVE	19.5	35.9	17.7	73.1	91.3
S.D.	9.2	9.3	7.7	12.3	3.5

Relationship between Headway Distance and Relative Velocity

Discriminant analysis is a technique for assigning measured values to data groups when multiple data groups exist. The boundary line to decrease the probability of the most erroneous distinction is called a discriminant function. The discriminant function with the execution group and the cancellation group is expressed as $y=0.496x-1.91$ in Figure 4, and it was found that the boundaries approximately agreed with the diagonal.

Relationship between Lane Change Maneuver and TTC

The reciprocal of the gradient in the above discriminant function, i.e., the headway distance divided by the relative velocity, corresponds to the time to collision (TTC). The distribution of TTC for headway distance was examined by separating the execution group and the cancellation group. This facilitated understanding by using TTC in a discussion of the warning timing, which was related to the danger of collision. Figure 5 shows that the TTC for the execution group exceeded 6 seconds, regardless of the headway distance. However, TTC for the cancellation group was 10 seconds or less.

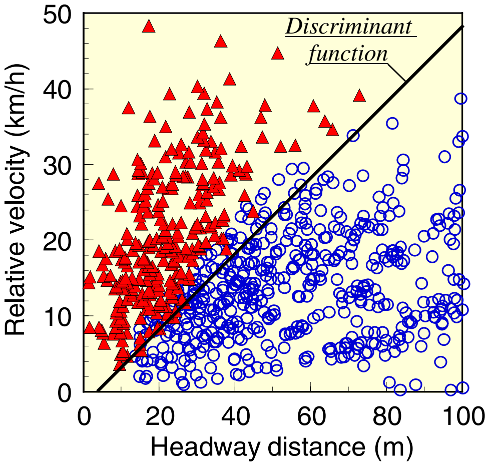

Figure 4. Relationship between headway distance and relative velocity of target vehicles (○ :Lane change execution ▲ :Cancellation).

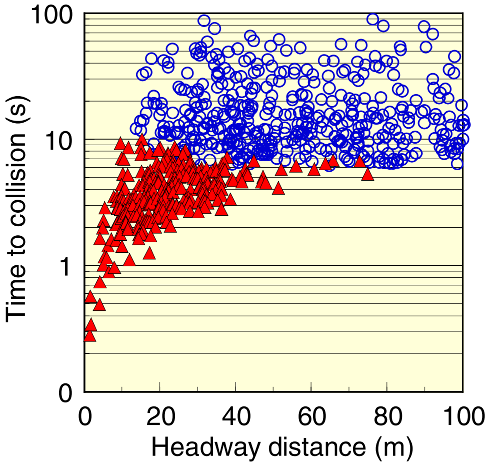

Figure 5. Distribution of time to collision (○ :Lane change execution ▲ :Cancellation).

Consideration in Warning Timing

From this analysis, TTC can be used as an evaluation index for deciding the warning requirements for LCDAS. Any warning requirement established, however, must resolve the contradictory issues of establishing safety and reducing nuisance alarms.

Of the 538 data points acquired in this test, the minimum TTC of the execution group was 6.17 seconds. When TTC was 6 seconds or less, all drivers concluded that the lane change would be dangerous and abandoned execution. Therefore, the warning should be presented at this minimum threshold to keep the driver's nuisance to almost zero in theory. For all 266 data points of the cancellation group, the maximum TTC was 9.98 seconds, and lane changes were not cancelled over this value, concluding that all drivers perceived a TTC of 10 seconds or over within the safety range. Therefore, a warning issued at over this threshold will increase the driver's annoyance.

The above findings set a reasonable standard of the warning threshold for LCDAS: TTC should be set at 10 seconds if the designer gives precedence to safety and to 6 seconds in order to minimize the driver's annoyance. We now examine why the threshold of TTC ranges from 6 to 10 seconds, i.e., why the decision point for lane change or cancellation exists in this range. Drivers' predictions before lane changing greatly influence this. Figure 6 shows a histogram of required time for lane change for all 831 data points in which the driver executed a lane change. The time required is distributed between 3.1 seconds and 8.8 seconds, and the average is 5.3±1.0 seconds. Therefore, the driver estimates the positions of his own vehicle and the adjacent vehicle for a period of lane changing, from the headway distance and the relative velocity of the vehicles. We next assume that the drivers will change lanes when they judge that their own vehicle will not collide with the leading vehicle and will not interfere with the adjacent vehicle. The driver may expect about 2 seconds as a margin of safety. When an error in these predictions and judgments, including missing the adjacent vehicle, is made, the potential for accidents increases. An important role of LCDAS is to anticipate the lane change when such errors occur.

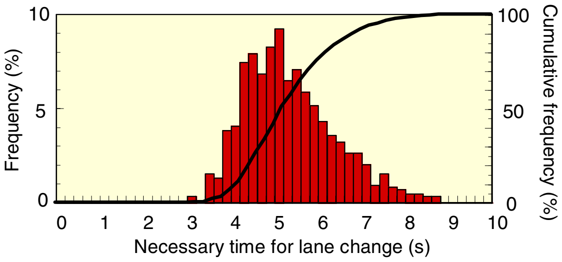

Figure 6. Distribution of required time for lane change.

SIMULATION OF LANE CHANGE MANEUVER

In the previous section, the warning timing of LCDAS was investigated based on the driver's lane change judgment. By making TTC an evaluation index, a warning threshold of 6 to 10 seconds was obtained. However, we cannot conclude that the LCDAS must warn the driver within this threshold. The TTC threshold should become lower if the driver rapidly returns to the original lane after the lane-changing warning is given. In this section, the minimum TTC at which the LCDAS must give a warning is verified from the results of lane-change simulations using a driver model.

Simulation Models and Conditions

A vehicle model with four degrees of freedom (longitudinal, lateral, yaw and roll) was used to calculate vehicle motion [6]. A passenger car of normal size (Table 2) was assumed.

The first prediction model (the most fundamental model) was used to calculate the driver's steering behavior. In this model, a driver estimates his/her vehicle's position after traveling *Tp* seconds at the present velocity and direction, then sets a steering wheel angle proportional to the error with the target course. In this study, prediction time *Tp* was set at 1 second, and the time lag of the steering input was set at 0.3 seconds. The driver gain, which is a proportional constant of the steering wheel angle to the prediction error, was obtained by optimization so that the lateral deviation between running path and target course was minimized. Although the driver gain was slightly different from each driving conditions, it was about 0.4 rad/m. The velocity of subject vehicle was set at 100 km/h, and the lane width was set at 3.5 m. The target course in lane changing was a curve connecting the start point and the end point by a half-cycle sine wave. This end point was determined according to the time required for the lane change.

Table 2.
Vehicle parameters for simulation model

Total mass	1180 kg
Length	4.400 m
Width	1.695 m
Height	1.385 m
Tread (front / rear)	1.470 / 1.460 m
Wheelbase	2.550 m
Distance from front / rear axle to C.G.	1.046 / 1.504 m
Overall steering gear rario	17.5

SIMULATION RESULTS

Normal Lane Change

A normal lane change task is simulated in Figure 7. The horizontal axis shows the elapsed time from the start of the lane change. The vertical axis shows the steering wheel angle (upper part) and the vehicle lateral position (lower part). The necessary time for lane change was set at 5.3 seconds, which was the average of the above-mentioned field experiment.

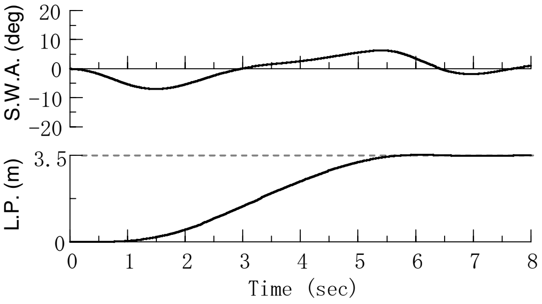

Figure 7. Simulation of normal lane change task.

The purpose of LCDAS is to cause the driver to steer in the opposite direction in order to return to the original lane after the warning output. Therefore, it is important to determine how long it takes the subject vehicle to return to the original lane. The situation in which the lane change was interrupted by a warning was simulated under the following conditions.

- Warning system detects the lane change with the start of steering input.
- System delay time from the lane change detection to output warning is 0.3 seconds.
- Driver's reaction time for presented warning is 0.89 seconds, which is the 95%ile of the steering reaction time for LDWS.
- Lane change time is 3.9 seconds, which is the 5%ile value of the above-mentioned field experiment.

Figure 8 shows that the maximum lateral position deviation reaches 0.50 meters 1.96 seconds after the start of lane change. If the subject vehicle is running in the center of the lane before the lane-changing starts, it can return to its original course without entering the adjacent lane. However, it risks colliding with the adjacent vehicle if the lane change is initiated from around the lane marker. In addition, if there are manifold lane widths and vehicle widths, it is more important to evaluate the delay time until the vehicle begins to return than to evaluate the vehicle's absolute lateral position. In short, the risk of collision is small if the adjacent vehicle does not catch up to the subject vehicle when the subject vehicle reaches maximum displacement. However, the risk of collision is high when the adjacent vehicle overtakes the subject vehicle before this maximum point. LCDAS should warn the driver to interrupt the lane change. Figure 8 clearly demonstrates that it is imperative for LCDAS to present a warning when the TTC with the adjacent vehicle is equal to or less than 2 seconds.

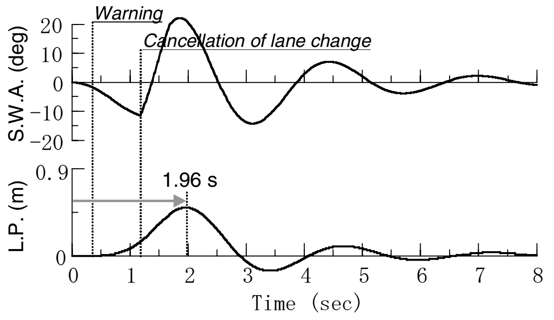

Figure 8. Simulation of stopped lane change situation.

From another perspective, we consider the situation in which the adjacent vehicle avoids the collision by applying the brakes when the subject vehicle changes lanes. In this case, the following conditions are required to prevent the adjacent vehicle from colliding with the preceding vehicle in the lane change, which means that the headway distance before lane changing must be less than the necessary distance for the following vehicle's deceleration.

$$\Delta V \bullet TTC > \Delta V \bullet T + \Delta V^2 / 2\alpha$$

$$TTC > T + \Delta V / 2\alpha$$

Where,

ΔV : Relative velocity between lane-changing vehicle and following vehicle

TTC : Time to collision with lane-changing vehicle and following vehicle

T : Delay time until following vehicle starts the braking

α : Deceleration of the following vehicle

When it is assumed that T=1second, ΔV=30km/h and α=4m/s^2, TTC required to avoid the collision is calculated to be over 2.04 seconds. Therefore, we can expect the following vehicle to avoid collision by braking, even if the warning is not presented for the lane-changing vehicle driver for TTC over 2 seconds. Braking alone will not avoid the collision when TTC is less than 2 seconds. From this perspective, it is imperative to warn the driver who initiates a lane change when the TTC with the adjacent vehicle is 2 seconds or less.

CONSIDERATION OF SENSING RANGE

From the above analysis, three TTC thresholds (2 seconds (time required for collision avoidance), 6 seconds (minimum value at lane change execution) and 10 seconds (maximum value at lane change cancellation)) were obtained as LCDAS warning requirements. Next, we examined the required sensing range for the adjacent vehicle detection based on these results.

TTC is calculated from the headway distance and the relative velocity. The relative velocity was obtained from all 804 field test data points in which there was an adjacent vehicle. Figure 9 shows that the 90%ile speed difference between the cruising lane and the passing lane in the four-lane expressway was 30 km/h or less. The headways obtained were 17m for a TTC of 2 seconds, 50m for a TTC of 6 seconds, and 83m for a TTC of 10 seconds (calculated from the headway distance using the TTC threshold and assuming an upper relative velocity limit of 30km/h). Therefore, the range in which LCDAS should detect the adjacent vehicles is 20m as a minimum requirement, 50m for lane-changing decision support, and 80m for maximum safety.

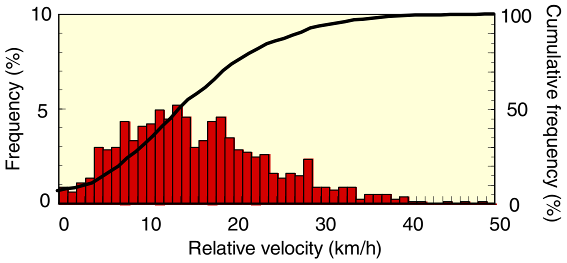

Figure 9. Distribution of Relative velocity of adjacent vehicle.

CONCLUSION

In order to determine suitable LCDAS warning timings from the drivers' characteristics at the lane-changing, field experiments were conducted on an expressway and computer simulations of lane change maneuver were performed. Using TTC with the adjacent vehicle as an evaluation index, the following warning times are proposed.

- 10 seconds and over : Unnecessary
  (LCDAS must not give a warning)
- 6 to 10 seconds : Adjustable range
  (LCDAS may give a warning)
- 2 to 6 seconds : Recommended
  (LCDAS should give a warning)
- Under 2 seconds : Imperative
  (LCDAS shall give a warning)

For the range to detect an adjacent vehicle, we consider 20m for the minimum requirement, 50m for lane-changing decision support, and 80m for maximum safety, when the upper relative velocity limit is assumed to be 30 km/h.

The values obtained in this study are the results simulated from representative driving situations. The following approaches will be continuously examined: Timing of the turn signal activation, tolerances of the lateral deviation, and necessary time for collision avoidance.

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STATUS REPORT ON USDOT PROJECT “AN INTELLIGENT VEHICLE INITIATIVE ROAD DEPARTURE CRASH WARNING FIELD OPERATIONAL TEST”

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ABSTRACT:

In support of the Intelligent Vehicle Initiative (IVI), the U. S. Department of Transportation (USDOT) initiated a field operational test (FOT) program of advanced technology in passenger cars designed to help drivers avoid road-departure crashes caused by drift off-road and/or by traveling too fast for an upcoming curve. A partnership between USDOT and the University of Michigan Transportation Institute (UMTRI), Visteon, and AssistWare Technology, was formed to conduct the "Road Departure Field Operational Test" program.

