IDENTIFICATION OF REAL WORLD INJURY PATTERNS IN AID OF DUMMY DEVELOPMENT

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ABSTRACT

Current testing mandated by regulations relies on well-designed dummies. These dummies must be able to detect highly injurious situations as identified in real world crashes. The current study seeks to rank the severity of specific types of injuries – denoted by body region and skeletal/non-skeletal – in terms of threat to life and costs.

The data approach attempted to explore the questions: What types of injuries should The National Highway Traffic Safety Administration (NHTSA) strive to prevent; what measurements are required of a crash dummy to ascertain whether such injuries are sustainable in a crash test; and how many lives are likely to be saved under a given performance requirement to prevent such injuries? A comprehensive data set has been formed to address these issues including crash, vehicle, occupant, and injury parameters. The data set allows for identification of the most severe injuries based upon a variety of identifiers. Identification of the crash type, vehicle type, and Delta V, etc. was made for each case. It can be disseminated amongst researchers in a spreadsheet or database software file.

This current work provides an update of the data analysis component of the dummy development effort within NHTSA. Further, it will serve to introduce a new data set specifically tailored to the needs of the dummy developers, as well as researchers in the field.

INTRODUCTION

The National Highway Traffic Safety Administration (NHTSA), of the United States Department of Transportation, has taken a lead in biomechanical research. For this reason, the development of dummies to test for injury conditions occurring in real world crashes has been of paramount importance. Dummy development has been reliant upon the feedback provided by the epidemiological databases, such as those compiled at NHTSA.

OBJECTIVES

The Crashworthiness Data System (CDS), a dataset compiled under the aegis of The National Automotive Sampling System (NASS), is a nationally representative sample of police-reported tow away crashes occurring on public roadways compiled since 1988, in its current form. This data was used to form a data set of crashes and their associated vehicle occupant injuries. Its high level of detail allowed for a description of the occupant injuries. These injuries could then be associated with the work of Zaloshnja (2004) to obtain a cost estimate.

The goal of this paper is, not only to aid in the NHTSA initiative to enhance dummy development but also to provide a tool for researcher to use in the form of a real world injury data set by crash mode. The final form of this data set would contemplate a ranking of injuries from the standpoint of mortality. It also could serve to provide live and cost saving estimates to calculate the benefit and cost associated with the introduction of a new countermeasure.

Advanced Dummy Development

A new generation of air bags and further occupant safety advances required improvements in dummy development and a broader range of crash test dummies to accurately measure various crash forces imparted to a range of occupant sizes in different crash situations. As occupant protection requirements for men, women and children of varying sizes, are expanded, appropriately sized and instrumented dummies will be needed to provide estimates of the severity and extent of injury.

Advanced dummies require considerable research and development prior to incorporation into Part 572 of the Code of Federal Regulations or any safety standard. Most NHTSA work on particular crash dummies focuses on a particular type of crash – e.g., frontal, side, rollover, and rear.

The aim of the advanced dummies is to provide a measurement instrument that can discriminate between effective and ineffective safety systems. Its ability to do so depends largely on the fidelity of the measuring instrument – the dummy – and the faithfulness of the performance yardstick – the injury criteria. In the THOR dummy, a more biofidelic instrument is sought to assure that vehicle safety systems are tailored to humans.

It should be noted that a critical preliminary subtask for several dummy rulemaking projects is a determination of the performance and injury criteria for the dummies.

Data Driven Research

NHTSA is responsible for reducing deaths, injuries, and economic losses resulting from motor vehicle crashes. This is accomplished in part by setting and enforcing safety performance standards for motor vehicles. The performance of a vehicle in mitigating injuries is assessed through the Federal Motor Vehicle Safety Standard (FMVSS) 200 series, which make use of a dummy exposed to collision forces. In searching for appropriate dummy metrics, NHTSA takes a data driven approach to assure that its use in a federal regulation will lead to a reduction in injuries. Within NHTSA's biomechanics division, real-world data are used to answer three basic questions that guide the search for injury metrics:

1. What types of injuries should NHTSA strive to prevent?
2. What measurements are required of a crash dummy to ascertain whether such injuries are sustainable in a crash test?
3. How many lives may be saved under a given performance requirement to prevent such injuries?

Generally, there must be enough existing data to show that a proposed countermeasure (such as implementing an additional or new head injury metric) will reduce the risk of injuries. To aid such assessments, NHTSA maintains epidemiological data on the nature, causes, and injury outcomes of crashes. While CDS outcomes are fatal/nonfatal, cost-per-injury figures have been applied, as described in subsequent sections to evaluate cost-based outcomes.

This document will provide an outline of the work to be completed during the course of the data analysis in support of NHTSA. Further, it will propose the questions that will be answered at the close of the data analysis and provide insight into the methods used to answer these questions. The work is in the data identification stage and reporting findings available to date.

DATA SOURCE

The creation of the current data set was predicated upon the use of several tools. The NASS CDS was consulted to select relevant crashes, as described below. Further, selection parameters were applied to increase vehicle fleet homogeneity in the data set. Finally, the injury coding information was merged with mortality rates and crash costs based upon the injury severity coding of the NASS CDS.

The National Automotive Sampling System - Crashworthiness Data System

The Crashworthiness Data System (CDS) is an epidemiological database maintained by NHTSA. CDS is a nationally representative probability sample of police-reported automobile crashes in the United States. CDS cases are limited to crashes that involve at least one passenger vehicle that was towed from the crash scene due to damage resulting from the crash. Each case is assigned a weighting factor that represents an estimate of the number of like-mannered cases that occurred during the sample year.

Abbreviated Injury Scale and CDS Injuries

All injuries to motorists involved in CDS cases are recorded in the database. Injuries are denoted with a seven-digit code in accordance with the Abbreviated Injury Scale (AIS). Maximum severity is denoted as MAIS.

NASS CDS injury codes were concatenated to form seven-digit AIS 90 codes (NHTSA, 2000). These seven digit codes formed the basis for sorting. An initial sort was performed based upon an abbreviated five-digit code and yielded over 300 different injury codes. A secondary sort was performed collapsing the 5-digit codes into 17 body region categories, per Table 1. The subsequent charts were based upon the 17 categories.

The most general practice has been to use the maximum injury sustained by each occupant in the population to calculate the total societal cost, HARM. Zaloshnja (2004) provided an update to these concepts and allowed for their application to individual injuries, as described using the NASS CDS AIS 90 injury coding.

Attributable cost, a further refinement based upon the work of Martin (Martin, 2005) allowed for a costing of the injury based upon the introduction of a countermeasure that alleviated the most serious injury for an occupant. Pursuant to this costing method, it was also possible to more accurately assess injury costs per case without summing all of the injury costs. This was important because a series of injuries would build on to the overall severity and the subsequent injuries may not be as costly because some part of the less severe injury costs might have been subsumed within the most serious injuries.

