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Problem Definition for Pre-Crash Sensing Advanced Restraints

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13. ABSTRACT (Maximum 200 words)

This report presents the results of crash analyses that defined and prioritized target crashes for advanced restraint systems based on pre-crash sensors. These analyses targeted the driver and front-seat passenger 13 or older, traveling in light vehicles of model year 1998 or newer that sustained frontal damage. The focus was on occupants who suffered an injury level 3 or higher on the Maximum Abbreviated Injury Scale. Crash analyses included data queries of national crash databases from the 1997-2006 Crashworthiness Data System (CDS), 2006 General Estimates System, and 2002-2006 Fatality Analysis Reporting System. Data queries were part of the top-down analysis that identified key crash scenarios and concomitant injuries. Crash scenarios incorporated pre-crash scenarios, impact modes, and occupant restraint use. Severity of priority crash scenarios was quantified in terms of the number of fatalities and functional years lost. Moreover, injured body regions and related injury levels were expressed for each crash scenario. Based on results of top-down analysis, cases were selected from the CDS for further examination to identify the injury sources and their link to crash scenarios and severities. Only belted occupants were considered. The steering wheel had the highest contribution rate to injury in chest, head, and upper extremity body regions. Injury to the abdomen was caused predominantly by the seat belt. The instrument panel caused the highest rate of injury to the lower extremity.

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METRIC/ENGLISH CONVERSION FACTORS

ENGLISH TO METRIC

LENGTH (APPROXIMATE)

1 inch (in)	=	2.5 centimeters (cm)
1 foot (ft)	=	30 centimeters (cm)
1 yard (yd)	=	0.9 meter (m)
1 mile (mi)	=	1.6 kilometers (km)

AREA (APPROXIMATE)

1 square inch (sq in, in^2)	=	6.5 square centimeters (cm^2)
1 square foot (sq ft, ft^2)	=	0.09 square meter (m^2)
1 square yard (sq yd, yd^2)	=	0.8 square meter (m^2)
1 square mile (sq mi, mi^2)	=	2.6 square kilometers (km^2)
1 acre = 0.4 hectare (he)	=	4,000 square meters (m^2)

MASS - WEIGHT (APPROXIMATE)

1 ounce (oz)	=	28 grams (gm)
1 pound (lb)	=	0.45 kilogram (kg)
1 short ton = 2,000 pounds (lb)	=	0.9 tonne (t)

VOLUME (APPROXIMATE)

1 teaspoon (tsp)	=	5 milliliters (ml)
1 tablespoon (tbsp)	=	15 milliliters (ml)
1 fluid ounce (fl oz)	=	30 milliliters (ml)
1 cup (c)	=	0.24 liter (l)
1 pint (pt)	=	0.47 liter (l)
1 quart (qt)	=	0.96 liter (l)
1 gallon (gal)	=	3.8 liters (l)
1 cubic foot (cu ft, ft^3)	=	0.03 cubic meter (m^3)
1 cubic yard (cu yd, yd^3)	=	0.76 cubic meter (m^3)

TEMPERATURE (EXACT)

[(x-32)(5/9)] °F	=	y °C

METRIC TO ENGLISH

LENGTH (APPROXIMATE)

1 millimeter (mm)	=	0.04 inch (in)
1 centimeter (cm)	=	0.4 inch (in)
1 meter (m)	=	3.3 feet (ft)
1 meter (m)	=	1.1 yards (yd)
1 kilometer (km)	=	0.6 mile (mi)

AREA (APPROXIMATE)

1 square centimeter (cm^2)	=	0.16 square inch (sq in, in^2)
1 square meter (m^2)	=	1.2 square yards (sq yd, yd^2)
1 square kilometer (km^2)	=	0.4 square mile (sq mi, mi^2)
10,000 square meters (m^2)	=	1 hectare (ha) = 2.5 acres

MASS - WEIGHT (APPROXIMATE)

1 gram (gm)	=	0.036 ounce (oz)
1 kilogram (kg)	=	2.2 pounds (lb)
1 tonne (t)	=	1,000 kilograms (kg)
	=	1.1 short tons

VOLUME (APPROXIMATE)

1 milliliter (ml)	=	0.03 fluid ounce (fl oz)
1 liter (l)	=	2.1 pints (pt)
1 liter (l)	=	1.06 quarts (qt)
1 liter (l)	=	0.26 gallon (gal)
1 cubic meter (m^3)	=	36 cubic feet (cu ft, ft^3)
1 cubic meter (m^3)	=	1.3 cubic yards (cu yd, yd^3)

TEMPERATURE (EXACT)

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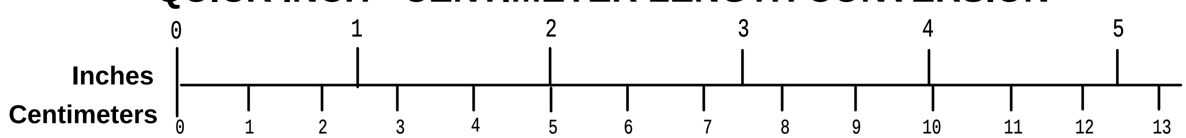