The goal of the program was to field test a technology designed to prevent or mitigate road-departure crashes and fatalities, which are defined as any single vehicle crash where the first harmful event occurs off the roadway. Statistical reviews of the General Estimates Systems (GES) and the Fatality Analysis Reporting System (FARS) databases, shows that road-departure crashes are the most serious of crash types within the US vehicle crash population. These crashes account for over 20% of all police-reported crashes (1.2 million/year), and over 41% of all in-vehicle fatalities, about (15,000/year).

The FOT vehicle fleet was constructed based on a Nissan Altima platform and consisted of 11 test vehicles, each equipped with the road-departure crash warning system designed and perfected during this program. There were 78 FOT drivers, each driving for a one (1) week baseline, with the system activated but unavailable to the driver, and three (3) weeks with the road-departure crash warning system activated, and available to the driver. During the above (1) week baseline period, all test data was being recorded by the crash warning system, but the system did not provide warnings to the driver. The system did provide warnings to the driver during the (3) week test period. The Field Test required a 10-month time period to conclude the required amount of vehicle driving by the 78 drivers.

The road-departure crash warning system FOT generated a large amount of test data representing the driver performance, driver reactions, and the FOT system performance, during the variety of driving environments encountered by the drivers during the FOT. In addition to the data analysis performed by the contractors, an independent evaluator was also used to study and analyze the resulting FOT test data to determine such things as driver acceptance and safety benefits of the FOT system. The following paper will present a discussion of the magnitude of the road departure safety problem, a brief outline of how the road departure FOT system works, and the FOT results and conclusions to date.

BACKGROUND:

The goal of this project was to field test a technology designed to prevent or mitigate road departure crashes, injuries, and fatalities by warning the driver of an impending road departure. This effort does not include any attempt to use driver active controls in the crash warning system. Road departure crashes are defined as any single vehicle crash where the first harmful event occurs off the roadway, except for backing and pedestrian related crashes. Road departure crashes may also be referred to as “run-off-road crashes”, or “lane departure crashes”

The effort to define and quantify the safety benefits of run-off-road crash avoidance systems began over ten years ago and refinements continue to this day. A statistical review of the 1992 General Estimates System (GES) and the Fatality Analysis Reporting System (FARS) databases, as part of a previous NHTSA contract entitled “Run-Off-Road Collision Avoidance Using IVHS Countermeasures”, (Report number DOT HS 809 170), indicated that run-off-road crashes are the most serious of the major crash types within the US vehicle crash population. The run-off-road crashes accounted for over 20% of all police-reported vehicle crashes (1.2million/year), and over 41% of all in-vehicle fatalities, about (15,000/year). A recent review of GES 2001 and FARS 2001 data for run-off-road crashes by the NHTSA authors, Figure 1, shows that out of 1,095,000 run-off-road crashes in 2001, the in-vehicle fatalities were 15,436. Thus a run-off-road crash avoidance system could potentially reduce the severity of, or eliminate, about 17.3% of the yearly crashes, and 41% of the yearly fatalities occurring on the nation’s highways.

Some of the more important characteristics of road departure crashes found in the 1992 study are listed in Table 1.

Table 1: Important Sources of Road-Departure Crashes (GES 1992)

- Occur Often on Straight Roads (76%)
- Occur on Dry Roads (62%) in Good Weather (73%)
- Occur on Rural or Suburban Roads (75%)
- Occur Almost Evenly Split Between Day and Night

It was also found that run-off-road crashes are caused by a wide variety of factors. Detailed analysis of 200 National Automotive Sampling System (NASS) 1992 crash reports during the previous study, indicated that run-off-road crashes are primarily caused by the following six factors (in decreasing order of frequency) listed in Table 2.

Table 2: Major Causes of Road-Departure Crashes (CDS 1992)

- Excessive Speed (32.0%)
- Driver Incapacitation (20.1%)
- Lost Directional Control (16.0%)
- Evasive Maneuvers (15.7%)
- Driver Inattention (12.7%)
- Vehicle Failure (3.6%)

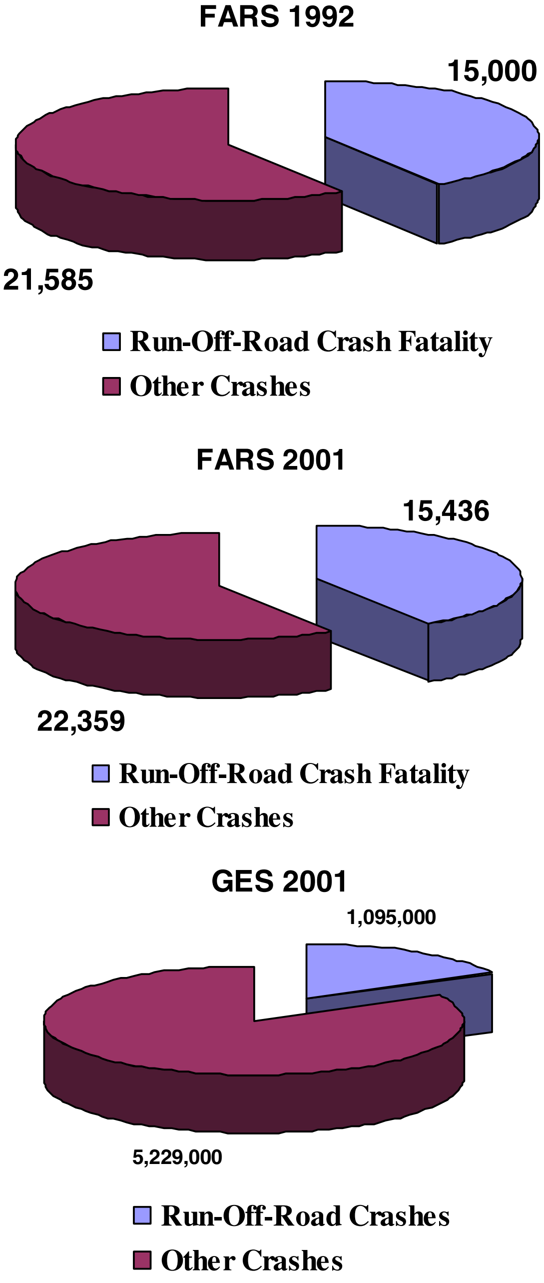

Figure 1: Run-Off-Road Crashes (FARS 1992 and 2001, GES 2001)

Vehicle rollover crashes are known to be particularly severe. The NHTSA 2001 Crashworthiness Data System (CDS) was examined by the NHTSA authors to determine the magnitude of the run-off-road vehicle rollover problem.

The results in Figure 2 show that, out of 217,879 rollover crashes occurring in 2001, 197,788 rollovers, about 91 %, occurred off the roadway. On-roadway rollover crashes accounted for a mere 19,039 rollovers. Thus a run-off-road crash avoidance system could potentially reduce the severity of, or eliminate, about 90% of the off-the-road rollover crashes.

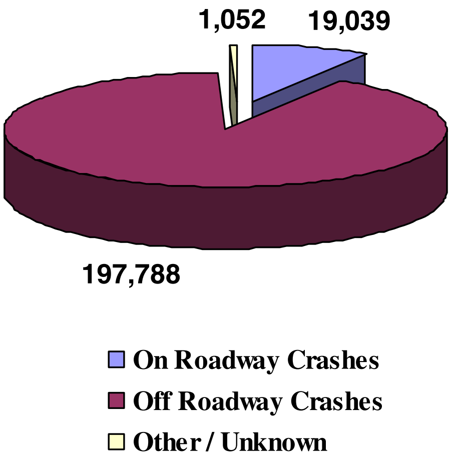

Figure 2: Vehicle Rollover Problem (CDS 2001)

Rollover crashes result in a high percentage of fatalities when compared with other types of crashes. The FARS 2001 database was searched, by the NHTSA authors, to determine the magnitude of the rollover fatality problem. The results are shown in Figure 3.

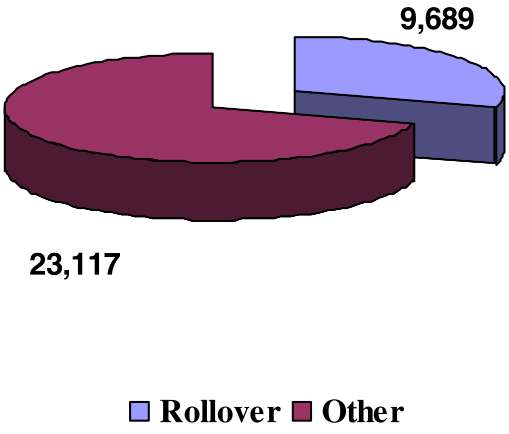

Figure 3: Fatality Problem (FARS 2001)

The results show that out of 32,806 in-vehicle fatalities occurring in 2001, 9,689 of these fatalities resulted from rollover crashes. In addition, the FARS 2001 data base system was examined by the NHTSA authors to determine the percentage of vehicle rollover fatalities resulting from single vehicle off-roadway crashes. The results are shown in Figure 4

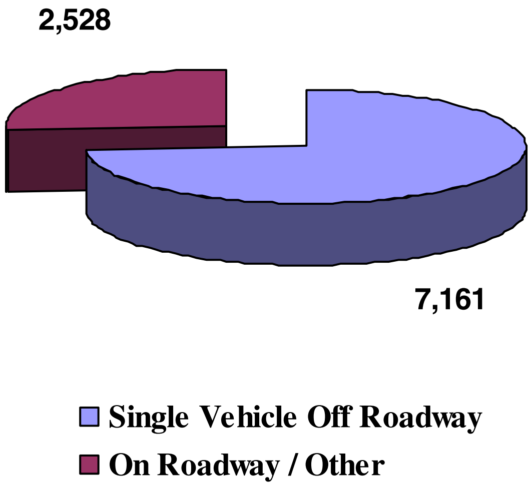

Figure 4: Rollover Fatalities (FARS 2001)

It was found that out of the 9,689 vehicle rollover fatalities occurring in 2001, 7,161 fatalities occurred in single vehicle off-roadway rollover crashes. Thus a run-off-road crash avoidance system has the potential to reduce the severity of, or eliminate, 7,161 single vehicle rollover fatalities or about 22% of the yearly in-vehicle fatalities.

Design Goals of the Run-Off-Road Crash Avoidance System FOT

The run-off-road crash avoidance system field operational test program is being conducted by a partnership between the Federal Highway Administration, the University of Michigan Transportation Institute (UMTRI), AssistWare Technology Corporation, and Visteon Corporation. The run-off-road crash avoidance system developed by the above partners for the field operational test effort is composed of two distinct functionalities, which are Lane Drift Warning (LDW) and Curve Speed Warning (CSW). The LDW function is designed to warn the driver when the vehicle begins to unintentionally drift from the roadway. It uses data about the dynamic state of the vehicle in combination with information about the geometry of the road ahead to determine if the vehicle's current position and orientation may lead to an unintentional road departure. If the likelihood of a roadway departure exceeds a predetermined threshold, vehicle-driver interface functions are triggered to alert the driver of the danger. It is believed that a countermeasure which implements the LDW function has the potential to prevent run-off-road crashes caused primarily by driver inattention, and incapacitation, which together account for approximately 33% (Table 2) of roadway departure crashes.

The second functional goal of the developed run-off-road crash warning system was to develop a curve speed warning capability. The CSW function is designed to warn the driver when the vehicle is traveling too fast for the upcoming curve. It utilizes vehicle dynamic state and performance data in combination with information about the current pavement conditions and upcoming road geometry, derived in real time from an electronic map and Global Positioning System signals, to determine the maximum safe speed for the vehicle through the upcoming curve. If the vehicle's current velocity exceeds the above safe speed for the curve, which is derived as explained above, a sequence of vehicle-driver interface functions is triggered to alert the driver of the danger and avoid a run-off-curve crash. A countermeasure algorithm, which implements the CSW function, has the potential to prevent those run-off-road crashes caused by loss of directional control, due to excessive speed, while negotiating a curve. It is believed that approximately 16% (Table 2) of road departure crashes result from directional control loss while negotiating a curve above a safe speed.

Together, it is estimated that the LDW and CSW functions of the FOT run-off-road crash avoidance warning system, have the potential to prevent or mitigate approximately 50% of all road departure crashes and fatalities.

Components of the Run-Off-Road Crash Avoidance System FOT

Situational Awareness Module

The heart of the system is the Situational Awareness Module, Figure 5, which serves as the information clearinghouse for the countermeasure. This module is where the diverse sensor data regarding the vehicle state and characteristics of the local road environment are merged into a unified representation for use by the other modules. A conceptual representation of the information that is encoded in the Situational Awareness Module is shown in Figure 5.

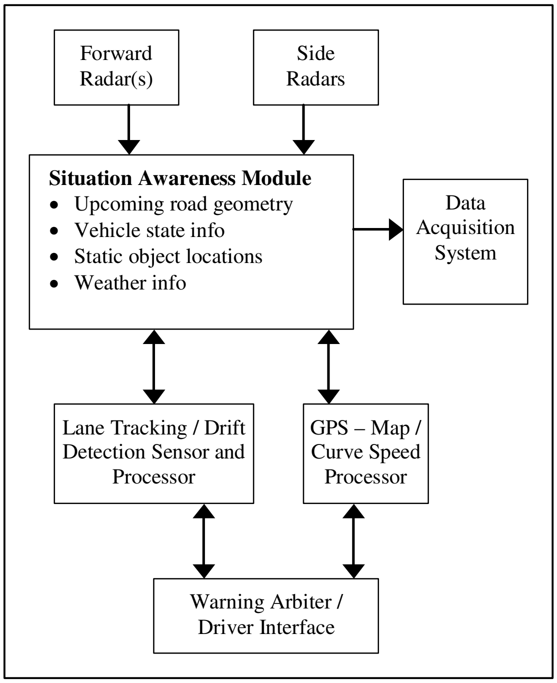

Figure 5: Conceptual Representation of Situational Awareness Module

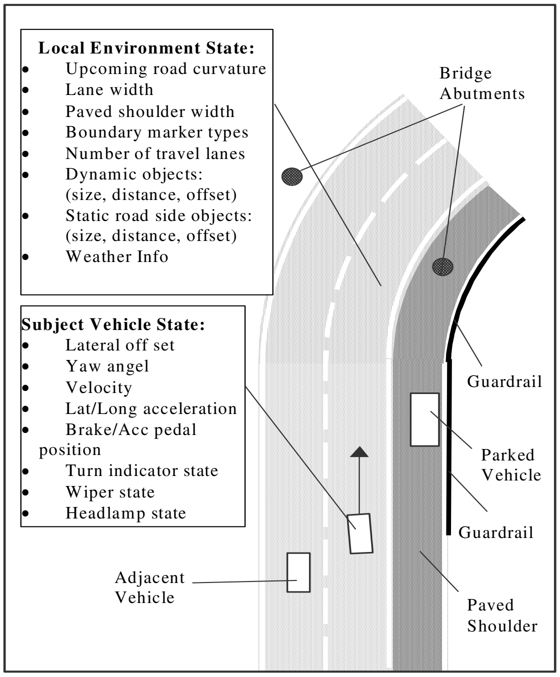

Figure 6: Examples of Situational Awareness Module Input Data

Examples of data merged by the Situational Awareness Module shown in Figure 6 are upcoming road curvature information from the GPS/map module, the Lane Tracking module, and potentially the Forward Radar Module (based on the lead vehicles and/or geometry of continuous roadside features like guard rails). A graphic depiction of the run-off-road crash avoidance system is shown in Figure 7.