Table1.
Identification Code Mapping, as used in the Analysis

ID	Body Region Identification	ID	Abbreviated Body Region Identification
1	Skull	1	Skull
2	Brain/Intercranial	2	Brain/Intercranial
3	Ear	3	Ear
4	Eye and adnexa	3	Eye and adnexa
5	Nose/mouth/face/scalp/neck	4	Nose/mouth/face/scalp/neck
8	Neck-internal organs/blood vessels	3	Neck-internal organs/blood vessels
9	Neck-spinal cord	5	Neck-spinal cord
10	Shoulder/clavicle/scapula/upper arm	6	Shoulder/clavicle/scapula/upper arm
11	Elbow	6	Elbow
11.1	Upper extremities, superficial	6	Upper extremities, superficial
12	Forearm	6	Forearm
13	Wrist/hand/finger/thumb	6	Wrist/hand/finger/thumb
16	Upper extremities, multiple/unspecified	6	Upper extremities, multiple/unspecified
17	Chest/breast/abdomen	7	Chest/breast/abdomen
18	Ribs/sternum	8	Ribs/sternum
19	Back (including vertebrae)	9	Back (including vertebrae)
21	Trunk - Superficial	10	Trunk - Superficial
22	Trunk, multiple/unspecified	10	Trunk, multiple/unspecified
20	Trunk-spinal cord	11	Trunk-spinal cord
23	Thoracic organs/blood vessels	7	Thoracic organs/blood vessels
24	Liver	12	Liver
25	Spleen	12	Spleen
26	Kidney	12	Kidney
27	Gastrointestinal	12	Gastrointestinal
28	Genitourinary	12	Genitourinary
28.1	Trunk, other organs/blood vessel	10	Trunk, other organs/blood vessel
30	Pelvis bone and external	13	Pelvis bone and external
31	Lower extremities, superficial	15	Lower extremities, superficial
32	Hip/thigh	13	Hip/thigh
33	Knee	14	Knee
34	Lower leg	15	Lower leg
35	Ankle/foot/toes	15	Ankle/foot/toes
38	Lower extremities, multiple/unspecified	15	Lower extremities, multiple/unspecified
40	Burns, unspecific body part	16	Burns, unspecific body part
41	Whole body-minor external,	17	Whole body-minor external
41.1	Burns, unspecific sev	16	Burns, unspecific body part

Source: Zaloshnja, 2004

Application of Crash Cost to Crash Occupant Injuries

The HARM method of categorizing and ranking the crash injuries was used (Malliaris, 1982). This is a method for applying a societal cost, or HARM. HARM was calculated by assigning a dollar cost to injuries by maximum injury severity (MAIS).

CDS Case-By-Case Characterization: Mortality and Cost

Mortality rates and injury costs are assigned to each case in the data set. Lives saved are computed using the methods described in Martin (2003a,b). Costs are assigned in accordance with Zaloushnja (2004). The rationale for using MAIS>1 as a threshold is that mortality rates associated with all AIS 1 injuries are known to be extremely low; this is not necessarily the case for all AIS 2 injuries.

Attributable fatalities are the number of lives lost due to a particular injury. The method for computation is shown in Appendix A.

Computing the costs attributable to a particular injury follows a similar methodology, per Appendix B.

Interactive Application of Mortality Rates

The factors set forth by Zaloshnja were instrumental in the publications of Martin (2003) for refining the mortality rates attributable to each injury classified using the AIS 90 injury coding. An iterative algorithm was developed to increase the precision of these estimates. This gave rise to a concept termed "survival rate." (Martin, 2003) This was not only used to compute overall survivability but to select which two injuries were chosen to represent the injured victim. This will be used in the development of the data analysis.

METHODOLOGY

By incorporating epidemiological and biomechanical parameters, the data set may be assessed in terms of crash mode injury frequency and associated costs for the crash mode. The baseline comparison considered all of the previously described adult occupants. This data set was further disaggregated by crash mode: planar frontal, planar rear, planar near side, planar far side, and other. Other included any crash mode not specifically stated and could contain planar or non-planar crashes.

Baseline Data Set Composition

The data set governing this project, consisting of 3,456 unweighted records representing approximately 402,800 occupants involved in tow away crashes, was selected based upon the following parameters:

- Vehicles of model year 1998 or later
- MAIS injury greater than or equal to MAIS 2 (all AIS 1 injuries were disregarded).
- Injuries of unknown severity (AIS=7) were included in the dataset.

The data set also included traditional descriptive variables, such as model year, vehicle type, crash type, delta-v, occupant age, body region injured, and AIS level of injury. Additional variables relating to mortality and cost attributable to injuries were included, per Table 2.

Within the CDS injury severity coding, about 10% of all injury codes have a "Not Further Specified" (NFS) designation. NFS is used when detailed medical information is lacking. NFS injuries are always given an AIS score that is equal to or lower than the same general injury that is described more fully. Thus, counts based on MAIS are biased toward more severe injuries.

Initially the occupant body region injuries were ranked on four bases:

- Total injuries to occupants (counting all injuries to every occupant)
- Maximum injury to an occupant MAIS (ties were broken using mortality rate)
- Mortality variables (greatest contributor to potential or actual fatality)
- Cost variables (highest to lowest cost injuries, per Zaloshnja, 2004)

Currently, work has focused on disaggregating the various crash modes. The frontal results were reached based on the above parameters and excluding unbelted occupants. This subset of data consisted of 763 records estimating approximately 138,000 occupants. Among these cases, 57 cases involving fatality were reported representing 2,800 occupants.

Injury Tree

A schematic was created to indicate the areas of focus in dummy creation and their representation within the context of all crashes involving adult occupants with moderate through fatal injuries. Figure 1 was prepared as a five-tiered summarization of the data analysis efforts. The next tier disaggregated the occupants into front-seated adults, rear seated adults, children seated in safety seats secured to a rear seating position, and other. The front seated adults, rear seated adults, and children seated in safety seats secured to a rear seating position were further disaggregated by restraint usage. The belted members of each group were then categorized by crash mode: planar front, planar side, and planar or non-planar other impact. For the front seated and rear seated adults, only, the side crash was further segmented by near and far side impacts. Among the children involved in side impacts, none were seated on the near or far side of the crash.

The highlighted subgroups were also shown by percentage contribution to total fatality, MAIS 3 through 6 injuries, and percentage of aggregate costs

APPLICATIONS

The dummy development initiative is ongoing and the data analysis results are reported periodically. These findings will form the basis of subsequent publications focusing on the topics to be investigated using the NASS CDS. Potential areas of study have been identified as: near side impacts, frontal impacts, children in child restraints, face/neck/scalp injuries, characterization of brain injuries.

Injury Distributions for Specific Cases

Several specific studies have been chosen to examine the distribution of injuries compared to the baseline distribution. A comparison will consist of examining the distributions using the five metrics described above based on specific CDS investigations. Moreover, the influence of an aging population will be highlighted for all proposed investigations.