QUICK FAHRENHEIT - CELSIUS TEMPERATURE CONVERSION

°F	-40°	-22°	-4°	14°	32°	50°	68°	86°	104°	122°	140°	158°	176°	194°	212°
°C	-40°	-30°	-20°	-10°	0°	10°	20°	30°	40°	50°	60°	70°	80°	90°	100°

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PREFACE

The Volpe National Transportation Systems Center (Volpe Center) of the United States Department of Transportation's Research and Innovative Technology Administration is supporting a cooperative research program between the National Highway Traffic Safety Administration and the automotive industry in pre-crash sensing applications. This research program addresses pre-crash sensing countermeasures that are aimed at reducing injuries once the crash is deemed unavoidable. Two concurrent projects dealing with crash-imminent braking (CIB) and advanced restraint systems (ARS) based on pre-crash sensing are targeted. This program will produce a preliminary set of minimum performance specifications, objective test and evaluation procedures, and preliminary estimates of CIB/ARS safety benefits. These products are essential to determine if this CIB/ARS technology warrants further research and development.

This report presents the results of the crash problem definition for ARS applications. Results were derived from data queries and individual case examinations from the 1997-2006 Crashworthiness Data System (CDS), 2006 General Estimates System (GES), and 2002-2006 Fatality Analysis Reporting System (FARS) crash databases.

The authors acknowledge the technical contributions by David Smith, retired, Yannett Gaspare, James Saunders, and Steve Summers of NHTSA; John D. Smith, Samuel Toma, and Chris Spring of the Volpe Center; and James Chang, James Foley, and Richard Glassco of Noblis. Also acknowledged are the technical contributions by the automotive partners from General Motors, Ford, and Mercedes. Special thanks are extended to NHTSA case reviewers Matthew Craig, Harold Herrera, Kristin Kingsley, Rodney Rudd, James Saunders, and David Sutula.

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LIST OF ACRONYMS

ARS	Advanced Restraints System
CCW	Counter-Clockwise
CDS	Crashworthiness Data System
CW	Clockwise
FARS	Fatality Analysis Reporting System
FD	Front Damage vehicle
FSP13$^+$	Front Seat Passenger 13 years of age or older
FYL	Functional Years Lost
GES	General Estimates System
LTAP/OD	Left Turn Across Path from Opposite Direction
LVD	Lead Vehicle Decelerating
LVM	Lead Vehicle Moving at slower constant speed
LVS	Lead Vehicle Stopped
MAIS	Maximum Abbreviated Injury Scale
MAIS2$^-$	MAIS 2 or lower
MAIS3$^+$	MAIS 3 or higher
MI	Multiple-Impact crash
MY98$^+$	Model Year 1998 or higher
NASS	National Automotive Sampling System
NHTSA	National Highway Traffic Safety Administration
RO	Restrained Occupant
SI	Single-Impact crash
UO	Unrestrained Occupant
VO	Vehicle-Object crash
VV	Vehicle-Vehicle crash

EXECUTIVE SUMMARY

This report addresses research in advanced restraint systems to mitigate disabling injuries and reduce fatalities of front seat occupants. This research is conducted as part of a cooperative program between the National Highway Traffic Safety Administration and the automotive industry to improve the effectiveness of current restraint systems by adapting them to the crash scenario and specific occupant using forward-looking pre-crash sensors and advanced occupant sensors. The automotive industry partners include Ford, General Motors, and Mercedes-Benz. Crash data analyses are performed by NHTSA using national crash data to identify intervention opportunities for potential crash countermeasures. Results of these analyses will then drive the automotive industry partners to develop countermeasure functional requirements, performance specifications, and objective test procedures. Benefit/cost estimation will be later conducted by NHTSA to estimate the cost and national safety benefits that could be accrued from a full deployment of pre-crash sensing advanced restraints. This report presents the results of the crash analysis in support of ARS prototype development and testing. Based on these crash analysis results, preliminary functional requirements were developed and documented in a companion report by the automotive partners.

Crash analyses were performed to identify and prioritize crash scenarios and occupant injuries that could be amenable to ARS applications. These analyses targeted the driver and front-seat passenger 13 years old or older ($FSP13^+$), traveling in light vehicles of model year 1998 or newer ($MY98^+$) that sustained frontal damage. The focus was on occupants who suffered an injury level 3 or higher on the Maximum Abbreviated Injury Scale ($MAIS3^+$).

Initial crash analyses were performed on the 1997-2005 Crashworthiness Data System databases to correlate injured body regions and their concomitant injury severity levels to high-level crash scenarios. Injury data was reported based on the most harmful event in multi-impact crashes. High-level scenarios represented combinations of obstacle type struck, number of impacts, occupant type, and occupant restraint use. About 56 percent of all $MY98^+$ light vehicles suffered frontal damage from the most harmful event based on CDS statistics. About 90 percent of drivers and 86 percent of $FSP13^+$ occupants in target vehicles were belted. Drivers had the highest $MAIS3^+$ risk (12%) when unbelted in multi-impact crashes and the lowest (1%) when belted in vehicle-vehicle crashes. $FSP13^+$ occupants had the highest $MAIS3^+$ risk (11%) when unbelted in multi-impact vehicle-object crashes and the lowest (1%) when belted in single-impact vehicle-vehicle crashes. Lower extremity, chest, upper extremity, and head accounted respectively for 33 percent, 27 percent, 18 percent, and 12 percent of all $MAIS3^+$ injuries by belted drivers and $FSP13^+$ occupants.