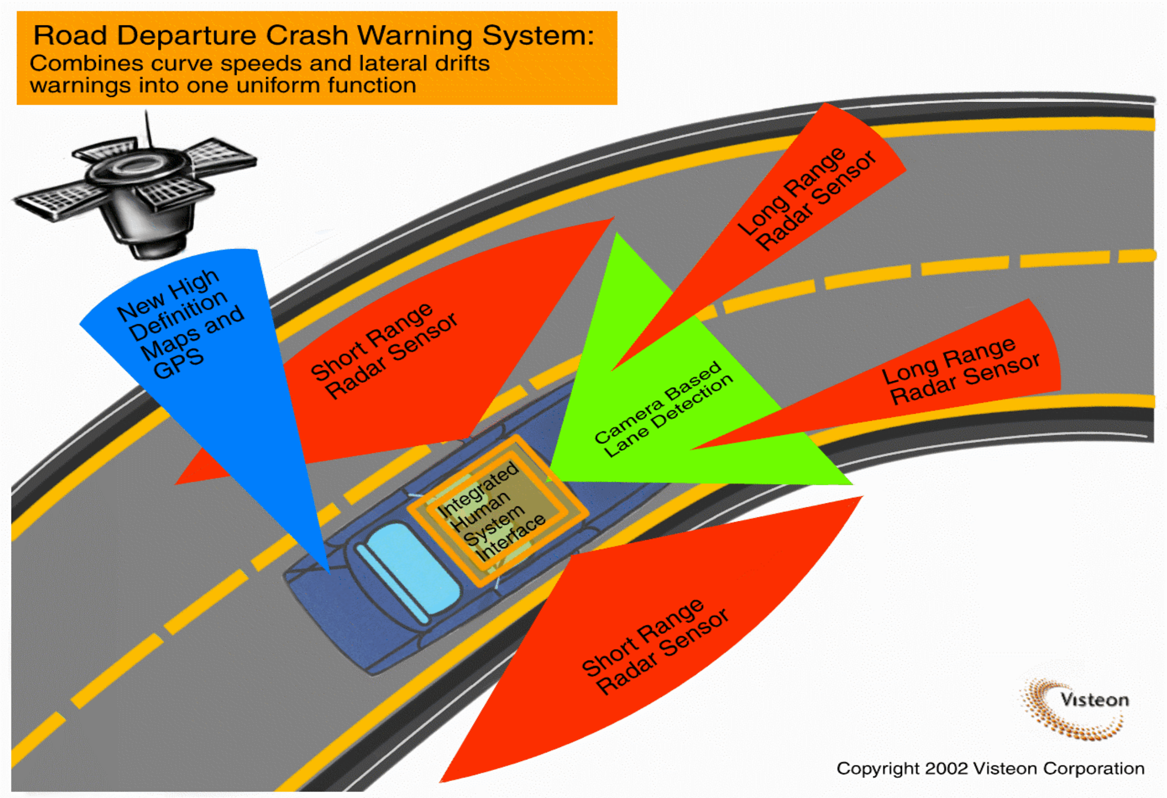

Figure 7: Graphic Depiction of FOT System

The Situational Awareness Module also estimates the maneuvering room available on each side of the travel lane based on estimates of paved shoulder width from the Lane Tracker Module, as well as the locations of objects on the roadside or in the adjacent lane from the forward and side radars.

A very important part of the Situation Awareness Module is the representation for "dynamic" and "static" objects ahead of, and adjacent to, the subject vehicle. In this case, dynamic objects refer to objects not detected on earlier traversals of this stretch of road. These may be temporary objects, like parked vehicles, or permanent objects like bridge abutments, which have not yet been observed enough times to warrant a "static" designation. Static objects refer to objects like guard rails, bridge abutments or road side trees, which have been observed repeatedly on previous traversals of this stretch of road, and have thus earned a permanent annotation in the map. The Situation Awareness Module maintains a "look-aside” file to the NAVTECH® digital map, to encode the, location and size of these static objects. Information encoded in the Situation Awareness Module, including available maneuvering room and upcoming road curvature, is used to modulate the behavior and decision thresholds of the lane drift and curve speed warning modules.

Forward Radar(s)

This module merges upcoming object information provided by one or more forward looking radars. These radars provide information to the Situation Awareness Module about the size, distance ahead, and offset from the lane, of forward objects like parked vehicles, roadside trees, and bridge abutments. It is expected that a detection range of 30m to approximately 60m will provide adequate coverage and sufficient forward preview of upcoming roadside objects for the required purpose of estimating roadside maneuvering room. Seeing both the left and right roadside 30-60m ahead requires more than one forward radar sensor. The RDCW system uses an adapted version of the Visteon 77GHz radar developed primarily for adaptive cruise control and forward crash warning applications. The FOT vehicles employ a pair of Visteon forward radars to gain sufficient azimuthal coverage of both sides of the road.

Side Radars

This module senses the lateral proximity of the subject vehicle in order to detect the offset from topographical features on the roadside, including parked vehicles or guardrails. This information is used by the Situation Awareness module to estimate available maneuvering room to each side of the travel lane, as well as to refine the position and offset of objects detected by the forward radar(s) for subsequent designation as a "static" object. Visteon's commercial side-looking radar is used to see, beside and ahead of, the vehicle to a distance of approximately 10 m, complementing the forward radars' detection zone.

Lane Tracking / Drift Detection Camera and Processor

This module serves a dual role in the countermeasure system. It serves as a sensor, for the detection of the vehicle's state relative to the lane (i.e. lateral offset and yaw angle), and for the detection of certain road characteristics (lane width, paved shoulder width, limited curvature preview). It communicates this sensor data to the Situational Awareness module, along with its confidence in its estimates, where the data is merged with other information to build a representation of the local environment.

At the same time, this module serves as the lane drift detection processor. This function involves assessing the danger of a road departure event, based on the vehicle's position in the lane, the vehicle's trajectory, and importantly, the available maneuvering room adjacent to the travel lane. Figure 8 presents a visual depiction of the LDW crash warning system in action. The last piece of information, provided by the local map, provided by the Situation Awareness Module, will be used to modulate the drift warning algorithm's sensitivity. In other words, a lane drift event will be signaled earlier, if limited maneuvering-room is available for recovery, perhaps due to a narrow shoulder or the presence of a roadside object. It is important to note that the maneuvering-room data will serve a modulatory role in the drift warning algorithm. The drift warning system will continue to operate (with reduced accuracy) in the absence of reliable maneuvering room information, however. This is important for purposes of commercial deployment, since it is likely that the first commercial lane drift warning products will not have a sophisticated method for estimating roadside maneuvering room. An AssistWare Technolology SafeTRAC^{TM} lane and drift detection algorithm was built in order to implement the Lane Tracking / Drift Detection Processor. Prior versions of SafeTRAC^{TM} were tested successfully as part of the Off-road specification program.

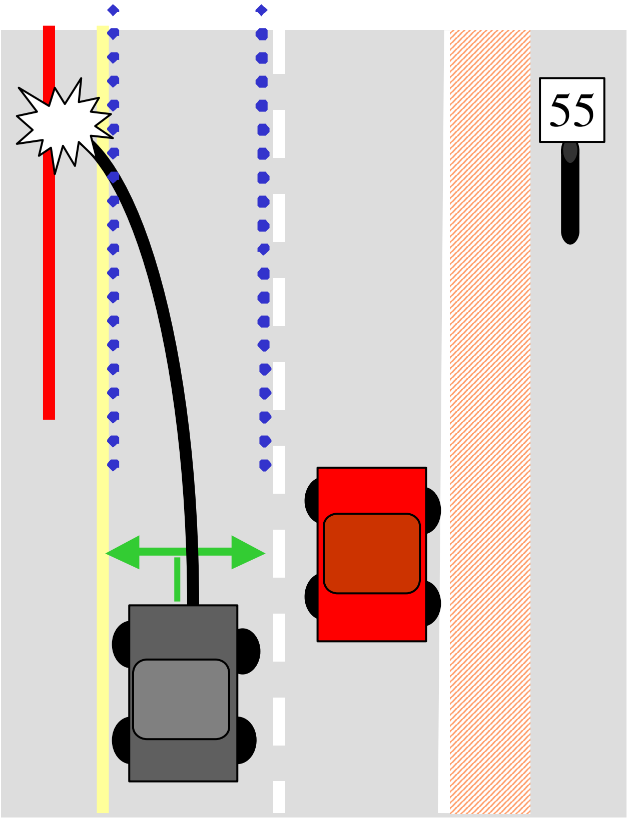

Figure 8: The Lateral Drift Crash Warning Countermeasure

Functional Scenario – Lateral Drift Warning

- Vehicle Drifting Laterally
- Without signaling, then results in
- Driver alert timed, scaled to threat of off road crash

The Lateral Drift Countermeasure Will Identify

- Lane Boundary Positions and Types
- Vehicle position in lane
- Shoulder width
- Crash obstacles, left and right
- Projected path relative to obstacle locations

GPS-Map / Curve Speed Processor

This module plays the same roles for the curve-speed warning function as the Lane Tracking / Drift Detection Processor plays for the lane-drift warning function. In particular, it serves as a sensor, estimating upcoming road geometry based on vehicle position and heading from a GPS system, combined with road information from the digital map database. Figure 9 presents a visual display of the CSW crash warning system in action. This road geometry information is communicated to the Situational Awareness Module, where it is combined with other sensory data, to build a representation of the local environment.

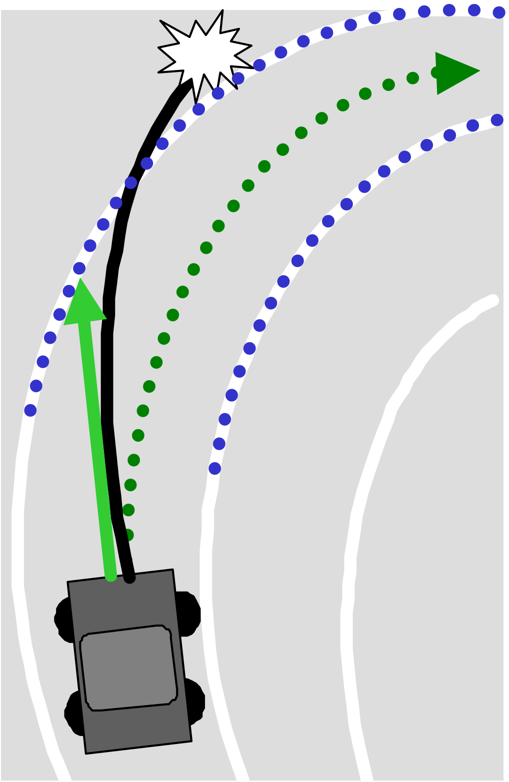

Figure 9: The Curve Over speed Countermeasure

Functional Scenario: Curve Speed Warning

- Vehicle Traveling Too Fast For Upcoming Curve
- Driver alert calls for speed reduction
- Will Identify:
- Curve site geometry and conditions
- Current vehicle path, deceleration, and speed
- Aggregate threat based on the above

Based on information about the upcoming road geometry, and the current vehicle speed provided by the Situational Awareness Module, the GPS-Map / Curve Speed Processor estimates the danger of a speed-induced road departure on the upcoming curve. The GPS-Map / Curve Speed Processor was implemented on the commercially available Visteon NavMate GPS navigation platform. Embedded on this platform is the latest, most accurate NAVTECH® map database called ADAS

Product 1.0. Also running on the NavMate® platform is a modified version of the curve speed warning algorithm developed by AssistWare. A prior version of this algorithm was tested successfully as part of the NHTSA Run-Off-Road specification program. CSW algorithms estimate a maximum safe speed for upcoming curves based on GPS digital maps, with support from the LDW camera and the Situational Awareness Module, and make use of available information on pavement condition (wetness, temperature). Drivers are warned to slow down if the approach speed is perceived as unsafe.

Warning Arbiter / Driver Interface

This module provides the driver with a unified, consistent interface to the roadway departure countermeasure. Its first role is to arbitrate between lane drift warning signals and curve speed warning signals based on the severity of each threat, to avoid driver overload/confusion. It also supports the driver-vehicle interface (DVI), which may include status information during times of low road departure danger, as well as, urgent warnings of an imminent road departure. The details for the status and warnings were determined early in the program based on an extensive set of human factors and proof-tests, and include combinations of visual, auditory, and/or haptic feedback signals. Finally, a form of limited driver adjustment, of the system sensitivity of the warning algorithm, was provided to achieve a higher level of driver acceptance. Accordingly, this module implements the driver controls for the system sensitivity tuning, the results of which, are communicated to the respective warning processors.

The Warning Arbiter / Driver Inteface functions were implemented on the commercially available Visteon NavMate® system, which is equipped with a high quality display, ideal for showing visual icons/messages. NavMate® also provides a sophisticated sound output capability for generating auditory tones and/or voice feedback. The driver interface for the countermeasure system was developed and implemented by UMTRI and Visteon human factors engineers. It has the "look and feel" of an integrated, production system.

Data Acquisition System

The data acquisition system (DAS), designed and implemented by UMTRI, is designed to acquire and store the data collected onboard each of the field test vehicles. The architecture of the RDCW DAS system affords convenient DAS access to almost all desired data variables through the Situational Awareness Module.