I. For Near Side Impacts – Front and Rear Seat Belted Adults, NHTSA's FMVSS No. 214 side impact upgrade proposal considers head, thorax, and pelvis protection, and side impact Anthropomorphic Test Devices (ATD's, including EuroSID2, SID2s, WorldSID) have instrumentation to measure responses in these three body areas. Two specific study areas relevant to this data set are discussed below. These are abdominal organ and thoracic injuries. Currently, accurate abdominal organ instrumentation is absent from current dummies.

Further, there is little basic biomechanical knowledge of injury thresholds associated with abdominal injuries largely due to the difficulty in observing such injuries in laboratory experiments. This interrogation will be aimed at examining the requirements of abdominal injury in an ATD.

Table 2. Baseline Injured Body Regions by Case Costs, Total Incidence, Maximum Injury Severity Count, Attributable Costs, and Attributable Fatalities						
Region Number	**Body Part**	**Case Costs $M**	**Weighted Total Incidence**	**MAIS**	**Attributable Costs ($M)**	**Weighted Attributable Fatals**
1	Skull	7,384	17,958	5,052	2794	4,964
2	Brain/intracranial	96,646	157,779	102,434	5663	68,612
3	Ear, eye, internal neck organs	556	1,289	453	5	529
4	Nose, mouth, face, scalp, neck	3,263	52,749	21,684	2739	2,935
5	Cervical spinal cord	9,240	3,281	2,514	509	5,116
6	Upper Extremity	10,150	137,682	72,729	182	7,631
7	Thorax	12,956	53,461	25,056	5843	7,199
8	Ribs/sternum	5,307	70,718	42,335	5128	5,199
9	Back (including vertebrae)	8,018	55,608	28,474	10	3,352
10	Trunk (other abdomen, thorax)	2,427	7,054	3,356	774	1,722
11	Trunk - Spinal Cord	1,099	718	278	26	444
12	Abdominal Organs	2,881	42,328	6,660	609	1,634
13	Hip, Thigh, Pelvis	13,224	55,224	18,515	644	7,875
14	Knee	2,194	52,711	46,890	12	1,977
15	Lower Leg	15,604	173,048	84,329	121	12,366
16	Burns, unspecific body part	4,758	2,534	2,144	1220	3,326
17	Whole body-minor external	0	0	0	0	0
Source: Source: NASS CDS, 1997 – 2003, and Zaloshnja, 2004						

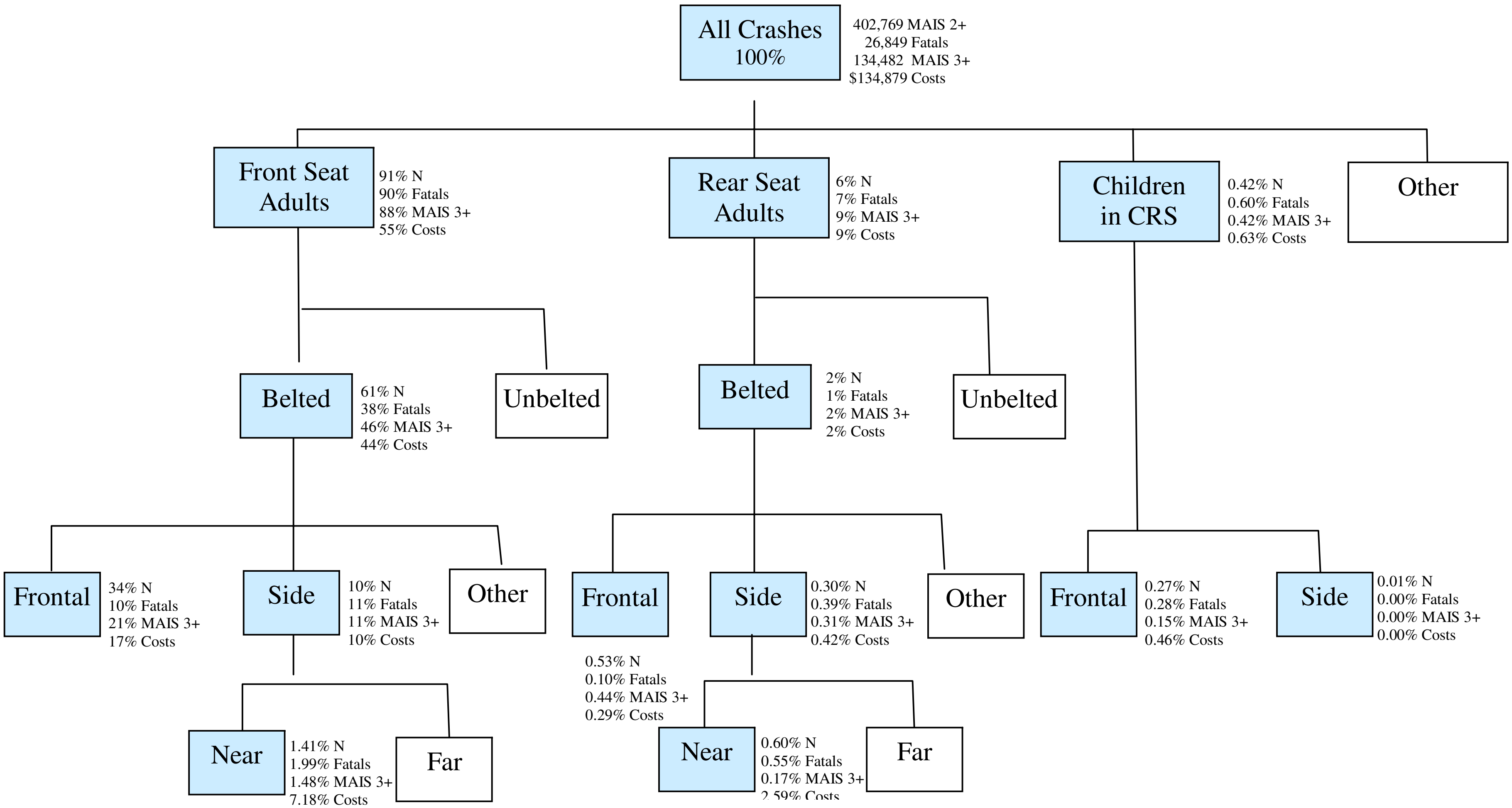

Figure 1a.

INJURY ANALYSIS TREE, Weighted Values

Note: Some zero percents are due to rounding (Near Side Impacts, Children in CRS, and Rear Seat Side) and were taken to decimal places. No Near Side or Far Side Impacts were registered for Children in CRS.