Additional data queries were performed using the 2002-2006 Fatality Analysis Reporting System, 2006 General Estimates System, and 1997-2006 CDS databases to prioritize pre-crash scenarios and impact modes based on the number of fatalities and functional years lost. The focus was on vehicles with frontal damage from the first harmful event.

Results of vehicle-object crashes revealed dominant crash scenarios that involved vehicles in road departure and control loss pre-crash scenarios striking ground, structure, tree, or pole. Results of vehicle-vehicle crashes identified opposite direction, rear-end, turning at junction, straight crossing paths, and left turn across path from opposite direction pre-crash scenarios with the front of the target vehicle striking the front, left side, right side, or back of another vehicle.

CDS cases were then selected from priority crash scenarios and examined individually by different reviewers. This examination linked occupant injuries to injury sources and crash scenarios. Only belted occupants were considered. Single- and multi-vehicle crash scenarios accounted respectively for 61 percent and 39 percent of all $MAIS3^+$ injuries to occupants. Chest was the highest injured body region at 36 percent of all $MAIS3^+$ injuries, followed by lower and upper extremities at 48 percent. The steering wheel had the highest contribution rate to injury in chest, head, and upper extremity body regions. Injury to the abdomen was caused predominantly by the seat belt at a high rate of 83 percent. The instrument panel caused the highest rate of injury to the lower extremity at 40 percent.

Results from these crash analyses were used by the automotive partners and their supplier contacts to devise potential countermeasure concepts based on pre-crash sensing ARS and to develop preliminary functional requirements. Development of objective test procedures and estimation of safety benefits constitute next research steps.

1. INTRODUCTION

Advanced technologies have recently become more capable and less expensive to enable the development of various automotive crash countermeasure systems. The performance of passive safety systems has been improved to bolster vehicle crashworthiness, including enhanced air bags with occupant sensing and seat belts with pretensioners and load limiters. New active safety systems have been fielded to mitigate crash severity and aid drivers in crash prevention.[1] Such systems encompass enhanced brake assist, stability control, adaptive cruise control, driver advisory systems such as blind spot monitors, and driver warning systems such as rear-end crash warning and lane departure warning. In addition, crash notification systems using cellular phone technology have been deployed to help emergency responders save crash victims.

Vehicle safety technologies incorporate crash countermeasures that address all aspects of the crash sequence.[2] Crash prevention constitutes the first set of countermeasures that assist the driver to better control the vehicle such as stability control systems, and to warn the driver of an impending crash such as rear-end crash warning and lane departure warning systems. Crash severity reduction represents the second set of countermeasures that act to mitigate the impact severity of crashes deemed unavoidable by pre-crash sensing such as the use of enhanced brake assist and crash-imminent automatic braking systems. Occupant injury mitigation forms the third set of countermeasures that alleviate potential severe injuries of an imminent impact by preparing crashworthiness systems using pre-crash sensing such as next-generation air bags and advanced seat belts. Post crash is also part of total vehicle safety in which appropriate emergency assistance is automatically summoned to provide medical attention.

This report addresses research in advanced restraint systems to mitigate disabling injuries and reduce fatalities of front seat occupants. The focus is on occupant protection from frontal impacts because the ARS will be enabled by forward-looking sensors that detect crash threats ahead of the host vehicle. This research is conducted as part of a cooperative program between the National Highway Traffic Safety Administration and the automotive industry to improve the effectiveness of current restraint systems by adapting them to the crash scenario and specific occupant using forward-looking pre-crash sensors and advanced occupant sensors.[3] The automotive industry partners include Ford, General Motors, and Mercedes-Benz. The execution of this program follows a system engineering approach as illustrated in Figure 1. Crash data analyses are performed by NHTSA using national crash data to identify intervention opportunities for potential crash countermeasures. Results of these analyses will then drive the automotive industry partners to develop countermeasure functional requirements, performance specifications, and objective test procedures. Benefit/cost estimation will be later conducted by NHTSA to estimate the cost and national safety benefits that could be accrued from a full deployment of pre-crash sensing advanced restraints. This report presents the results of the crash analysis in support of ARS prototype development and testing. Based on these crash analysis results, preliminary functional requirements were developed and documented in a companion report.[4]