Field Operational Test (FOT) Preliminary Results

The **FOT** was conducted over a time period of 10-months and utilized 78 (Picked to be representative of the driver population) drivers and an 11-vehicle fleet built for the FOT and equipped with the run-off-road crash warning FOT system. Each driver was able to drive a FOT test vehicle for one-week as a baseline with the FOT system operational but unavailable to the driver. The test driver was then allowed to drive the FOT test vehicle with the run-off-road crash warning system operational and available to the driver. Figure 10 is a graphic depiction of a portion of the trips made by test drivers for 3 weeks.

Each test driver was interviewed at the

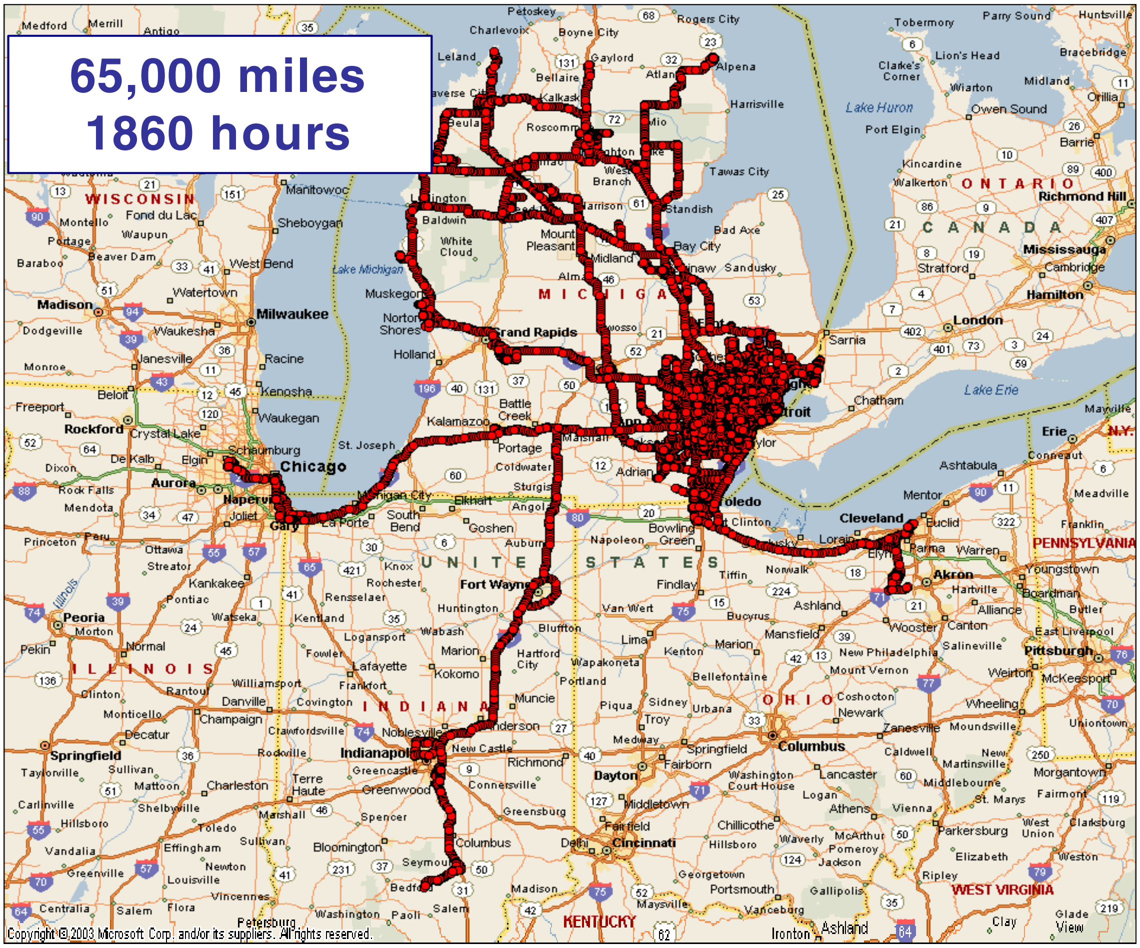

Figure 10: FOT Travel (First 56 Drivers)

conclusion of the 4-week test drive to determine how the driver evaluated the over all performance of the FOT system.

Figure 11 shows the increase in turn signal usage, as a function of time and direction, when performing a lane change maneuver. Use of the FOT run-off-road crash warning system, resulted in an 11% increase in turn signal usage when turning left and a 14% increase when turning right. It is presently believed that the system trained the driver to always use the turn signal when making a lane change.

Preliminary results in Figure 12 show a significant reduction in lane departures and near-departures, compared to baseline, during the three week driving period the FOT system was turned on for the test drivers. Quantitative results and definitions will be available in the final report

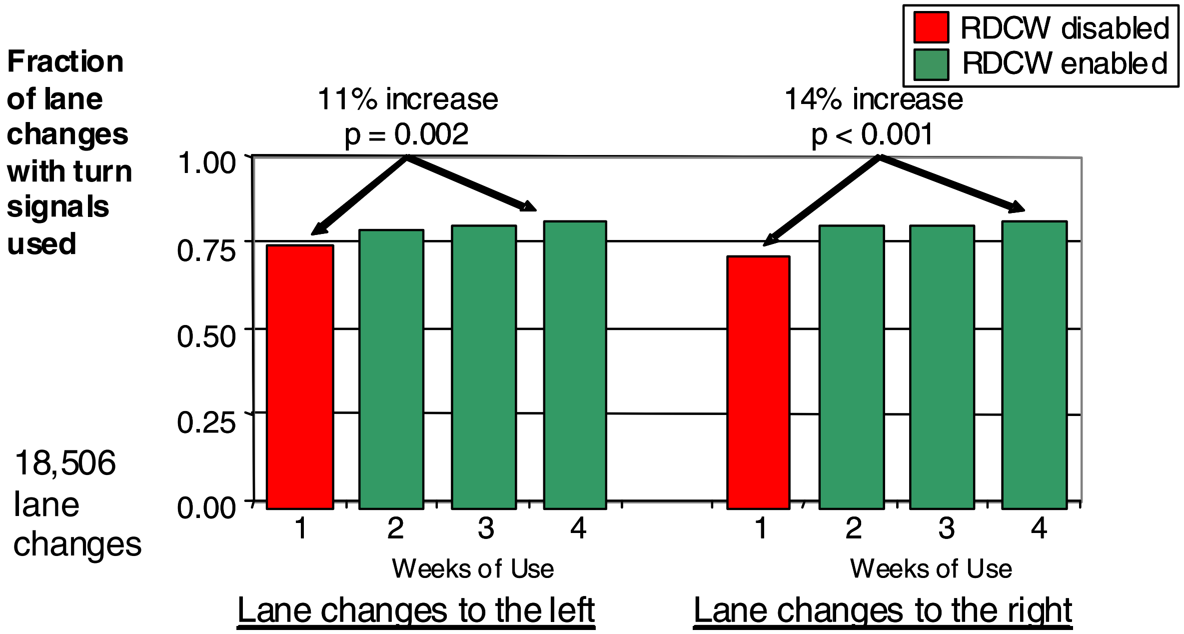

Figure 11: Preliminary Data-Driver Turn Signal Usage

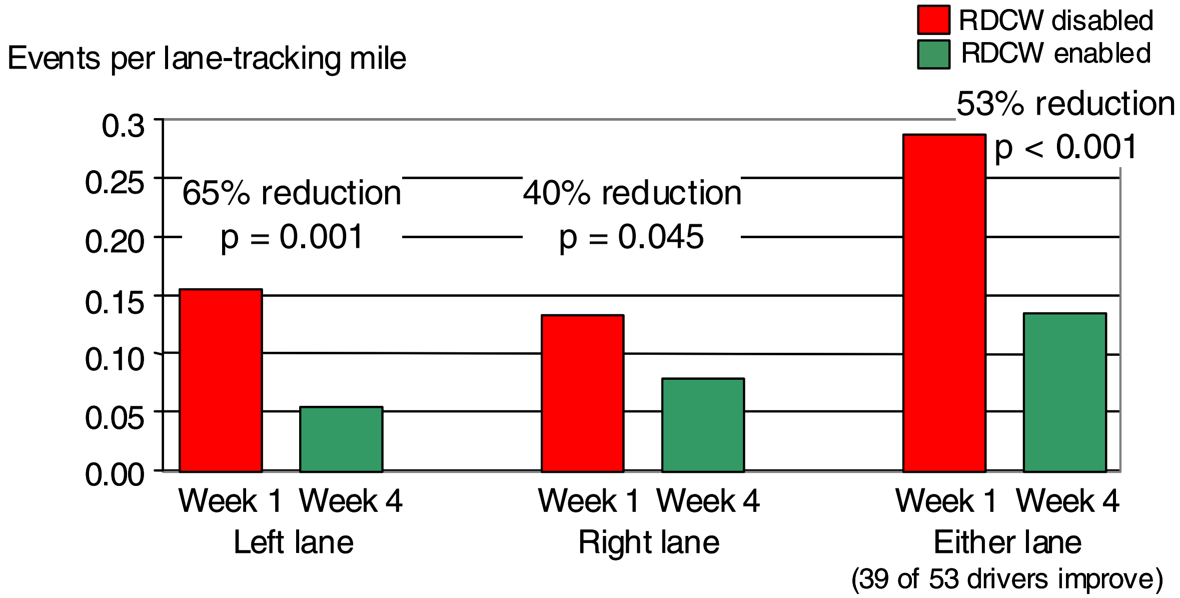

Figure 12: Preliminary Data- Rate of Lane Departures and Near Departures

Preliminary results in Figure 13 show the majority of test drivers believed they received the LDW warning an appropriate number of times. Quantitative results and definitions will be available in the final report

Figure 14 shows that the majority of test drivers believed the operation of the FOT system enhanced the driver's awareness of the vehicle position on the roadway

…..Overall, I received LDW Warnings…..

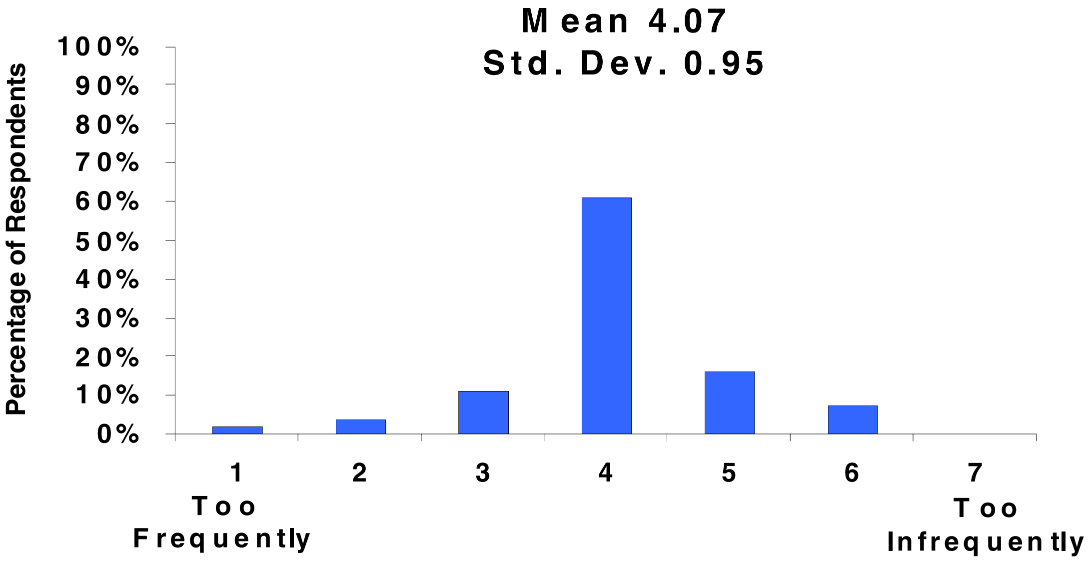

Figure 13: Preliminary Subjective Data- Lane Departure Warnings

Driving with the LDW system made me more aware of the position of my car on the road.

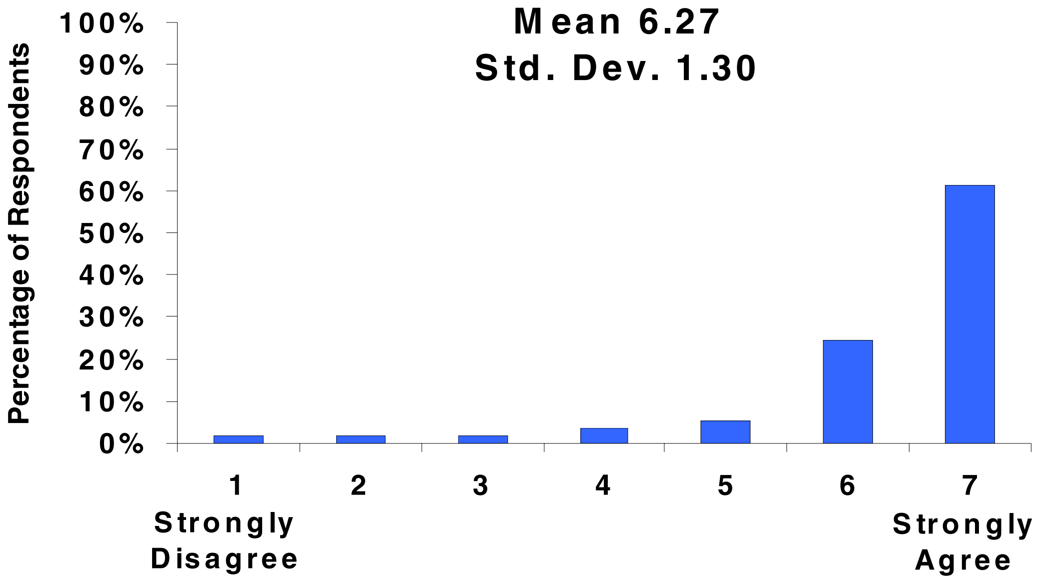

Figure 14: Preliminary Subjective Data- Vehicle Position Awareness

Figure 15 shows that the majority of test drivers believed they received CSW warnings an appropriate number of times.

Figure 16 shows that the majority of test drivers believed the CSW system enhanced their awareness of the upcoming curves.