Source: National Center for Statistics and Analysis, NASS CDS, 1997 – 2003, Model Year 1998 onward

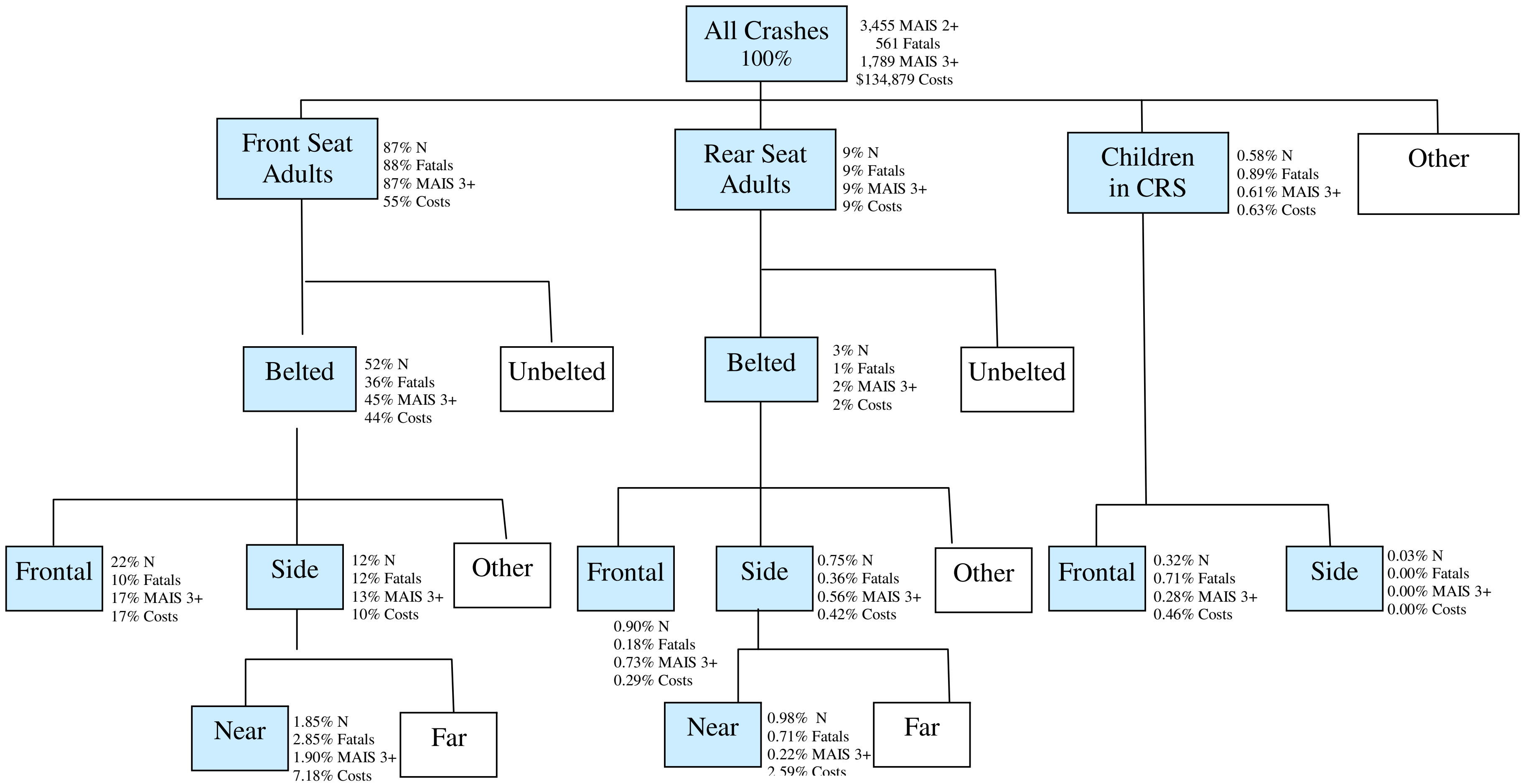

Figure 1b.

INJURY ANALYSIS TREE, Raw Values

Note: Some zero percents are due to rounding (Near Side Impacts, Rear Seat Side, and Frontal and Side Crashes with Children in CRS) and were taken to decimal places. No Near Side or Far Side Impacts were registered for Children in CRS.

Source: National Center for Statistics and Analysis, NASS CDS, 1997 – 2003, Model Year 1998 onward

ATDs use rib deflection sensors to assess potential for thoracic injury. Moreover, the criteria for thorax injury potential are largely based on the number of broken ribs observed in post-mortem human subjects (PMHS) tests. This interrogation will look for thoracic organ injuries with and without significant rib fractures to gain insights into whether rib deflection measurements adequately gauge thoracic trauma.

II. For Frontal Impacts – Front Seat Belted Adults, the Agency is also monitoring and investigating occult injuries from frontal crashes. Knee-thigh-hip (KTH) complex injuries to belted occupants are one of the injury patterns being investigated.

A specific study might include an interrogation aimed at examining the makeup of knee versus thigh versus hip and pelvis injuries in order to gain insights into the need for acetabulum measurements in an ATD and the need for a more biofidelic KTH assembly.

III. For Children in Child Restraint Systems, NHTSA has addressed the TREAD Act by incorporating new requirements into FMVSS No. 213, including improved child test dummies. Moreover, Anton's Law requires the development of an anthropomorphic test device simulating a 10-year-old child and an evaluation of integrated child restraint systems.

A specific study using the newly formed data set, might include the examination of general injury distributions for children in Child Restraint Systems (CRS) in frontal and side crashes in an effort to examine the body regions most apt to be injured.

IV. For Face/Neck/Scalp Injuries, preliminary analysis of the CDS Injury Distribution Dataset has shown a prevalence of face/neck/scalp injuries. These injuries can be studied in more detail under each of the crash modes described above to gain a better insight into their specific attributes and the circumstances under which they occur.

V. For Characterization of Brain Injuries, Table 1 shows that brain injuries have the highest total attributable costs. A general interrogation of the dataset reveals that brain injuries in real-world car crashes may be placed into three broad categories: those manifested by rotation only (such as diffuse axonal injuries), those manifested by translation only (such as skull fractures), and those manifested by either rotation or translation. The proposed metric relies on CDS reporting of general injury patterns and their related costs, Zaloshnja (2004), that will stimulates the ATD designer to focus on a body region of significance. This focus will allow the designer to start developing theories on mechanisms of injury within a particular body region.

In FMVSS standards, the risk of head injury is judged by the HIC metric, which is a function of the resultant linear acceleration at the center of gravity of a dummy headform. The HIC metric has roots as a correlate to skull fractures in drop tests performed on cadavers. Over the years, researchers at NHTSA and other institutions have contemplated the use of some other metric – such as angular acceleration – to be used along with or in lieu of HIC to assess head injury probability in a crash test.

A specific study might result pursuant to categorizing each code into one of the three categories, NASS-CDS data may be interrogated to gain insights into the various types of head injuries. Such results may help clarify the applicability of HIC and the need for a rotation-based anthropomorphic dummy metric to gauge head injury potential in crash tests.