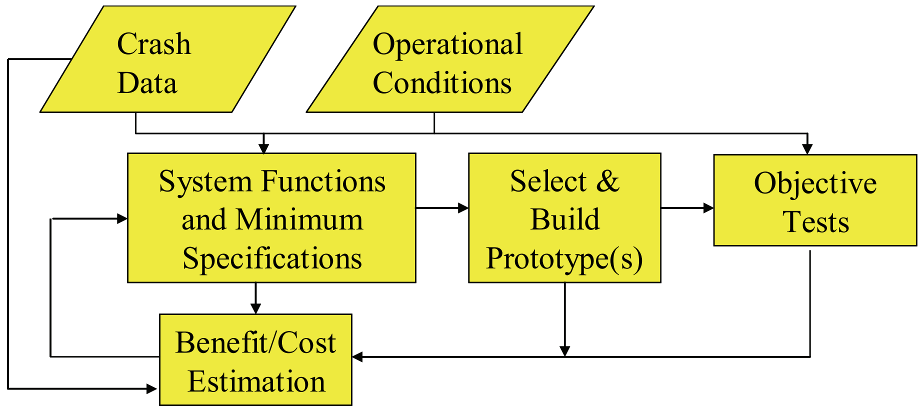


Figure 1. System Engineering Approach to Development of Vehicle Safety Systems

1.1. Pre-Crash Sensing Applications

Quicker crash sensing times and more robust information are required to upgrade motor vehicle safety involving the deployment of occupant protection systems. The main objective of pre-crash sensing applications is to detect a collision earlier than the current accelerometer-based approaches with anticipatory and more descriptive sensors, communicate this information to the vehicle and its occupant protection systems, and take appropriate actions to prevent or reduce the severity of crash injury. This type of active safety measure is aimed at reducing injuries once the crash is deemed unavoidable, as opposed to crash warning systems that help drivers avoid the crash.

Pre-crash sensing countermeasures fall under two categories.[5] The first category encompasses reversible features that are activated just before a potential crash, but usually with the capability of being reset in case the crash does not occur. Examples include air bag pre-arming, non-pyrotechnic seat belt pretensioning, bumper extension or lowering, and brake assist. The second category consists of non-reversible features that are initiated just before a crash, but usually with the drawback of not being re-settable, such as pyrotechnic seat belt pretensioning. System reliability is paramount for pre-crash sensing countermeasures, as is fast decision-making time, given the short time available to deploy such countermeasures. The potential benefits of pre-crash sensing applications span a number of vehicle-to-vehicle and vehicle-to-obstacle crash types.

A pre-crash sensing system is generally composed of sensors, decision-making units, and actuators. Sensors may include remote sensors (e.g., radar), vehicle sensors, occupant sensors, and/or pedestrian sensors. While remote sensors can detect obstacles on the road, vehicle sensors monitor vehicle kinematics and occupant sensors identify the existence and/or motions of vehicle occupants. Pedestrian sensing and discrimination can be applied to improve pedestrian protection. Computers serve as the decision-making units that process the signals received from the sensors and determine if a crash is unavoidable. Once a crash is deemed imminent, the decision-making units quickly determine the countermeasure strategies and send signals for the actuators to preemptively deploy the safety systems. Actuators can be activated automatically or upon receiving a signal from a driver interface such as a pressure pulse on the brake pedal. Production systems of pre-crash sensing applications follow the path toward total vehicle safety by sharing forward-looking sensors for crash prevention applications such as rear-end crash warning and adaptive cruise control.

1.2. Crash Scenarios

Clear definition of complete crash scenarios is required to identify effective intervention opportunities for different crash countermeasure systems based on pre-crash sensing. Figure 2 presents a high-level structure of a crash scenario that consists of three major blocks made up of various crash variables: pre-crash, impact, and injury scenarios. Two minor blocks, attempted avoidance maneuver and pre-impact stability, link the pre-crash scenario to the impact scenario. These two blocks are specifically shown in Figure 2 because of their importance to pre-crash sensing applications. Figure 2 also maps intervention opportunities for crash prevention, crash severity reduction, and occupant injury mitigation against the blocks of the crash scenario structure.

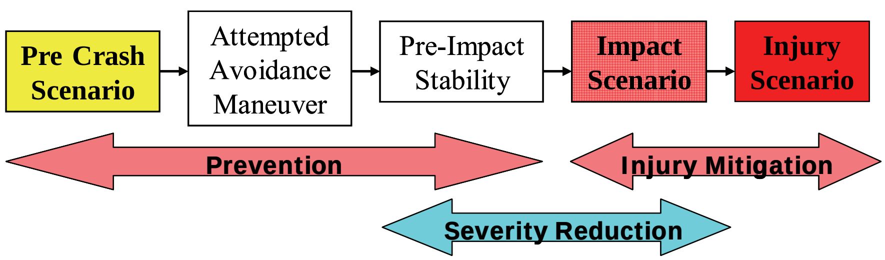


Figure 2. Crash Sequence Breakdown and Intervention Opportunities

Pre-crash scenarios depict vehicle movements and dynamics as well as the critical event occurring immediately prior to a crash. The National Automotive Sampling System /General Estimates System and Crashworthiness Data System crash databases contain pre-crash variables that allow the identification of common pre-crash scenarios from the national crash population. Specifically, three variables from these two databases were primarily used to identify a total of 37 pre-crash scenarios that accounted for all police-reported crashes involving at least one light vehicle: Accident Type, Movement Prior to Critical Event, and Critical Event.[6] Light vehicles encompass passenger cars, sport utility vehicles, minivans, vans, and light pickup trucks with gross vehicle weight rating at 10,000 pounds or less. The Accident Type variable in the GES and CDS databases categorizes the pre-crash situation.[7 8] The Movement Prior to Critical Event variable records the attribute that best describes vehicle activity prior to the driver's realization of an impending critical event or just prior to impact if the driver took no action or had no time to attempt any evasive maneuver. The Critical Event variable identifies the circumstances that made the crash imminent.