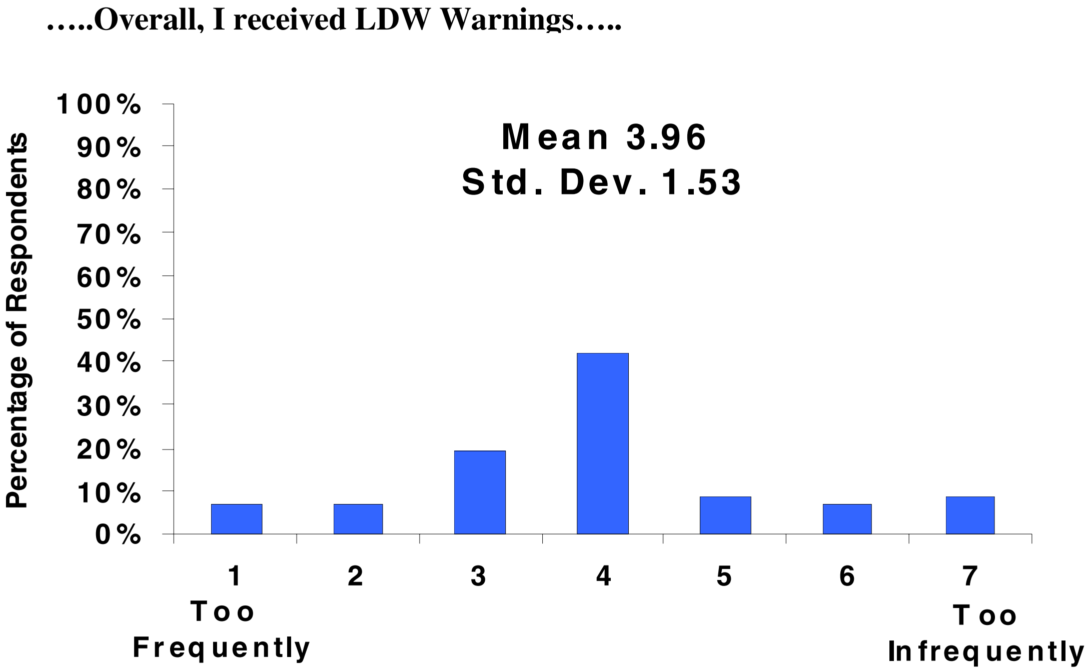

Figure 15: Preliminary Data- CSW Driver Acceptance

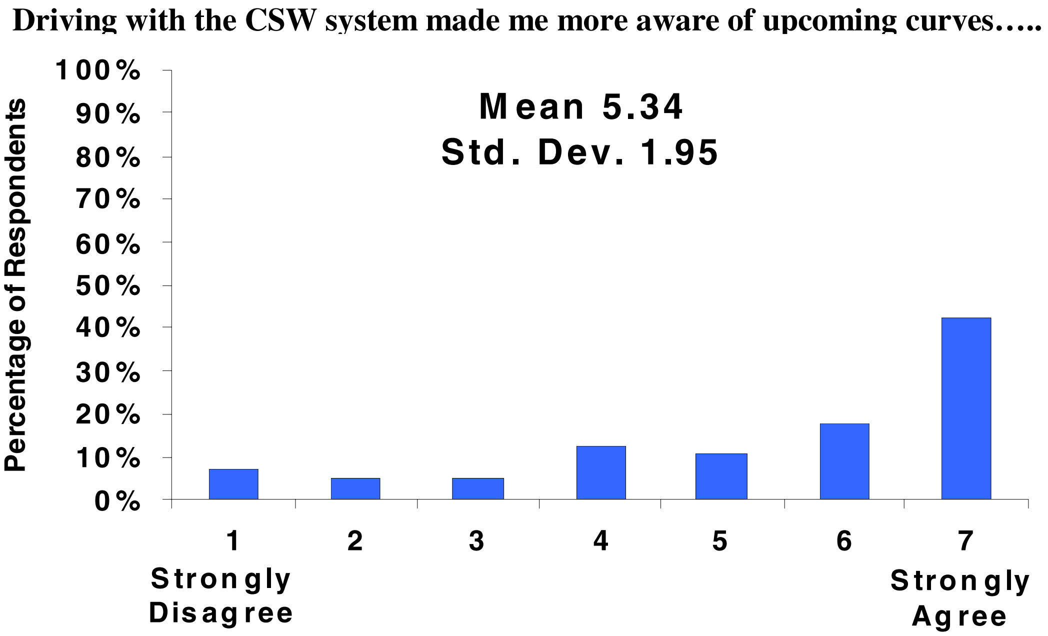

Figure 16: Preliminary Subjective Data- CSW Driver Awareness

Figure 17 shows that the FOT driver/vehicle interface warning system device of a vibrating seat was easy to recognize by the majority of test drivers.

Figure 18 shows that the majority of test drivers believed the presence of a run-off-road crash warning system will increase driving safety.

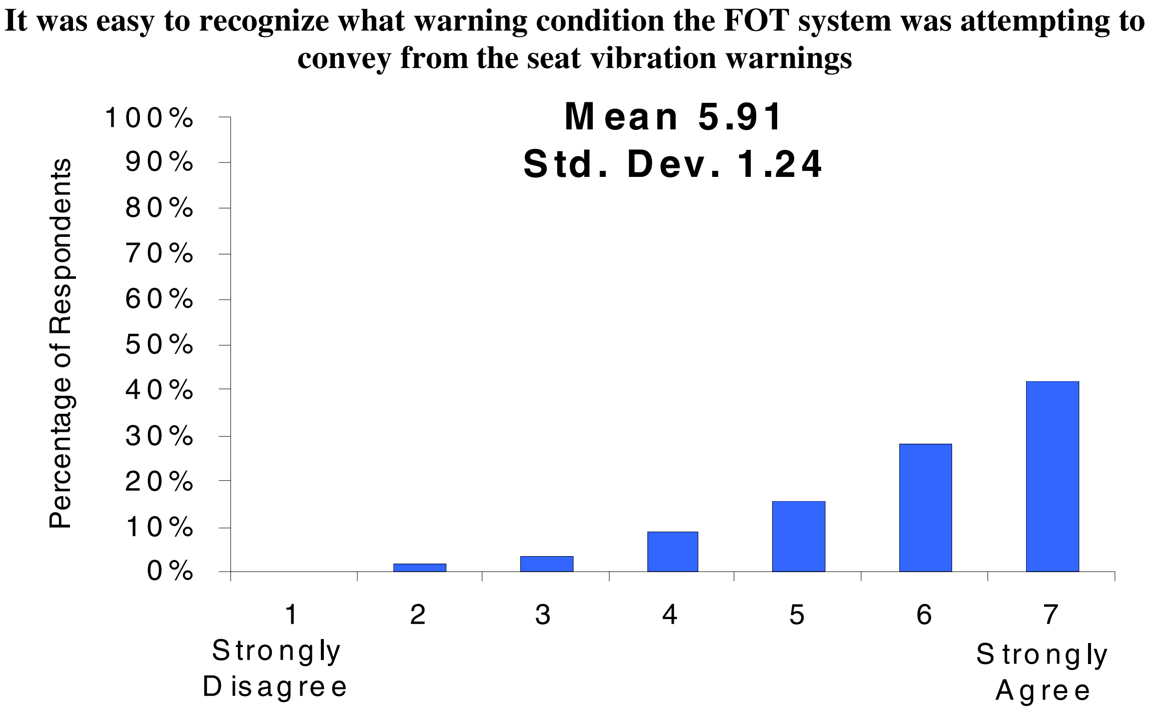
It was easy to recognize what warning condition the FOT system was attempting to convey from the seat vibration warnings

Figure 17: Preliminary Subjective Data- Recognition of Haptic Warnings

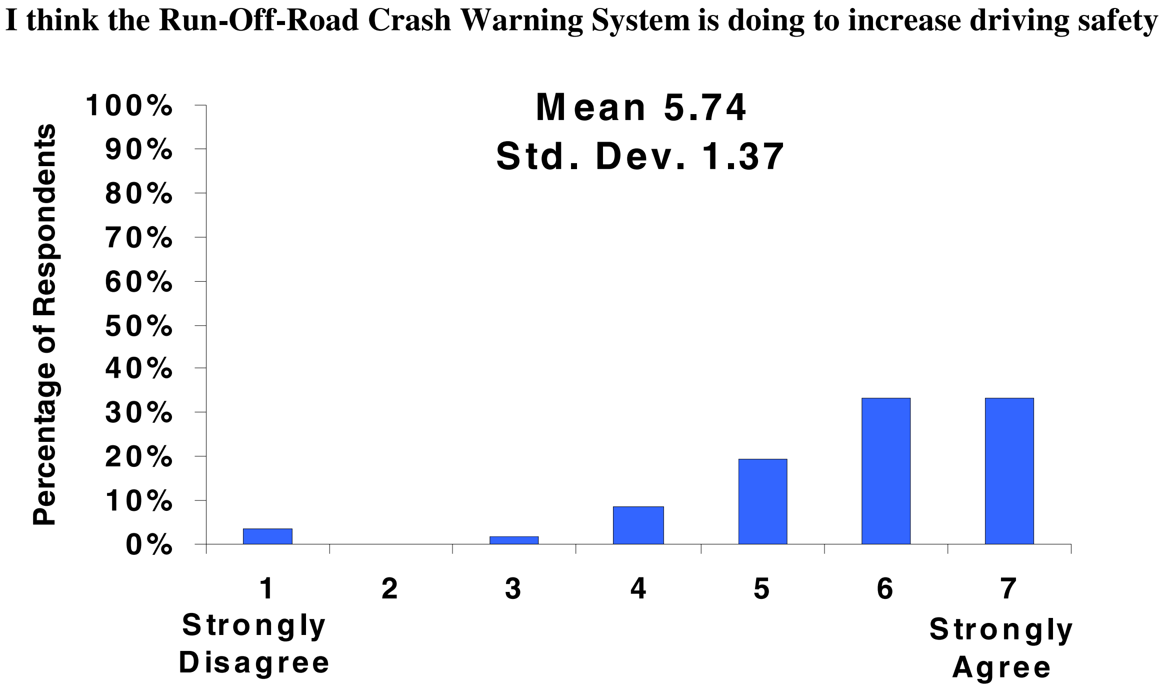
I think the Run-Off-Road Crash Warning System is doing to increase driving safety

Figure 18: Preliminary Subjective Data- Driver Belief in FOT System Providing Increased Safety

CONCLUSIONS AND BENEFITS

The FOT preliminary test results shown in this paper indicate positive benefits for highway safety. Analysis of final FOT test results will be performed by the project partners and an independent government evaluator. Estimations of possible safety benefits, including crashes prevented and lives saved, provided by run-off-road crash warning systems will be derived and made available at the conclusion of the contract. The final report for the project is scheduled to be completed by July 31, 2005.

DIFFUSION DEFLATION DETECTION USING WHEEL SPEED SIGNALS

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Paper Number 05-0082

ABSTRACT

For increased safety and economic reasons in the world, motor vehicle manufacturers are beginning to install TPMS (Tire Pressure Monitoring System).

There are two types of TPMS in the market; one is a direct TPMS using pressure sensor, the other is an indirect TPMS using the wheel speed sensor signals from ABS.

Most indirect TPMS are unable to detect a 4-tire simultaneous deflation condition because indirect TPMS are based on the principle that the 4-tire speed signals are compared with each other.

However, the SRI Group (Sumitomo Rubber Industries, Ltd.) has developed an indirect TPMS which can detect a 4-tire simultaneous deflation based on a newly developed principle using wheel speed signals from the ABS.

INTRODUCTION

Recently, Tire Pressure Monitoring Systems are being widely introduced in the car industry because of the safety and economic reasons. In Europe, ‘the No Spare Tire Concept‘ is promoted by the car manufacturers and runflat tires are introduced in the cars to realize this concept. Here, TPMS is inevitably required to avoid the tire burst caused by long time driving in a deflated condition. In the USA, the T.R.E.A.D Act was signed in 2000 and required all new cars to be equipped with an appropriate TPMS.

Now, there are two basic types of TPMS in the world. One is the so called ‘Direct TPMS’ and the other is the ‘Indirect TPMS’.

A Direct TPMS detects tire deflation using a pressure sensor and transmits the data to the receiver. Therefore, this system is accurate and able to detect deflation in any combination of 4-tires. But, on the contrary, this system is expensive, less durable and more difficult to maintain.

Most indirect TPMS detect tire deflation by comparing wheel speeds from the ABS sensor with each other. Therefore, this system is less accurate than a direct TPMS and can basically detect deflation in just one tire. But, on the contrary, this system is inexpensive and maintenance free.

PRINCIPLES OF THE CURRENT INDIRECT TPMS

Figure 1. shows the principle of the current indirect TPMS. The rolling radius of the tire becomes smaller in proportion to the rate of deflation and therefore the wheel speed of the deflated tire increases. Most indirect TPMS give a warning by comparing wheel speed signals from the ABS. Here, the sensitivity of rolling radius change caused by the deflation is higher in the case of low aspect ratio tires (including runflat tires) than that in the case of high aspect ratio tires such as 82% series. Therefore, such an indirect TPMS can detect deflation of runflat tires and modern generation low profile tires.

However, the tire rolling radius comes under the influence of production tolerances, cornering radius, weight distribution on cornering, acceleration condition, braking condition, rough road, low myu roads, etc. Therefore, we introduced various corrections and rejections in our system to improve accuracy.

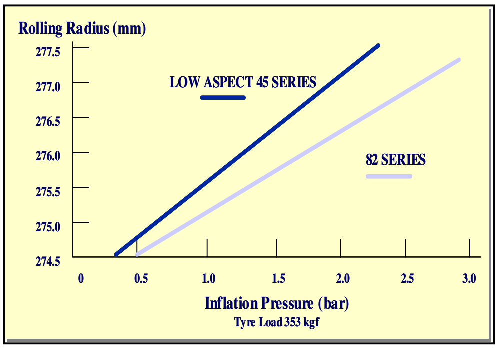
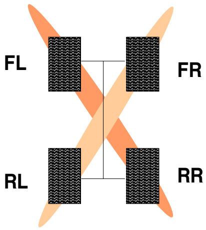


Figure 1. Tire rolling radius change according to the inflation pressure.

We introduced the diagonal difference defined by the following equation and detect tire deflation by referring to this value. This equation may cancel out the difference in 4-wheel speeds when cornering.

$$DEL = \frac{2 \times \{(FL + RR) - (FR + RL)\}}{FL + FR + RL + RR} \times 100$$

FL : Speed of Front Left tire
FR : Speed of Front Right tire
RL : Speed of Rear Left tire
RR : Speed of Rear Right tire



FEATURES OF CURRENT INDIRECT TPMS

Finally, current indirect TPMS has the following features.

-- No additional sensors.