The five topic areas are proposed applications of the baseline data set. No commitment has been made to undertake any of these studies nor have all other possible applications been discarded from consideration. For illustrative purposes, near side abdominal injuries were chosen as the applied example.

Applied Example

Restrained adult occupants, age 12 years and older seated near side of the left or right side impact, sustaining abdominal organ injury, have been chosen for a closer look. As part of the international harmonization, the Agency has studied this body region (March, 1999), however, the data was not analyzed using these techniques. Injuries to the liver, spleen, kidney, as well as insult to the gastrointestinal and genitourinary regions have been included to describe the aggregated abdominal region.

When considering abdominal injuries as a subset of all MAIS 2 through 6 injuries, approximately two percent of all attributable costs and three percent of the attributable fatalities may be assigned to this rubric. Of the nearly 31,000 front-seated, restrained, near side crash occupants (weighted from 307 sampled occupants,) 9 percent of all near side occupants sustained abdominal injuries, 2 percent of which were the maximum injury for the case. The abdominal injuries ranked tenth among the 17 injury groupings, with regard to total incidence. Among the estimates provided by CDS, only front seat occupants were involved in this crash scenario. For this reason, the 307 near side crashes describe the experience of front seat occupants. The near side crash occupants traveling in the rear seating positions only added 13 more occupants sustaining injuries other than abdominal.

When considering all abdominal injuries, regardless of whether it was the most severe injury to the occupant, the data set consisted of 66 occupants, estimating nearly 24,000 occupants, with injuries to the abdominal region. If this group was further reduced to include those cases in which the abdominal injury was the most severe, this group decreased to 11 cases, representing 548 weighted occupants. For purposes of analysis, any instance of abdominal injury was accepted regardless of the mortality ranking within the case. Abdominal injuries found among front-seated, nearside crash occupants, were found to have an attributable cost of approximately $138 million, per Figure 2. When considering the cases where at least one abdominal injury was present, the attributable costs of all injuries present, in concert with the abdominal injury, exceeded $1.5 billion. This cost included the presence of up to 15 maximum injuries, of which at least one was abdominal. These represented nearly 7,000, occupants, on average 1,000 per year, tow away crash occupants, traveling in vehicles of model 1998 or later, involved in nearside crashes since 1997. It should be noted, however, that the incidence of abdominal organ injuries did not indicate their overall severity for the occupant, per Figure 5. Brain and rib/sternum injuries continued to represent the highest incidence of maximum severity injuries. Cumulative case costs, where the occupant sustained at least one abdominal injury, approached $5 billion, of which abdominal injuries contributed 12 percent of these costs. This contrasted with the attributable costs, which assumed the elimination of the most severe injury, as in the case of a countermeasure introduction. When focusing the study to near side abdominal injuries in Table 3, as one of the top 15 mortality injuries, the brain continued to lead costs, however, the lower leg disappeared from considerations, as compared to all MAIS 2+ injuries in Table 2. The injury ranking, based upon attributable costs changed completely upon including occupants with abdominal injury sustained in a near side crash, as seen in Tables 2 and 3. Countermeasure introduction might account for this.

Currently, the working file consists of all crashes conforming to the parameters described earlier in paper. This data set has been disaggregated into the various crash modes for future study. The file will also be dependent upon the increasing accuracy of the mortality rates used to calculate survivability.

Table 3.
Body Regions with Cumulative Injury Costs for Occupants with Near Side Abdominal Injury

ID	Body Part	Cost, $M
1	Skull	118
2	Brain/intracranial	2,763
3	Ear, eye, internal neck organs	0
4	Nose, mouth, face, scalp, neck	0
5	Cervical spinal cord	278
6	Upper Extremity	119
7	Thorax	280
8	Ribs/sternum	0
9	Back (including vertebrae)	72
10	Trunk (other abdomen, thorax)	71
11	Trunk Spinal Cord	153
12	Abdominal Organs	568
13	Hip, Thigh, Pelvis	192
14	Knee	0
15	Lower Leg	0
16	Burns, unspecific body part	0
17	Whole body-minor external	0

Source: NASS CDS, 1997 – 2003, and Zaloshnja, 2004

Baseline Comparison

From the complete database, costs were most frequently associated with brain and intracranial injuries. These approach a composite cost of $68 billion. The lower leg injuries, the second most costly, accounted for nearly $12 billion, per Figure 3. Thoracic injuries over took the brain, with regard to fatality. Approximately 5,800 thoracic injuries were reported, as compared to approximately 5,600 brain injuries attributable to fatally injured occupants. The ribs and sternum, although less costly in monetary terms, were found to account for nearly 5,100 fatalities.

The frontal crash outcome was deemed the first priority, owing to its prevalence amongst all crashes, pursuant to disaggregation of the crash modes. The disaggregation was warranted since dummy development has been dictated by crash mode. This has been especially true in the instrumentation of the frontal versus side impact crash dummy. Further, only moderate through maximum injuries, AIS 2 through 6, for restrained occupants were considered in these findings.

It was found that lower limb injures occurred most frequently. When studying the highest severity