The attempted avoidance maneuver and pre-impact stability variables shown in Figure 2 are each made up of a single crash variable. The former variable describes the actions taken by the driver in response to the impending danger. The latter variable assesses the stability of the vehicle during the period immediately prior to the vehicle's initial involvement in the crash sequence.

Impact scenarios involve vehicle-object and vehicle-vehicle impact crash events. Single-vehicle crashes include one vehicle having a single impact or multiple impacts with object(s). Multi-vehicle crashes encompass one vehicle having a single impact with another vehicle in transport or multiple impacts with other vehicles or other vehicle-object combinations. Vehicle-object impact scenarios can be described by frontal offset, direction of force, and type of obstacle struck. On the other hand, vehicle-vehicle impact scenarios can be characterized by manner of collision, frontal offset, direction of force, relative weight, and relative clock direction between the two vehicles. The CDS crash database contains many coded variables that enable the identification of vehicle-object and vehicle-vehicle impact scenarios. Vehicle rotation is also another impact scenario variable; however, it is not readily available from the CDS but can be obtained from crash schematics provided with each CDS case.

Injury scenarios consist of restraints action (seat belts and air bags), occupant kinematics, injury causation, and injury source. Occupant kinematics describe occupant motions during the crash including longitudinal, lateral, vertical, and rotational motions. Injury causation can be attributed to restrained deceleration from the seat belt and air bag deployment or hard contact by the occupant.[9] During the crash, an occupant may hit a vehicle component or a vehicle component may intrude onto the occupant. The CDS crash database contains some variables that describe the injury scenarios; other information can be gleaned from a detailed examination of individual crash cases.[10] Understanding of injury scenarios is more difficult with vehicles suffering multiple impacts since the most harmful event may not be associated with the first impact.

Initial research steps were undertaken to determine the target crash population for advanced restraints by examining combined impact and injury scenarios.[10] This initial research developed and evaluated the problem definition by first determining the most common and the most harmful crashes for belted occupants and then presenting these results in scenarios detailing the sequence of events. A framework for a top-down analysis approach to the problem was developed and preliminary analyses were performed for light vehicles of model year 1998 or higher ($MY98^+$) in 1997 and later CDS data. Analysis of areas of damage and principal direction of force showed that the predominant types of crashes where belted drivers are getting injured are frontal and rollover crashes. Frontal crashes were analyzed in more detail showing four predominant injury areas in rank order: thoracic, head, neck, and abdomen. Head injuries in frontal crashes were examined in more detail to develop a framework for a bottom-up analysis approach, which would later be extended to all crash types. The most common types of head injuries were found to be cerebrum hematoma/hemorrhage, vault skull fracture, and orbit fractures. These injuries were caused by contact with the A-pillar, B-pillar, roof, and steering hub, rim, and wheel combination. This report links the results of the pre-crash scenario study.[6] and this initial research effort,.[10] and expands upon these results for a better definition of the complete crash scenario structure. Even though this report focuses on frontal impacts, ARS would mitigate certain disabling injuries of belted occupants in rollover crashes by reducing their vertical movement. ARS intervention opportunities exist for rollover crashes by using rollover sensor technologies that are widely available for light vehicles.

1.3. Crash Analysis Approach

Two types of analyses were performed to identify and statistically describe crash scenarios that could be amenable to the application of advanced restraints based on pre-crash sensors. These analyses targeted the occupants in MY98$^+$ light vehicles that sustained frontal damage. The model year served as the surrogate for modern restraint systems including three-point lap and shoulder belts, presence of pretensioners, load limiters, the advent of the second generation, de-powered air bags, and more advanced seat belt and air bag technology. This was done to preserve homogeneity in the restraints available within the late model vehicles. The focus was on understanding the injury suffered by the driver and the front-seat passenger 13 or older. The age restriction placed upon the front-seat occupant conforms to NHTSA recommendations for child passengers to ride in the rear seating positions until they are 13 or older.

The first type of analyses consisted of a top-down data query of the CDS to correlate injured body regions and their concomitant injury severity levels to high-level crash scenarios. This type reported injury data based on the most harmful event in multi-impact crashes. High-level scenarios represented combinations of obstacle type struck (vehicle or object), number of impacts (single or multiple), occupant type (driver or FSP13$^+$), and occupant restraint use (belted or not). Results indicated the frequency of occurrence of each injured body region by injury level based on the Maximum Abbreviated Injury Scale (MAIS).