-- Can detect deflation in one tire.

-- Is applicable for the low aspect tires including runflat tires.

-- Can work on the various types of cars, such as, front-driven car, rear-driven car, 4-wheel driven car and a limited slip differential equipped car.

APPROACH FOR DIFFUSION DEFLATION DETECTION

All tires lose air naturally over time and we refer to this condition as ‘4-Tire Diffusion Deflation’. To detect diffusion, we introduced a new concept. That is, ‘ Load sensitivity of rolling radius ‘, which means a tire rolling radius change rate in % when the tire load shifts. Figure 2 shows a tire rolling radius change rate in % when the tire load shifts 250kg. We found that the tire rolling radius change rate in the deflated condition (140 kPa) is smaller than that in the normally inflated condition (200kPa) over a wide aspect ratio range of tires (70% to 50%).

<Test condition> (INDOOR TEST)

Tire size : 185/70R14 Delta Load=250 kg
: 205/60R15
: 225/50R17

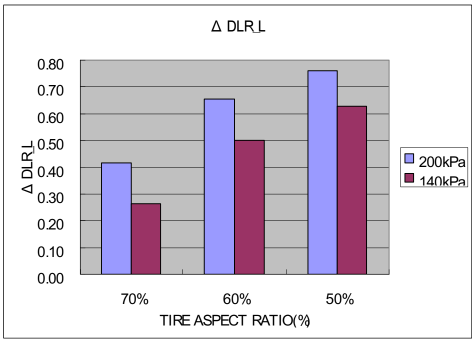


Figure 2. Load sensitivity of tire rolling radius.

TEST RESULTS

Considering that the load shift occurs under cornering and acceleration/deceleration, we can detect a 4-tire diffusion deflation by comparing the tire rolling radius change rate under cornering or acceleration/deceleration between a normally inflated tire and a deflated tire.

Figure 3 shows the rolling radius change in the normally inflated condition under cornering and

Figure 4 shows that of a 4-tire 40% deflated condition. Here, the slope of line represents the load sensitivity of the tire in each condition. There is a difference in slope and thus we can detect a 4-tire simultaneous deflation.

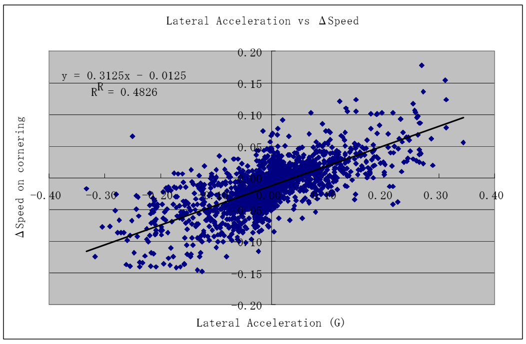


Figure 3. Speed difference in cornering due to load shift. (Normally inflated condition)

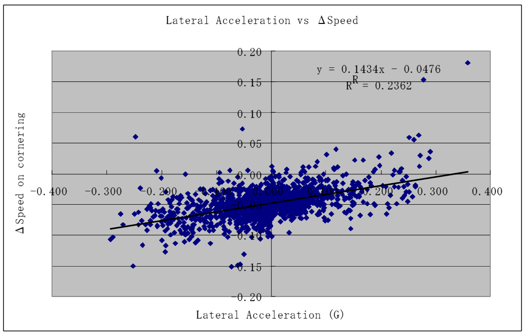


Figure 4. Speed difference in cornering due to load shift. (4-tire 50% deflation condition)

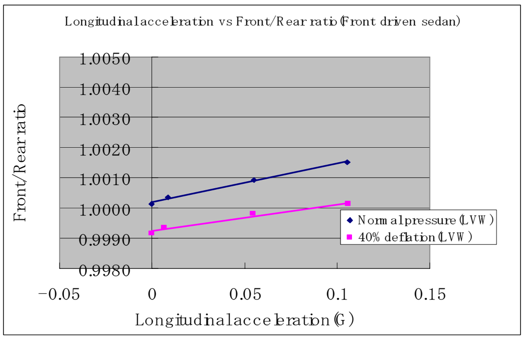


Figure 5. Rolling radius change rate under acceleration (Front driven sedan)

The load sensitivity during acceleration and deceleration was also evaluated using a front driven car and a rear driven car.

Figure 5 shows the rolling radius change of a normally inflated and a 4-tire 40%-deflated condition under acceleration using a front driven sedan.

Figure 6 also shows the rolling radius change of a normally inflated and a 4-tire 40%-deflated condition under acceleration using a rear driven sedan.

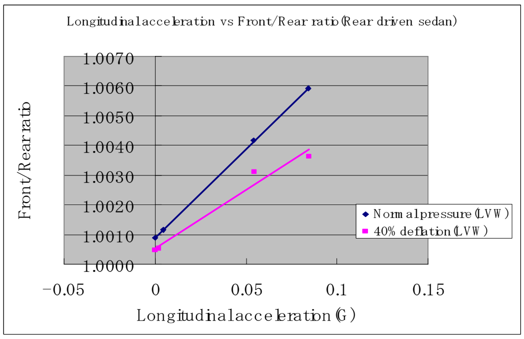


Figure 6. Rolling radius change rate under acceleration (Rear driven sedan)

In the both figures, there is difference of slope between normally inflated tire and 40% deflated tire. And in addition, we can easily find that the intercept of the line decreases when all 4-tires are deflated because the difference of tire rolling radius between the front axle and the rear axle varies according to the inflation pressure. Therefore, we can detect a 4-tire diffusion deflation condition by comparing the slope or intercept of the line.

TEST RESULT ON THE PROVING GROUND

To determine if this concept can meet the requirements of the NPRM by NHTSA, we made additional testing as follows. We used the High Speed Test Track at the Transportation Research Center, Ohio as the test surface. And the test vehicle was the front driven sedan. We designed the driving pattern to include acceleration, deceleration, braking and stop and driving in the speed range 50km/h to 100km/h to simulate the real world.

We did a calibration, of course, at the normal pressure condition under this driving pattern and then checked to see if the system could finish calibration within 20 minutes and detect a 25% 4-wheel diffusion deflation. within 10 minutes.

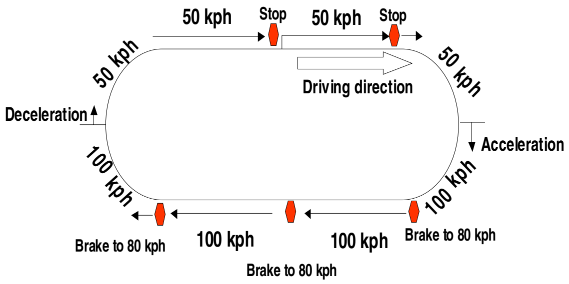


Figure 7. Driving pattern

Table 1. shows that this system could complete the calibration 17 minutes and detect a 4-tire 25% deflation in 6 minutes under the two different load conditions.

Table 1.

Test results on the proving ground

	Weight condition	Results
Calibration time (min.)	3 persons	17
Detection time (min.) @ 25% (4-Tire)	3 persons	6
	GVW	6

CONCLUSIONS

We have developed a 4-tire simultaneous deflation detection indirect TPMS. This TPMS system only requires the wheel speed sensor signals from the vehicle ABS.

On the proving ground, this system showed that the time to reach full system capability following reset is within 20 minutes and the detection time is within 10 minutes.

We also believe that this indirect TPMS system will meet new NHTSA requirements and be able to contribute to a driver's safety while maintaining superiority in cost and durability.

RESEARCH ON THE EVALUATION METHOD OF DRIVER BEHAVIOR USING DRIVING SUPPORT SYSTEMS

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Japan

Paper Number 05-0353

ABSTRACT

Driving support systems, such as Adaptive Cruise Controls and Lane Keeping Assists, are believed to change driving behavior. These changes allow drivers to ignore the tasks performed by the driving support system, which can cause dangerous driving circumstances. A few reasons can account for the increased danger. First, decreasing driving responsibilities can make a driver lazier, while increased driving tasks require a quicker and more accurate under- standing of the system. Second, an observant driver may disagree with the system's assessment of a situation.

In order to solve these problems, it is necessary to observe driving behavior more closely, to clarify the decision-making process by using some indexes measured by drivers' signals, and to discover why a driver's behavior changes through traced indexes.

This study reviews one method of determining a drivers' thinking process. We chose the Low-Speed Following system as the driving support system model item. The Driving Simulator in the Japan Automobile Research Institute was used to conduct the experiments. The indexes measured were breaking reaction time, moving time of eye points, and subject information based on the indirect method of Situation Awareness.

As a result, our method illustrated the drivers' decision-making process, and the reason for drivers' using the driving support system was specified. Furthermore, we estimated the validity of driver behavior changing when using driving support systems.

INTRODUCTION

Driving support systems control the vehicle for the driver, making driving easier and safer. When drivers use these systems, they change their driving style. Since these changes create two problems, we should judge the safety of these changes, before they are instituted globally. We applied Situation Awareness (SA), the method used to clarify the cause of plane accidents, to evaluate which of these changes were safe for drivers. The purpose of this research was to confirm that this method was able to evaluate driving support systems.

Two Important Tasks and Problems

Figure 1 depicts a driver's style when using a driving support system. A driver should pay attention to the traffic environment, whether or not the system is being used. We call this task the "Environment Observing Task." Furthermore, a driver who is using a system is responsible for observing the system controls instead of performing some vehicle operations (controlling the throttle, pressing the brake pedal, and turning the steering wheel). We call this new task "System Observing Task." These two tasks are important for driving safely with driving support systems. Present driving support systems may sometimes not control the vehicle safely. The driver must operate his vehicle independently, if the system controls malfunction. The driver must therefore maintain awareness of other vehicles and his own vehicle through those two important tasks.

There are primarily two problems in this new style of driving. One problem is that a driver may neglect one of these important tasks. A driver may not respond or the response may be delayed in serious situations when the system fails to control the vehicle safely. A driver who does not perform these two tasks may not become aware of serious situations. Since the support system relieved the driver from some vehicle operations, the driver was apt to assume that he or she could omit these two important tasks. This condition is called over reliance.

Another problem was that a driver failed to understand system conditions, and had a delayed reaction to or became confused in a serious situation. System Observing Task demands that a driver quickly understand the condition of the system, the operation by the system control, and the movement of their vehicle in the near future. A driver was in danger if he or she did not discover a system error or misunderstood the tendency of system control. This condition is called an error of system recognition.

New Method of Evaluating Driver's Operation

There are two different causes of driver error, over reliance and recognition error. The effects of these problems are the same. Drivers do not take over control from the system or their taking control is delayed in serious situations. We cannot find the reason for a driver's operation and evaluate the driving support systems by just measuring a driver's reactions during serious circumstances.

We needed new methods for evaluating a driver's operation of a vehicle and driving support systems. Some systems have been developed for more than vehicle support. The method of Situation Awareness (SA) is used to clarify the causes of airplane accidents. The method indicates a pilot's awareness for the systems, copilots, controllers, etc. We show why the method is suitable for accounting for human recognition in the next chapter. We applied SA and found a new method that acquires a driver's thinking process in reaching an operation decision.

In this research, we clarified the basis of a driver's vehicle operation and evaluated the driving support system by providing indexes to the driver's thinking process.

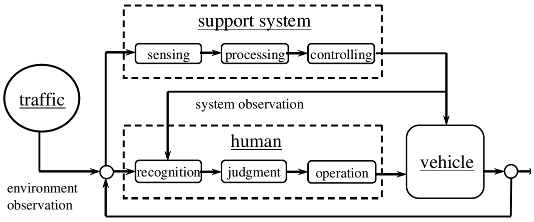

Figure 1. Relationship between driver and system operation, via two important observing tasks.

SITUATION AWARENESS

Situation Awareness is the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future[1].

SA Levels

Airplane pilots must process a great deal of system information and accomplish very complex operations. It is believed that many airplane accidents are related to lack of recognition[2]. In most of those cases, pilots were not able to grasp the environmental situation. This is called "Loss of Situation Awareness"[3]. The SA method breaks down why loss of situation awareness has occurred and clarifies and prevents plane accidents.

SA systematizes the process of operators' becoming aware of matters happening around them. SA investigates the recognition process in detail. The recognition process is divided into three levels[1,4]. Each of the three hierarchical phases will be described in more detail.

Level 1 SA: Perception of the Elements in the Environment - This is the first step in achieving SA. A subject at this level perceives the status, attributes, and dynamics of relevant elements in the environment. In a pilot's case, he or she would perceive elements such as aircraft, mountains, or warning lights along with their relevant characteristics (e.g., color, size, speed, location). Elements for vehicle operation with driving support systems correspond to what surrounds the vehicle, load condition, warning sounds, etc.

Level 2 SA: Comprehension of the Current Situation - Comprehension of the situation is based on a synthesis of disjointed Level 1 SA elements. Level 2 SA goes beyond simply being aware of the elements that are present by including an understanding of their significance in light of pertinent operator goals. Based on knowledge of Level 1 SA elements, the decision maker forms a holistic picture of the environment, comprehending the significance of objects and events. For example, a vehicle driver comprehends a vehicle's emergency brake from relative velocity and so on.

Level 3 SA: Projection of Future Status - The ability to project the future actions of the elements in the environment, at least in the very near term, forms the third and highest level of SA. This is achieved through knowing the status and dynamics of the elements and comprehending the situation (both Level 1 and Level 2 SA). For example, knowledge of the system limits and the sound of system alarms allow the driver to project that deceleration of the system would not be enough to avoid collision.

SA Models

Operators recognize their environments through this three levels process. These levels are organized by elements. Furthermore, it is useful to classify the sources of these elements. This classification shows the connection between the operator and an element. Useful classification models have been proposed, including the SHELL Model (Hawkins)[5]. The authors have proposed the Transformed SHELL Model[6]. We altered the models to be suitable for vehicle driving. The Transformed SHELL Model interfaces between driver and environmental elements (See Figure 2). The traffic environment, condition of the driver's car (Vehicle), passengers and ITS instruments surround the driver. Using the Transformed SHELL Model, we are able to examine the problems encountered when thinking of the relationship between the operator and the sources of elements.

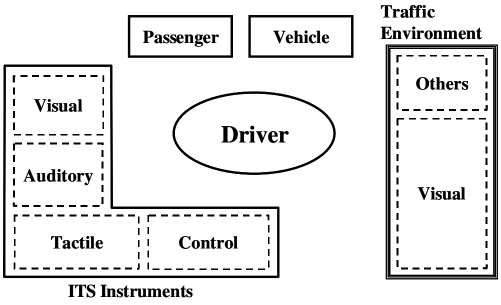

Figure 2. Interface model for the analysis of situation awareness in driving (Transformed SHELL Model).