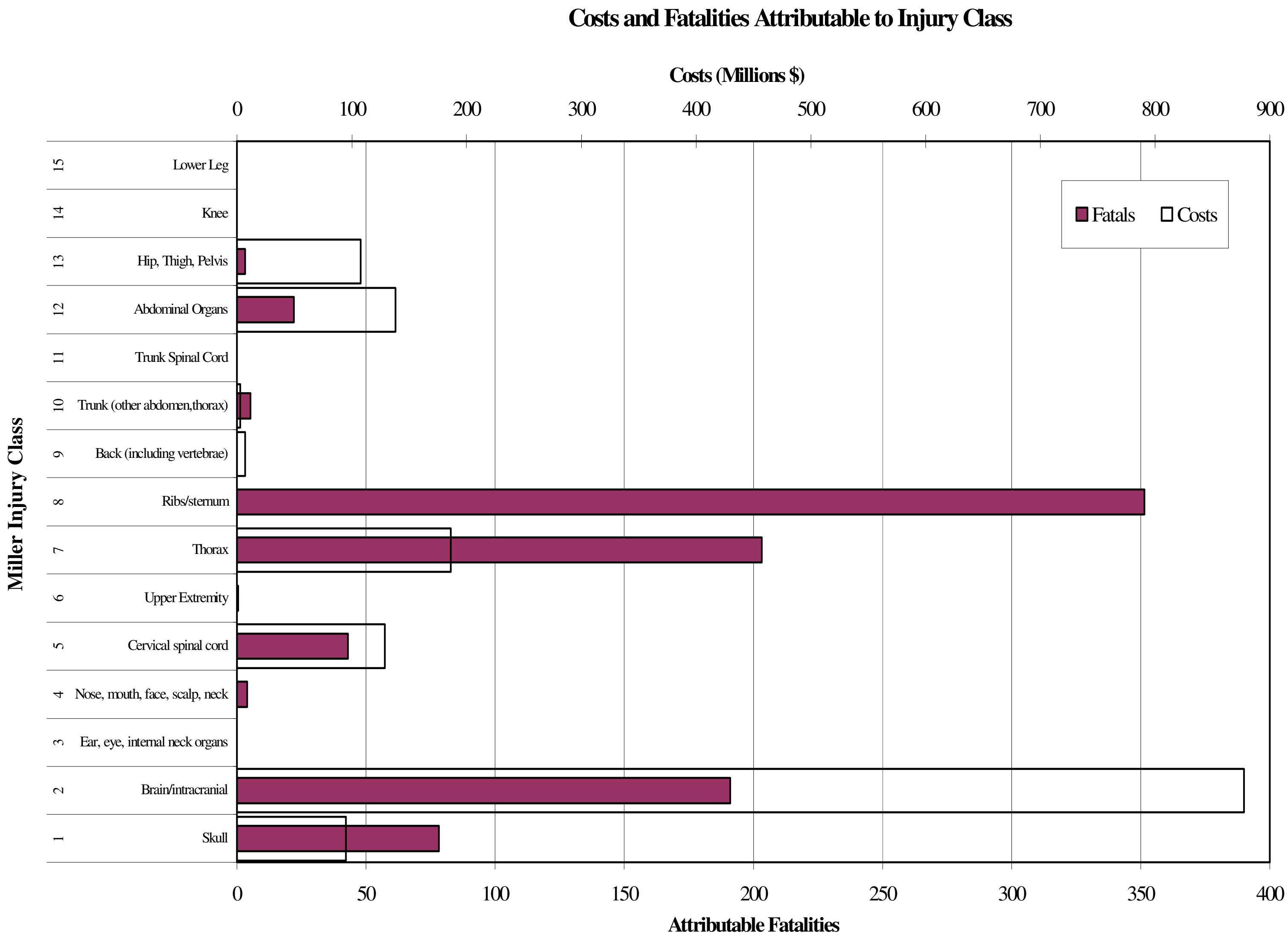

Figure 2.

Cumulative Costs and Weighted Fatalities Attributable to Injured Body Regions for Belted Front Seat Passenger Vehicle Occupant with at least one MAIS 2+ Abdominal Injuries Pursuant to a Tow Away Near Side Crash

Source: National Center for Statistics and Analysis, NASS CDS, 1997 – 2003, Model Year 1998 onward

injury per occupant, lower limb injuries continued with prevalence. When considering case costs, however, brain injuries were the most costly, followed by lower leg injuries. Costs per case were attributed to a single injury (the one having the highest associated cost per case according to Zaloshnja, 2003.) When considering costs attributable to each injury, lower leg injuries were the most costly, followed by brain injuries. These were referred to as attributable cost. Injuries to the ribs and thorax, in general, were associated with the most fatalities. These attributable fatals were described as the number of fatalities attributable to each injury.

DISCUSSION

The preceding sections provided a framework for the dummy development predicated on data analysis. Many priorities exist in the development of biofidelic dummies to replicate real world injury outcomes induced in laboratory vehicle crash testing. Within this context, a better understanding might be gained in the search for injury metrics.

It should be noted, that although brain injuries are of maximum frequency, the other injury categories should not be ignored. This argument was based upon frequency, as well as maximum injury severity. Most injured occupants sustained more than one injury. Further, these injury costs were not meant to be summed to obtain a case cost. Each injury may increase severity, however, the injury costs were devised on a per injury basis. The development of attributable and overall case costs was required to accurately assess the cost of injuries to an occupant. This composite approach allowed for a ranking of priorities with regard to frequency, as well as societal cost of injuries.

The baseline example provided a data set from which to examine injury mitigation opportunities. Among these cases, the illustrative example was found to rank fifth among total near side incidence, when considering only cases in which at least one abdominal injury occurred. Among the injuries of maximum severity for near side crashes, abdominal injuries ranked tenth out of seventeen injury types.

The selection of the abdominal injuries sustained by near side crash occupants was meant as an illustrative example of the data base contents and use. It is the intention to examine the remaining topics and report these in subsequent publications.

A framework of data analysis has shaped dummy development by focusing on the real world crash data. The use of such data allowed for identification of injury mechanisms present in the different crash modes. To this point, NHTSA has used three issues to guide this study. These have been: the type of injuries to prevent, dummy measurements needed to ascertain the presence of these injuries, and calculation of lives to be saved under a given countermeasure regime.

What types of injuries should NHTSA strive to prevent? This issue has been very much a question of policy tempered by the needs of the safety community at large. Within the confines of this project, however, the data base queries have been meant to ascertain injury frequencies. From these frequently occurring injuries, a ranking by means of a universally accepted metric had to be made. The mortality rates have been shown, in previous publications (Martin, 2003) to have merit and provide the basis for calculation of survivability. This disaggregation of the two most severe injuries allowed for accurate occupant injury costs to be calculated. Upon completion of the data analysis initiative, a ranking of the top ten injuries of concern will be available.

What measurements are required of a crash dummy to ascertain whether such injuries are sustainable in a crash test? Based upon the findings of the data analysis, experts in biomechanics will be able to draw conclusions regarding injury prevalence, costing, and countermeasure development. These can be examined within the framework of benefit cost models. Further, the current capabilities of the dummies must be outlined and matched to the emerging needs found from the real world analysis. These findings will be published for use by dummy manufacturers, regulators, and test designers.

Upon providing a listing of the top ten injuries by crash mode, crash mechanisms may be isolated. From this point, the crash kinematics may be recreated. It would then be incumbent upon manufacturers to refine instrumentation to collect data relevant to the injuries in question.

How many lives are likely to be saved under a given performance requirement to prevent such injuries? Based upon the refinements to the mortality iterations, the survivability rate (Martin, 2003) also allows for countermeasure valuation within the framework of injury severity and costing. This topic will continue to be developed during the preparation of this data analysis initiative. This method is not currently used in NHTSA rulemaking.