The second type of analyses followed the top-down and bottom-up analysis approaches as illustrated in Figure 3 to better understand the relationships between injuries and crash scenarios at more detailed levels. This type of analyses considered the first harmful event of the crash as opposed to the most harmful event in multi-impact crashes. This was adopted to accommodate the development of functional requirements for forward-looking pre-crash sensors that would augment advanced restraints.

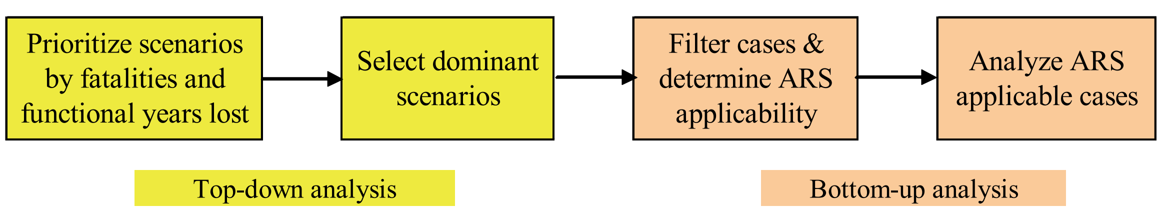


Figure 3. Crash Analysis Approach

The top-down analysis involved data queries of national crash databases to identify and prioritize crash scenarios for further examination in the bottom-up analysis. Crash databases included the Fatality Analysis Reporting System (FARS), GES, and CDS. Crash scenarios were limited to correlations between pre-crash scenarios and the manner of collision such as pole in vehicle-object crashes and front-back in vehicle-vehicle crashes. Severity of crash scenarios was quantified by the number of fatalities from FARS data and the number of functional years lost from MAIS data in the CDS and GES. The FYL measure sums the years of life lost to fatal injury and the years of functional capacity lost to nonfatal injury.[11] This analysis did not distinguish occupants by seat belt use and only counted MAIS levels 3 through 6 by the driver and FSP13^{+}, which correspond respectively to serious, severe, critical, and fatal injuries. A dominant set of scenarios emerged based on scenario ranking in terms of fatality and FYL measures.

The bottom-up analysis encompassed detailed examinations of individual filtered cases to understand why and how the target occupants were at least seriously injured. The top-down analysis identified lists of case numbers from the CDS for the dominant crash scenarios. Researchers then reviewed these cases and assessed their usefulness for the bottom-up analysis. As a result, some cases were excluded from the analysis due to insufficient data, incorrect crash modes, and unique modes not applicable to this study such as A-pillar contact with predominant side impact damage. Also excluded were cases that had losses in passenger compartment integrity. Moreover, this bottom-up analysis focused on belted occupants with air bags deployed since opportunity still exists to alleviate this problem and near-term countermeasures are more likely to be effective with belted occupants than with unbelted occupants. Case reviewers used a special tool developed for this project to ensure uniformity in synthesis of case analyses.[12] Reviewers were asked to consider coded, photographic, graphic, and supplementary unedited data sources resident on the NASS CDS case access viewer.[13] This analysis yielded detailed information on injury scenarios and identified injury sources and injured body regions that might be mitigated or avoided with newer generation restraint systems.

1.4. Report Structure

The introduction of this report is followed by:

- General description of crash severity of vehicles with front damage using 1998-2005 CDS crash databases. Information on injured body regions will be provided for different impact scenarios based on the most harmful event;
- Prioritization of target crashes through top-down analysis using 2002-2006 FARS, 2006 GES, and 1997-2006 CDS crash databases. Information on the number of fatalities and functional years lost will be presented for different pre-crash and impact scenario combinations based on the first harmful event;
- Delineation of ARS applicable crash cases using a selected set of CDS cases via the bottom-up analysis approach; and
- Concluding remarks summarizing key results and elaborating on follow-on research steps.

2. SEVERITY DESCRIPTION OF FRONT-DAMAGE VEHICLES

The 1998-2005 CDS crash databases were queried to statistically describe the occupant injury and crash severity of vehicles that suffered frontal damage from the most harmful impact or event. This analysis focuses on vehicles with frontal damage because ARS will be enabled by forward-looking pre-crash sensors. Target vehicles are light vehicles (e.g., passenger cars, vans or minivans, light pickup trucks, and sport utility vehicles), which belong to MY98^{+} and are towed from the crash scene due to damage. Target occupants include drivers and FSP13^{+}.

The CDS crash database samples approximately 4,500 crashes per year. These crashes are weighted to estimate the tow-away crash population on roadways in the United States. Reporting practices dictate that, where possible, the crash will be disaggregated into discrete units called events. Each event is a distinct occurrence in the crash sequence. Vehicle class, damaged plane, identification of struck vehicle or object, and class of the other vehicle, in the event of a struck vehicle, are reported for each event. These events are ranked in order of crash severity by algorithm output or estimation. Crashes in this analysis were sorted by the number of events. If one event was recorded, the crash was classified as a single-impact crash. In case of two or more events, these crashes were considered multi-impact crashes. Crashes were classified by the most severe event that has been designated in a composite variable as: frontal planar, right side planar, left side planar, back planar, other planar, tripped rollover, untripped rollover, or other crash type. This classification may lose merit for highly complex, multi-event crashes, with events of competing severity. The composite variable was devised using the coded NASS CDS variables and attributes.[10] This analysis focuses on frontal planar crash or simply vehicles with frontal damage. The object contacted associated with the most severe event was also reported. This CDS variable was disaggregated into two subgroups: vehicle contact and object contact. The vehicles, numbered from 1 through 30, struck during the most severe event were reported as vehicle contacts or vehicle-vehicle crashes. Objects contacted, subsuming fixed and non-fixed object contacts, were called vehicle-object crashes.