It is possible to verify the cause of a human error by using the three levels and the Transformed SHELL Model. It makes it easier to think about the most suitable systems for a driver.

EXPERIMENTAL METHOD

We used a motion-based driving simulator[7] and arranged the following situation on a four-lane straight expressway. A host vehicle was equipped with a Low Speed Following system (LSF). The system followed another vehicle and controlled its own vehicle's throttle

Table 1.
Specifications of LSF in this study

Scope of system support	+Stop the vehicle when following vehicle stops. +Start the vehicle when following vehicle starts.
Maximum deceleration	$2.5 m/s^2$
Time headway	1.6s
Stopping distance	3.0m
Turn off system control	+Driver applies the brakes +Turn off the switch

and brakes automatically. Table 1 presents the specifications of the LSF in this study. In this study, LSF started automatically when the following vehicle started. Deceleration by this system was limited to 2.5m/s^2. This system was programmed not to follow safely so that a collision would occur if the driver did not apply the brakes at system limit condition.

Experimental Event

Figure 3 illustrates the event in which driver behavior was evaluated. There were four vehicles in front of the driver's vehicle. Usually, these vehicles maintained a low speed and stopped very often, as if in a congested area. Vehicle A, Vehicle B and the driver's vehicle were in the same lane. Vehicle C and Vehicle D drove in the adjacent lane. The driver's vehicle followed Vehicle B.

At the beginning of the event, Vehicle C turned on the turn signal and started to cut in between Vehicle A and Vehicle B. At the same time, Vehicle A decelerated to 3.5m/s^2. Therefore, Vehicle C, just cutting in, decelerated sharply (4.0m/s^2) and Vehicle B panic stopped (5.5m/s^2).

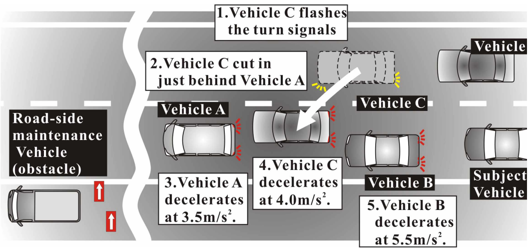

Figure 3. Illustration of the event.

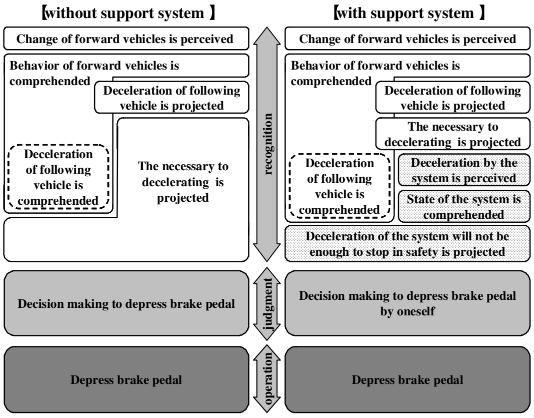

Figure 4. Driver's thinking process in the event.

Decision-Making Process for Experiment Event

Figure 4 depicts the decision-making process for the driver during the experiment event. The driver's thinking progressed downward or sideways on the figure. The necessary SA elements in this event were relation to traffic environments and ITS instruments.

Figure 4 Applying indexes to the decision-making process. We were able to investigate the driver's operation from his or her thinking factors. Therefore, we measured three elements related to the driver's thinking, perceiving changes of leading vehicles, comprehending deceleration of following vehicles and projecting system limits. Perception was measured by eye-point reaction. The eye point would move to forward vehicles if the driver perceived change. Comprehending and projecting time were measured by asking drivers directly with video of their driving.

Test Subjects

A total of twenty-six drivers, nineteen males and seven females, participated in this study. Their ages ranged from 23 to 53 years old, with an average age of 32.9 years. We divided subjects into three groups. The conditions of each group are shown Table 2. Group A subjects did not use the LSF system. Subjects belonging to Group B and Group C drove with the LSF system, but

Table 2.
Experiment conditions of groups

	LSF system	knowledge of system limit condition
Group A	Without	-
Group B	With	With
Group C	With	Without

Group C was not instructed in the system limitations.

EXPERIMENT RESULTS

We measured the driver's thinking elements and braking action. The thinking elements were perception of forward vehicles' change, comprehension of following vehicle's deceleration and projection of system limit condition, shown in the previous chapter. Braking actions were separated into covering and applying the foot to the pedal. The status of the driver covering the break pedal was measured before decision-making, while pedal operation was measured after decision-making.

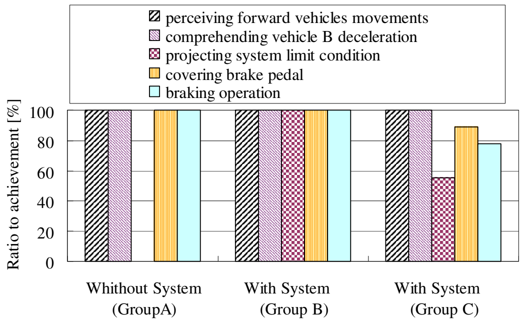

Figure 5. Ratio of achieving reaction / thinking.

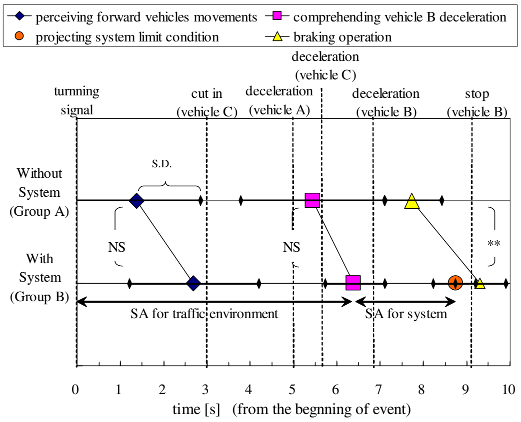

Figure 6. Reaction time of drivers' thinking process.

Achievement of Thinking and Operations

Figure 5 shows the ratio of thinking and operations in each subject group. Bar graph values indicate the percentage of group members achieving to get thinking elements or operating the brake pedal.

Perception and Comprehension of Leading Vehicles' Movement - Perception and comprehension indexes were SA elements of the traffic environment. Those thinking factors were 100% for all three groups. This meant that all subjects achieved SA for the traffic environment.

Projection for System Limit Condition - Projection index measured in this study was SA elements for the system. It was projecting system limit condition. Percentage of Group B was 100%, but Group C, which had not been informed about system limits, achieved 55%. This meant that half of Group C subjects did not achieve SA for system by lack of system knowledge.

Braking Actions - All Group A and Group B subjects performed braking actions (covering and putting the foot on the pedal). Only Group C had subjects who did not brake. It was clearly caused by not achieving SA for the system.

Thinking and Brake Operation Timing

All subjects belonging to Group A and Group B got thinking elements (SA for traffic environment and system) and operated the brake pedal. However, timing varied. Average times and standard deviation to achieve indexes are shown Figure 6. Horizontal-axis means passage of time from the event start (Vehicle C flashed turn signal). Incidentally, we permitted the comprehension time containing a driver's estimate for decelerating of Vehicle B. Therefore the driver comprehended Vehicle B's movement earlier than Vehicle B's actual decelerating time.

Attention to Traffic Environment - Driver formed SA for traffic environment between event start and achieving driver's comprehension forward vehicles movements. Two average times (driver perceived and comprehended forward vehicles movement) of Group A were shorter than those of Group B, but the results were not significantly different. This suggested that using the LSF diverts a driver's attention to the traffic environment.

Difference of brake operation time - The average brake operation time in Group B was longer than that in Group A, and the result was significant.

On average, Group B subjects comprehended deceleration of vehicle B earlier than the average brake operation time in Group A. Consequently, drivers who were using the system paid attention to the traffic environment containing forward vehicles when drivers who were not using the system operated the brake pedal.

Driver formed SA for the system between comprehending deceleration vehicle B and projecting system limit condition. At the average brake operation time of Group A, Group B drivers were forming SA for the system. In other words, drivers who were using the system were observing the system (System Observing Task), when drivers who were not using system operated the brake pedal.

Therefore, braking latency generated by using the system under the study conditions was caused by the System Observing Task and was minimally influenced by lack of attention to the traffic environment.

Classifying a Decision-Making Pattern

Group C had subjects who did not brake and crashed into the leading vehicle. Most of those subjects crashed without covering the brake pedal. However, some subjects covered the brake pedal, but never depressed the pedal. This suggested that a driver's decision-making process could be classified into several patterns. We patterned Group C's combination of achieved indexes shown in Table 3.

In Pattern 1, all indexes were achieved. This pattern fulfilled their two tasks (environment and system observing). Pattern 4 was opposite from Pattern 1. System Observing Task was neglected at Pattern 4. Subjects classified in this pattern crashed without brake actions.

At Pattern 2, drivers covered and operated the brake, similar to actions in Pattern 1. However, they had not formed SA for the system because they failed to project system limits. Their brake operation occurred reflexively and the process to project the system limit condition was skipped.

Table 3.
Subjects' reaction pattern

	Perceiving of forward vehicles movement	comprehending vehicle B deceleration	projecting system limit condition	covering brake pedal	breaking operation
Pattern 1	○	○	○	○	○
Pattern 2	○	○	×	○	○
Pattern 3	○	○	×	○	×
Pattern 4	○	○	×	×	×

In Pattern 3, drivers covered the brake pedal but did not depress the pedal. Those subjects said that they covered the brake pedal because they felt danger, but they did not know what they did at that time. Group C subjects did not know the system limits. Consequently, this event was an unexpected accident, and they were surprised at the automatic response (said Automation Surprise[8]).

This chapter shows that a driver's decision-making process may be different even if the operations are similar. There may thus be latent problems in reactions that looked best. Understanding the driver's decision-making process may help disclose those latent problems.

APPLICABILITY OF SA METHOD

In this study, we verified the applicability of a new method to evaluate driver behavior and support systems. The SA method, which has been used for aircraft accidents, was applied for the evaluation. A driver's decision-making process was obtained by this method.

A driver's thinking timing was investigated using this new method. We were able to clarify how using a driving support system changed a driver's operation.

A drivers' decision-making processes could be classified into several patterns. These processes were different for each pattern even if their operations were similar. Latent problems may still be found in reactions that looked best.

Comprehending drivers' decision-making processes was useful in uncovering latent problems.

These results clarified driver behavior and decision-making processes. Therefore, we believe that this new method is applicable.

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CONTEXT-AWARE DRIVING BEHAVIOUR MODEL

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ABSTRACT

Existing driving behaviour models have a strong emphasis on the driver's cognitive components including aspects such as motivation, risk assessment, attention, compensation, capability, workload, individual traits and experience. Each existing model was designed specifically for a particular driving situation such as speeding or fatigue. A general and comprehensive model is still unavailable despite 60 years of research on the topic. No consensus has been reached mainly due to the inability to generalize, operationalise and validate these subjective cognitive models in real driving conditions. This paper defines a framework for a new context aware driving behaviour model capable of predicting driver's behaviour. This approach broadens the cognitive focus of existing driving behaviour models to integrate contextual information related to the vehicle, environment, driver and the interactions between them. The theoretical model is an information processing, probalistic based model. Context awareness concepts from the Ubiquitous Computing research community are integrated into the model. Such integration improves the descriptive power and generalisability of our driving behaviour model.

I INTRODUCTION

Driving behaviour models explain and predict the behaviour of drivers. Existing models are largely subjective and based on self-report scales (Ranney 1994). They strongly emphasise the driver's cognitive state and have incorporated important behavioural change concepts such as motivation, or risk assessment. However motivational models such as risk compensation (Wilde, 1982), risk threshold (Naatanen *et al.*, 1976) or risk avoidance (Fuller, 1984) remain highly subjective concepts. For example, risk is often associated with perceived probability of harm or negative event and its severity. The measurement of perceived risk is often focused at the probability of the risk. The probability of negative event is rarely the same for everyone and varies per circumstances. The possible use of a baseline measures to compare risk perceptions is debatable. Understanding one's personal sensitivity to risk requires knowledge of other factors—such as personal behaviours, family history, and environmental exposures—that determine that probability (Weinstein, 1999).

Although the driver is the main actor in the driving activity, driving is not an isolated activity. It takes place in a wider context in which the driver constantly interacts with its immediate environment and the vehicle. The observation of how drivers actually act on the road, also known as "driver behaviour" as opposed to "driver performance" (what the driver can do, e.g., perceptual and motor skills), has generated significant body of work in which traffic psychologists have played major roles (Dorn, 2003). Driver behaviour and driver performance have mainly been used to analyse factors contributing to crashes. Pre crash analysis to create predictive models as well as post crashes analysis to identify contributing factors leading to crashes are the two complementary approaches used to address crash prevention. The contributing factors as broad as cognitive abilities, social context, emotion, driver's trait, experience, hazard perception skills and so on have been identified as driver's individual factors affecting driver's performance.

The situation in which the driver evolves plays a crucial role in determining the type of actions. A situation is also called context in the rest of this document. Existing "cognitive" models do not take into account the dynamic nature or context in which a driver's actions evolve. Without the context, the validation of these models in real driving situations would be difficult. The lack of a data based model to predict drivers' behaviour is a major weakness of existing models. A generalizable and comprehensive driver behaviour model has yet to be developed, despite 60 years of research on the topic. Therefore context is essential to explain driving behaviour and to improve the generalizability and reliability of existing driving behaviour models.

Section II describes related work. Section III describes how we approximate cognitive models to computational models. Section IV briefly describes contest aware systems concepts that we use to predict driver's behaviour. Section V presents our context aware prediction framework based on Bayesian network. Section VI describes what a Bayesian network is and how we use it in our framework. Section VII shows a simple example of how a Bayesian network could be used to take into account factors related to risk and vehicle position on a freeway. Section VIII extends this approach to Dynamic Bayesian Networks. Finally, Section IX concludes the paper and discusses future work.