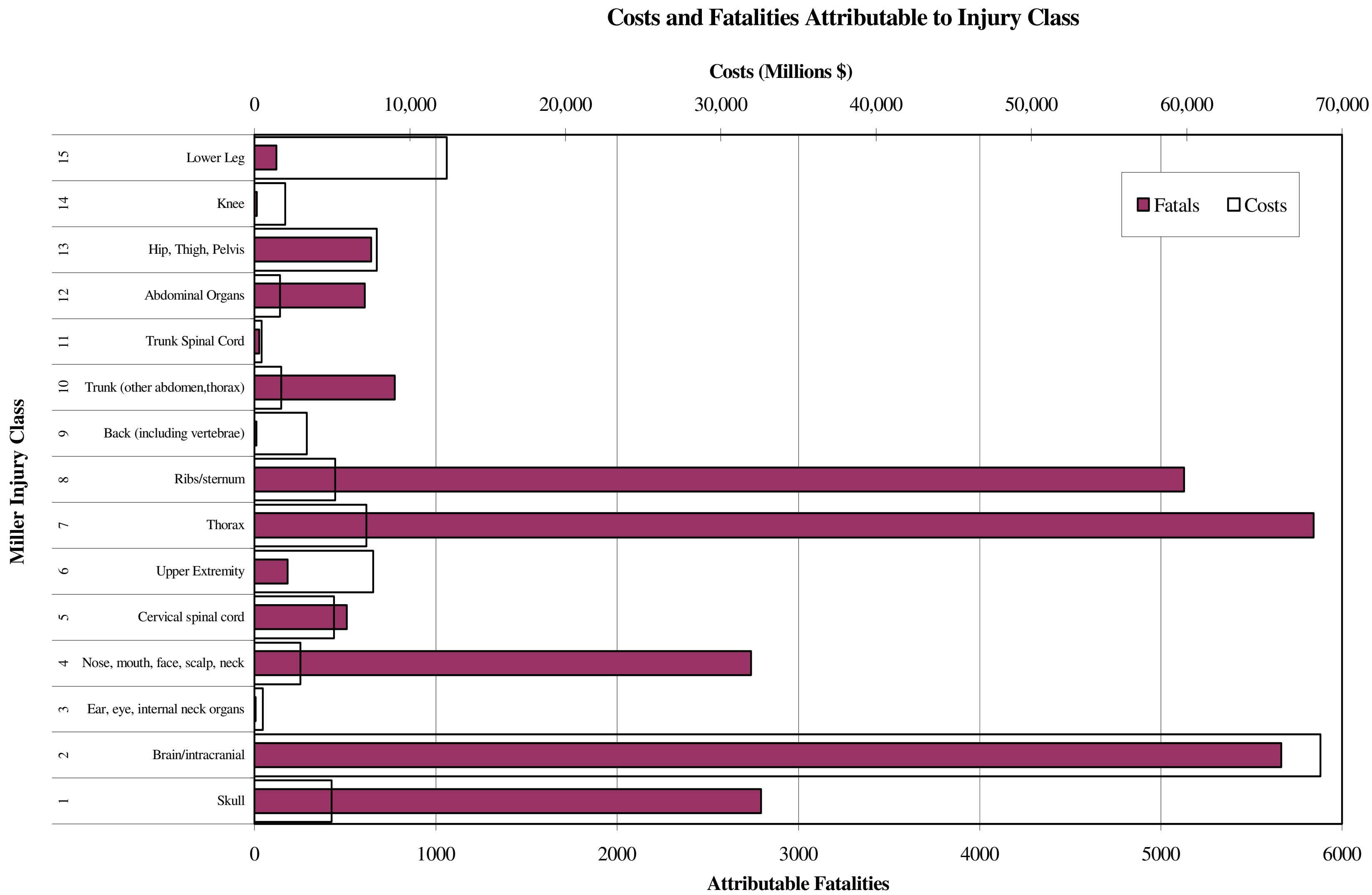

Figure 3.

Cumulative Costs and Weighted Fatalities Attributable to Injured Body Regions Passenger Vehicle Occupant MAIS 2+ Injuries Pursuant to a Tow Away Crash

Source: National Center for Statistics and Analysis, NASS CDS, 1997 – 2003, Model Year 1998 onward

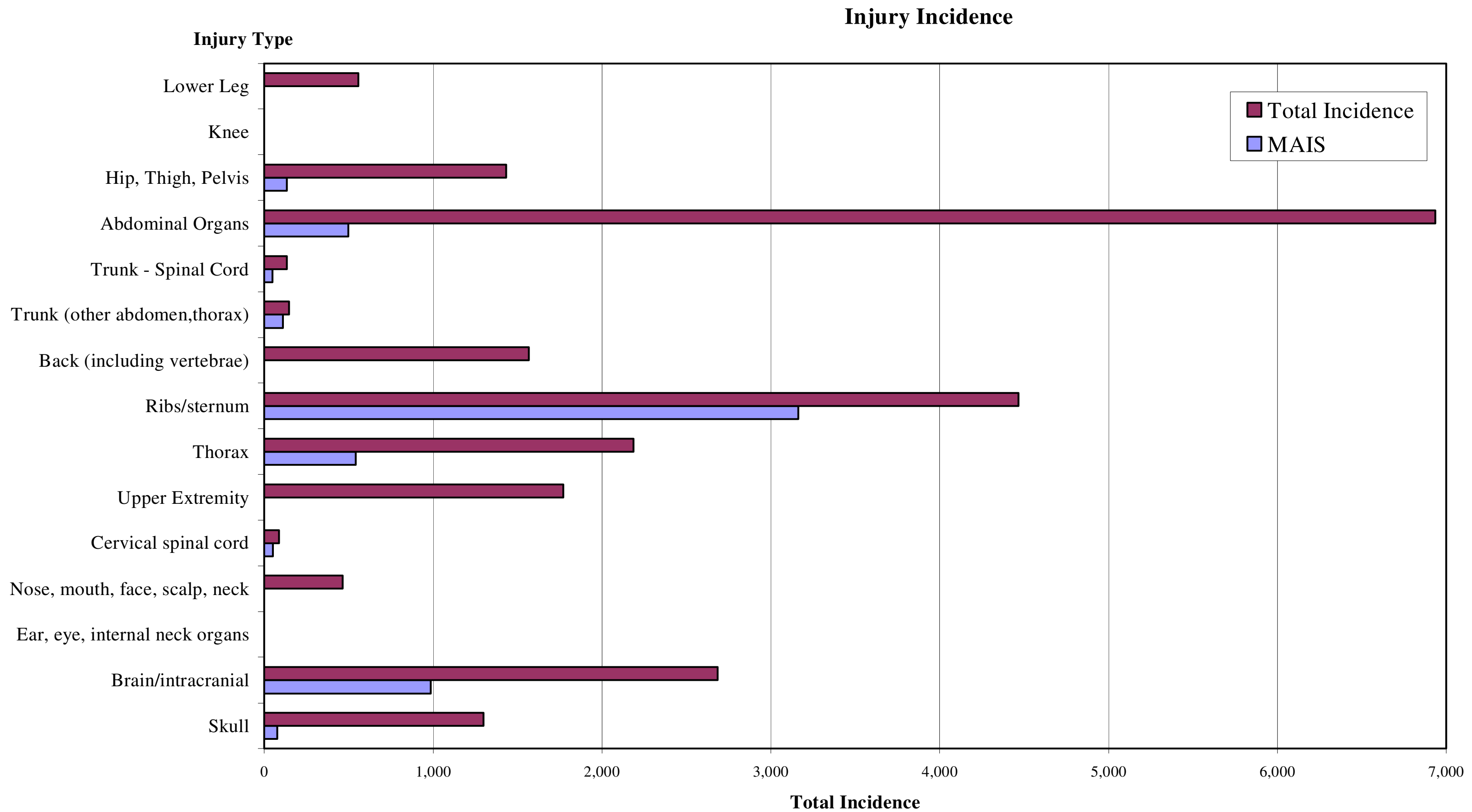

Figure 4.