2.1. General Target Vehicle Statistics

Based on 1998-2005 CDS statistics, there were about 6,237,000 MY98^{+} light vehicles involved in all impact types. Approximately 3,514,000 or 56 percent of all target vehicles suffered frontal damage from the most harmful event. Table 1 lists vehicle statistics, in terms of weighted frequency numbers, by involvement in single-impact or multi-impact crashes and vehicle-object or vehicle-vehicle crashes. The categorization of single- or multi-impact crashes was based on the maximum number of events experienced solely by the target vehicle with frontal damage. The following percentages can be easily derived from Table 1:

- 62 percent of front-damage vehicles had single-impact crashes, compared to 60 percent of all vehicles.

– 73 percent of all front-damage vehicles were involved in vehicle-vehicle crashes, compared to 77 percent of all vehicles.

Table 1. Breakdown of Target Vehicles by Number of Impacts and Crash Type (1997-2005 CDS)

	Single-Impact Crash		Multiple-Impact Crash		Total	
	All Vehicles	FD Vehicles	All Vehicles	FD Vehicles	All Vehicles	FD Vehicles
Vehicle-Vehicle Crash	3,038,000	1,684,000	1,750,000	898,000	4,788,000	2,582,000
Vehicle-Object Crash	675,000	497,000	774,000	435,000	1,449,000	932,000
Total	3,713,000	2,181,000	2,524,000	1,333,000	6,237,000	3,514,000

FD: Front-Damage

Figure 4 illustrates the proportions of front-damage vehicles by the number of impacts and crash type. Front-damage vehicles are more likely to get involved in multiple impacts in vehicle-object crashes than in vehicle-vehicle crashes. About 47 percent of FD vehicles in vehicle-object crashes had multiple impacts as opposed to only 35 percent of FD vehicles in vehicle-vehicle crashes, as seen in Figure 4.

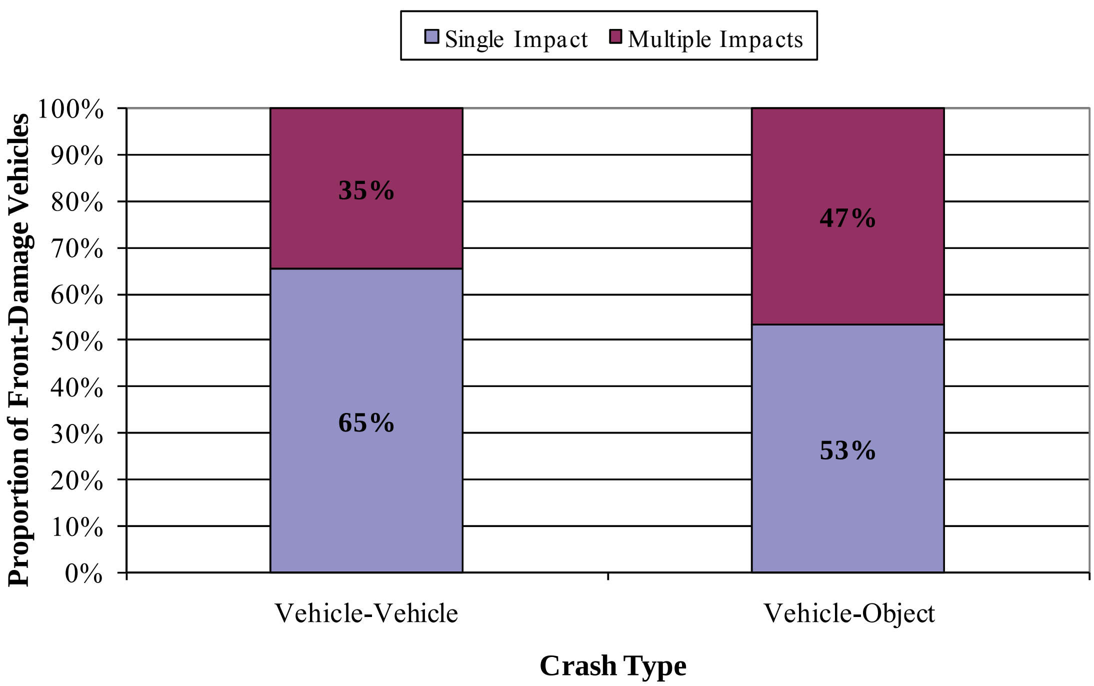


Figure 4. Breakdown of Front-Damage Vehicles by Number of Impacts and Crash Type (1997-2005 CDS)