II RELATED WORK

Existing driver behavioural models have so far failed to deliver sustainable technology that can reliably predict impaired behaviour such as fatigue (Hartley et al., 2000; Sensation, 2004). This failure is attributed to (i) the dependability of biological markers on broader contextual factors (e.g., perception, individual characteristics) and (ii) the absence of baseline that specifies a normative behaviour. Recently, statistical models have been used to predict driving behaviour. The SmartCar project models and recognize driver manoeuvre at tactical level. It uses HMM (Hidden Markov model) to predict future manoeuvres (Oliver et al., 2000). Kumagai et al., 2003 uses Bayesian network to predict future stop of vehicle at an intersection. Sakaguchi, 2003 also uses Bayesian network to detect unusual driver behaviour. Neural networks and Bayesian networks have been used for building real time recognition of large-scale driving pattern from vehicle dynamics and different classes of driving situation such as highway, main road (Engstrom et al 2001).

Other work uses physiological measures (EMG, EKG) and algorithms such as sequential forward floating selection to detect driver stress (Healey 2000) or driver hypovigilance (Rakotonirainy 04). Stress, fatigue or hypovigilance are among cognitive state that could influence future behaviour of a driver. Therefore such concepts could be included as factors influencing driver behaviour.

The cited works have not fully exploited integrated contextual information related to the driver, vehicle and environment. Despite the extensive research on context awareness concepts (Dey, 2001), the use of context aware systems in vehicles has not been fully investigated (Olsson, 2003).

III FROM COGNITIVE TO COMPUTATIONAL MODELS

The programming existing cognitive or motivational models into in-vehicle devices is the natural inclination of an ITS (Intelligent Transport System) approach toward predicting driver behaviour in real time. Unfortunately, the subjectiveness of motivational models, make such approach challenging. In order to make this process rigorous and scientific, drivers' subjective perception or cognitive concepts must be mapped into numerical values (e.g. level of risk or motivations). Then an absolute numerical measure which can be used to compare risk perception of different drivers for each situation must be determined. Statistical method could be used as a mean to achieve such a goal. However the validity and objectivity of such approach are questionable. Hence, concepts such as risks depend on too many factors that the assessed participant or the assessor could evaluate or keep track of.

Our approach consists in observing the driver in his/her real driving condition with sensor technology. The observation is a learning process that can improve the prediction capability. We have pointed out in Section I the prevalence of uncertainty in a driving environment. Thus we use Bayesian learning as a form of uncertain reasoning from observations. Bayesian learning simply calculates the probability of the occurrence of an event, given an observation, and makes predictions on that basis.

Driver's cognitive concepts, such as risks, are deduced from various sensors such as the dynamics of the vehicle in a certain situation or physiological measures. Such observations could also be augmented with questionnaire such as Sensation Seeking Scale (Zuckerman, 1979). The observation of the driving condition is classified with statistical tools to create a computational model. Such observations are technically possible due to the advent of sophisticated in-vehicle sensors and context aware systems which can gather and analyse data about (i) the physiological state of the driver, (ii) the behaviour of the driver (iii) the dynamics of the vehicle and (iv) the description of the environment surrounding the vehicle and the driver. We borrow techniques from context-aware systems research community to achieve the observation functionalities.

IV CONTEXT AWARE SYSTEMS

Almost 95% of the accidents on the road are due to the human factors. In almost three-quarters of the cases human behaviour is solely to blame. On European roads, 40.000 persons are killed and 1.7 Million are injured every year. Drivers represent the highest safety risk. Computing assistance can improve situational awareness and reduce drivers' errors. Although context-aware systems have a great potential to save lives and prevent injuries on the road, they have not been integrated to safety critical applications such as cars yet. Concretely, context-aware systems can improve the driver's handling of a car by augmenting the awareness of the cars state (e.g. following distance), the environment (e.g. road conditions), the physiological and psychological state of the driver (e.g. available attention level, fatigue). In this paper we store and classify the behavioural information gathered from the context aware system. The history of behaviour is then used to predict future behaviour.

Context-awareness is a computationally oriented design method which improves the flexibility of autonomous systems. It is a concept which has emerged from pervasive and ubiquitous computing research community. Contextual information of an entity X describes relevant information related to the surrounding environment of X. If X is a user then, a context aware system provides *relevant* information and/or services to the user, the relevancy of information depends on the current user task (Dey, 2001). Such relevant information is used to adapt the behaviour of a computational (autonomous) entity/user.

Context can be modelled as value, attribute and relationships between attributes. The values of attributes are gathered from sensors of from users. Context exhibits a range of temporal characteristics; it is imperfect; it has many alternative representations and its content is highly interrelated (Henricksen 2002). Identifying the relevant attribute is a challenge as the type and the number could vary significantly per situation and per driver and can become an intractable problem.

V FRAMEWORK BASED ON BAYESIAN NETWORK

The Framework we are using to model and predict driver behaviour is shown in Figure 1. A context aware system gathers information about the environment. Sensors are mainly video cameras. Vision based technology is available to observe the shape of the road, traffic, road signage, pedestrians, cyclists or other objects. Vehicle dynamics are recorded with data logger and maps. Driver's motor movement are also mainly recorded with vision based computing mechanisms. Head movement, eye blink, steering grip, visual scanning pattern are among observable behaviour that can be recorded with existing technology. Driver's physiological state could be recorded or deduced (from) with different physiological devices such as Galvanic Skin Response (GSR – skin conductivity), Electrocardiogram (EKG – heart rate), Electrooculograph (EOG – eye movement), Electromyograph (EMG – muscle movement) or accelometer (head movements or arms motor pattern) (Rakotonirainy et al., 2004).

Sensors record the state of a given variable related to the driver, vehicle or environment. The states are fused, analysed and interpreted to create a driving situation also called context. The situation is then fed into Bayesian based machine learning system from which a probability based prediction is deduced from the history of behaviour.

VI USE OF STATISTICAL MODELS TO PREDICT DRIVER BEHAVIOUR

A driver"*manages behaviours sequentially in space and time and it organizes goals, intentionally and anticipatory set, which it maintains or changes as appropriate. It plans, prepare, formulates and oversees the execution of action sequences; it monitors the strategic aspects of success or failure, the consequences (including social) of actions, it applies both foresight and insight for non-routine activities and provides a sustained and motivating level of drive" (Bardshaw , 1995)*

It is virtually impossible to design a computational program which could predict future driver behaviour by taking into account all the complex factors shown above. These factors are not necessarily measurable and are afflicted with uncertainty. Our approach consists of using belief networks such as Bayesian networks to model and predict behaviours. Bayesian methods are used as statistical analysis which can provide a flexible theory for making inferences in the presence of uncertainty. It is an extremely powerful tool to provide general solutions to the problems of noise, over fitting and optimal prediction. Bayesian networks are well suited for modelling the joint probability distribution of the random variables representing the state of the driver and his/her environment. They provide the best framework to model, understand and predict complex systems such as driving.

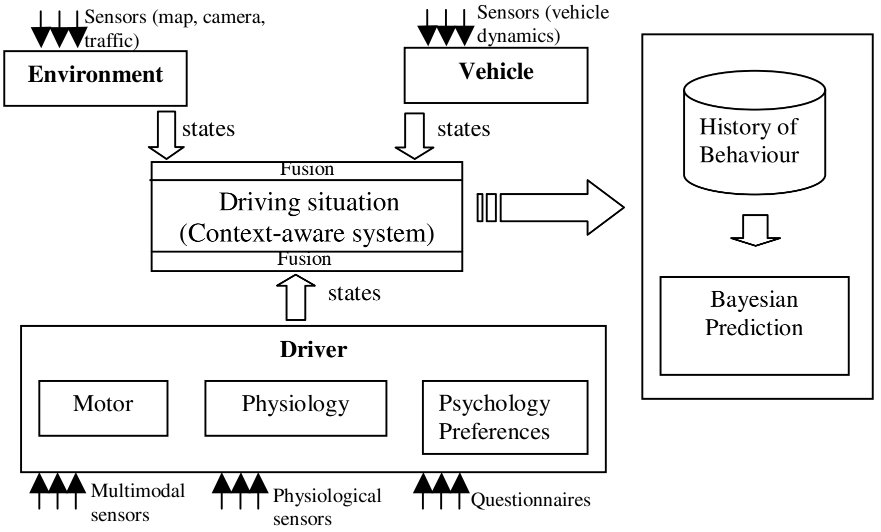

Figure 1: Driver behaviour

An accurate prediction of driver behaviour requires an understanding of a large number of conditions (context) which cannot be quantified with individual observational measures, such as recording ocular, traffic flow, and cognitive activities. Therefore relevant contextual information related to the driver, the vehicle and the environment need to be fused and analysed to contextualise an action. These contextualised actions are represented in a Bayesian Conditional Probability Table (CPT). Such contextualisation improves the accuracy of the prediction.

The main advantage of using a Bayesian network is the compactness of the representation of the joint probability distribution of its random variables whenever causal relationships in the problem domain are known. For example if no conditional independence relationship is known about four binary values random variables $X_1,\dots,X_4$, a table with $2^4 = 16$ entries is needed to represent the joint probability distribution $P(X_1,\dots,X_4)$. Whereas if we know that

$$P(X_1,\dots,X_4) = P(X_4 \mid X_3, X_2)\times P(X_3 \mid X_1)\times P(X_2)\times P(X_1) \qquad (1)$$

then only $2^2+2^1+2^0+2^0=8$ entries are required. Provided a decomposition of the joint probability distribution such as (1) can be given by a domain expert, far fewer experimental data will be needed to estimate the parameters of the CPTs. The decomposition (1) implies that given the knowledge of the values of X_2 and X_3, information about X_1 is irrelevant in predicting X_4. More formally,

$$P(X_4 \mid X_3, X_2) = P(X_4 \mid X_3, X_2, X_1)$$

We can view the variables X_1, X_2 and X_3 as influences (causes) on X_4. Not only, Bayesian networks allow to quantify predictions, like computing the probability that X_4 is true given the value of X_2 and X_3. But, Bayesian networks allow us also to make diagnostics, like computing the probability that X_1 is true given the values of X_2 and X_4 (even if X_3 is unknown). The random variable X_4 could describe some attribute of the driver behaviour, X_1 X_2 and X_3 could describe some attributes of the environment, the vehicle or the driver.

VII EXAMPLE: EXIT LANE

This example shows how we can model a simplified scenario in which a driver exits a freeway with Bayesian network. This example combines drivers' cognitive concepts such as risks with vehicles and environmental information such as vehicle position in a lane.

The freeway has two lanes as described in Fig 2. A vehicle on Lane 1, close to the exit will exit the freeway if the driver is willing to take high risk. Otherwise the driver will continue on the same lane.

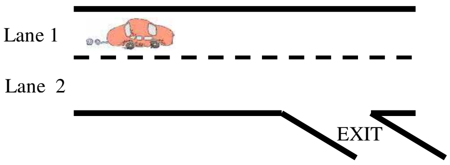

Figure 2: Vehicle exiting a freeway

Age factor as well as the level of alcohol or drug intoxication could influence one's aversion to risk. The Bayesian network associated with the scenario is depicted in Figure 3. Nodes represent quantitative probability information. An arc between a node X and Y means that X has a direct influence on Y. Note that Risk is independent of Lane.

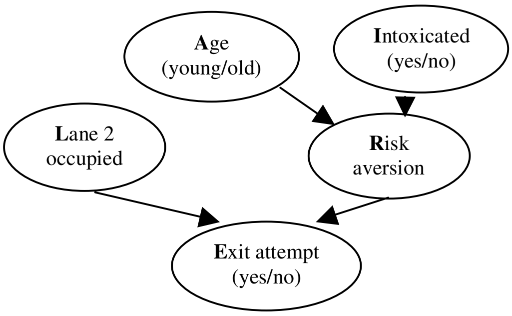

Figure 3: A Bayesian Network for the *freeway exit* scenario

The Bayesian network above factorizes the probability that a vehicle on Lane 1 wishing to exit will actually attempt to exit given the age and state of the driver as

$$\begin{aligned} P(E, L_2, A, I, R) &= P(E \mid L_2, R) \times P(L_2) \times \\ &P(R \mid A, I) \times P(A) \times P(I) \end{aligned} \tag{2}$$

To estimate $P(E \mid L_2 = \text{occupied}, A = \text{old})$, we would need to sum over the possible states of intoxication. That is,

$$\begin{aligned} &P(E \mid L_2 = \text{occupied}, A = \text{old}) \\ &= P(E \mid L_2 = \text{occupied}, A = \text{old}, I = \text{sober}) \\ &+ P(E \mid L_2 = \text{occupied}, A = \text{old}, I = \text{drunk}) \end{aligned}$$

Then we would need to sum over all the possible states of *risk aversion* before being able to use Equation (2).

In this simple example, we hypothesised only two factors for the risk aversion. But, we could refine this model by introducing new random variables. Risk aversion might depends on police presence, on whether the driver is late and on other factors.

VIII EXTENSION TO DYNAMIC BAYESIAN NETWORKS

The time dependency of some random variables follows a Markov process and can be integrated into a Dynamic Bayesian Networks (DBN). A DBN is a Bayesian network that represents a temporal probability model. The Markov assumption states that the current state depends on only a finite history of previous states (Russell, 03). An example of temporal probability is the level of driver-fatigue F_t which increases with time. The random variables F_t take their values in {low, medium, high}. On an hourly time scale, the fatigue can be modelled by stating the values of the $9 = 3 \times 3$ entries of the matrix $P(F_{t+1} \mid F_t)$. DBN can be particularly useful for modelling long journeys of truck drivers. Driver monitoring data could provide the CPT $P(F_{t+1} \mid F_t, R_t)$, where R_t is a Boolean random variable indicating whether or not the driver had a short break during the period t. The random variable F_t can be integrated in the Bayesian Network of Figure 3 on the same level as "Age" and "Intoxicated".

Building a large generic Dynamic Bayesian Network modelling driver behaviour would allow the prediction of the likely impact of policies (compulsory rests for example) on road safety.

IX CONCLUSION AND FUTURE WORK

Fusing contextual information about the environment, vehicle and driver requires large data sets. Data recorded from sensors are unreliable and uncertain. We have described a framework to predict driver behaviour. We have shown that Bayesian network could be used to predict driver's behaviour with certain probability. Such mechanism will be used as a driving assistance mechanism that could detect deviated or abnormal behaviours. This is a preliminary work and we plan to develop methods for automating the process of estimating the parameters of Conditional Probability Table (CPT) from multimedia recordings. We will explore the use of *Dynamic Bayesian Networks* as a modelling tool for situations where the evolution of some random variables can be modelled as a Markov process.

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