Cumulative Weighted Incidence and Maximum Injury Severity by Injured Body Regions for Belted Front Seat Passenger Vehicle Occupant with at least one MAIS 2+ Abdominal Injuries Pursuant to a Tow Away Near Side Crash

Source: National Center for Statistics and Analysis, NASS CDS, 1997 – 2003, Model Year 1998 onward

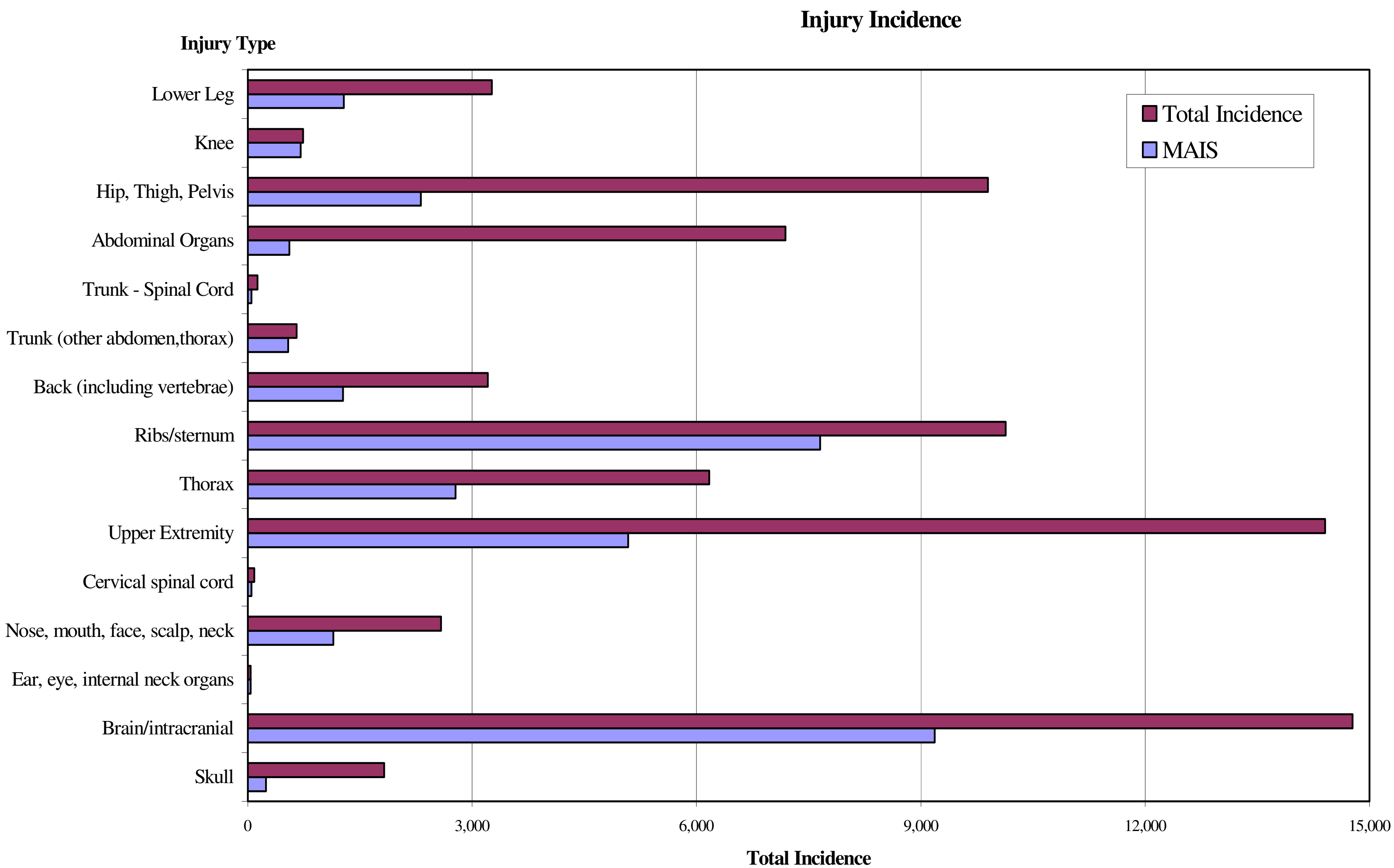

Figure 5.

Cumulative Total Weighted Incidence and Maximum Injury Severity by Injured Body Regions for Belted Front Seat Passenger Vehicle Occupant MAIS 2+ Injuries Pursuant to a Tow Away Near Side Crash

Source: National Center for Statistics and Analysis, NASS CDS, 1997 – 2003, Model Year 1998 onward

SUMMARY

The dummy development of NHTSA is on going. This publication is meant to provide an update of the data analysis activity. This component is one of several activities occurring simultaneously and supporting the overall biomechanics effort within the Agency. The data analysis results have been presented on a regular basis. Subsequent results may be reported on an intermittent basis in the form of future research notes, technical reports, or conference papers.

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Appendix A: Attributable Fatality Calculation

Step 1. Examine the injury record of each case. Associated with each injury is a mortality rate, which was determined in the Martin (2003b). An overall fatality probability is computed from mortality rates as describe in the Martin (2003b). The product of the probability and the case weight is an estimate of the number of fatalities that occurred in the U.S. for occupants having those types of injuries. **Step 2.** Consider a particular type of injury -- say, e.g. injuries. Examine the injury record again, only this time *REMOVE* from the injury record all brain injuries. From the remaining list of injuries, compute a new estimate of the number of fatalities. **Step 3.** [Fatalities computed in Step 1] - [Fatalities computed in Step 2] = Fatalities attributable to brain injuries in the U.S. for all like-mannered cases.

Total fatals attributable is found by performing this **3-step** operation for every case, and summing the differences from Step 3. This sum is an estimate of the lives saved if all brain injuries could be eliminated.

Appendix B: Attributable Cost Calculation

Step 1. Examine the injury record of each case. Associated with each injury is a cost, which was determined in the Zaloshnja (2004). An overall case cost is taken as the cost corresponding to the most expensive injury. (This may or may not be the same as the MAIS injury or the injury having the highest mortality rate). **Step 2.** Consider a particular type of injury – e.g., brain injuries. Examine the injury record again, only this time *REMOVE* from the injury record all brain injuries. From the remaining list of injuries, find the case cost as in Step 1. **Step 3.** ([Cost computed in Step 1] - [Cost computed in Step 2]) x NASS CDS Case Weighting Factor = Costs attributable to brain injuries in the U.S. for all like-mannered cases.

Total costs attributable is found by performing this **3-step** operation for every case, and summing the differences from Step 3. This sum is an estimate of the costs saved if all brain injuries could be eliminated.