2.2. General Target Occupant Statistics in Front-Damage Vehicles

Based on 1997-2005 CDS statistics, there were records for 3,472,000 drivers and 769,000 $FSP13^+$ in $MY98^+$ light vehicles with front damage. Front-seat occupants were separated by their restraint use status and by their involvement in single- or multi-impact crashes and in vehicle-object or vehicle-vehicle crashes. Occupants restrained with a lap and shoulder belt were considered restrained. Occupants seated in positions with an inoperable or missing lap and shoulder belt or those occupants who omitted lap and shoulder belt usage were labeled unrestrained. Approximately 3,115,000 or 90 percent of drivers were restrained. On the other hand, about 663,000 or 86 percent of $FSP13^+$ were restrained.

Table 2 shows the statistics of restraint use by drivers in front-damage vehicles, broken down by number of impacts and crash type. The following percentages can be deduced from weighted driver counts in Table 2:

- 90 percent and 88 percent of drivers were restrained respectively in vehicle-vehicle and vehicle-object crashes;
- 91 percent and 88 percent of drivers were restrained respectively in single-impact and multi-impact crashes;
- In vehicle-vehicle crashes, about 91 percent and 89 percent of drivers were restrained respectively in single-impact and multi-impact crashes; and
- In vehicle-object crashes, about 88 percent and 87 percent of drivers were restrained respectively in single-impact and multi-impact crashes.

Table 2. Breakdown of Driver Restraint Use in Front-Damage Vehicles by Number of Impacts and Crash Type (1997-2005 CDS)

	Single-Impact Crash		**Multiple-Impact Crash**		**Total**	
	Restrained	Unrestrained	Restrained	Unrestrained	Restrained	Unrestrained
Vehicle-Vehicle Crash	1,521,000	148,000	790,000	99,000	2,311,000	247,000
Vehicle-Object Crash	435,000	57,000	369,000	54,000	804,000	111,000
Total	1,956,000	205,000	1,159,000	153,000	3,115,000	358,000

Table 3 shows the statistics of restraint use by the $FSP13^+$ population in front-damage vehicles, broken down by number of impacts and crash type. The following percentages can be deduced from weighted $FSP13^+$ counts in Table 3:

- 86 percent and 87 percent of the $FSP13^+$ population were restrained respectively in vehicle-vehicle and vehicle-object crashes;
- 87 percent and 85 percent of the $FSP13^+$ population were restrained respectively in single-impact and multi-impact crashes;
- In vehicle-vehicle crashes, about 87 percent and 84 percent of the $FSP13^+$ population were restrained respectively in single-impact and multi-impact crashes; and

– In vehicle-object crashes, about 89 percent and 85 percent of the $FSP13^+$ population were restrained respectively in single-impact and multi-impact crashes.

Table 3. Breakdown of FSP 13^+ Restraint Use in Front-Damage Vehicles by Number of Impacts and Crash Type (1997-2005 CDS)

	Single-Impact Crash		Multiple-Impact Crash		Total	
	Restrained	Unrestrained	Restrained	Unrestrained	Restrained	Unrestrained
Vehicle-Vehicle Crash	291,000	44,000	171,000	32,000	462,000	76,000
Vehicle-Object Crash	127,000	16,000	74,000	13,000	201,000	29,000
Total	417,000	60,000	246,000	45,000	663,000	105,000

2.3. Injury Level of Target Occupants in Front-Damage Vehicles

Target occupants of the front-damage vehicles were separated by the injury level they suffered in the crash using MAIS. They were allocated to bins of MAIS 3 or higher ($MAIS3^+$), MAIS 2 or lower ($MAIS2^-$), and other. About 67,000 or 1.9 percent of all drivers in front-damage vehicles suffered $MAIS3^+$ injury as compared to 13,000 or 1.7 percent of all the $FSP13^+$ population. Table 4 presents the breakdown of drivers and the $FSP13^+$ population with $MAIS3^+$ injury by eight crash categories that combine number of impacts, restraint use, and crash type. The categories are listed in a descending order in terms of the number of drivers who suffered $MAIS3^+$.

Results in Table 4 indicate that:

– 45 percent of the 67,000 drivers who suffered $MAIS3^+$ were unrestrained. This is very high given that only 10 percent of drivers were not restrained. By comparison, about 30 percent of the 13,000 $FSP13^+$ who suffered $MAIS3^+$ were unrestrained;
– 1.4 percent and 2.8 percent of drivers suffered $MAIS3^+$ in single-impact and multi-impact crashes, respectively. Similarly, about 1.4 percent and 2.4 percent of the $FSP13^+$ population suffered $MAIS3^+$ respectively in single-impact and multi-impact crashes; and
– 1.6 percent and 2.9 percent of drivers suffered $MAIS3^+$ in vehicle-vehicle and vehicle-object crashes, respectively. Similarly, about 1.5 percent and 2.4 percent of the $FSP13^+$ population suffered $MAIS3^+$ respectively in vehicle-vehicle and vehicle-object crashes.

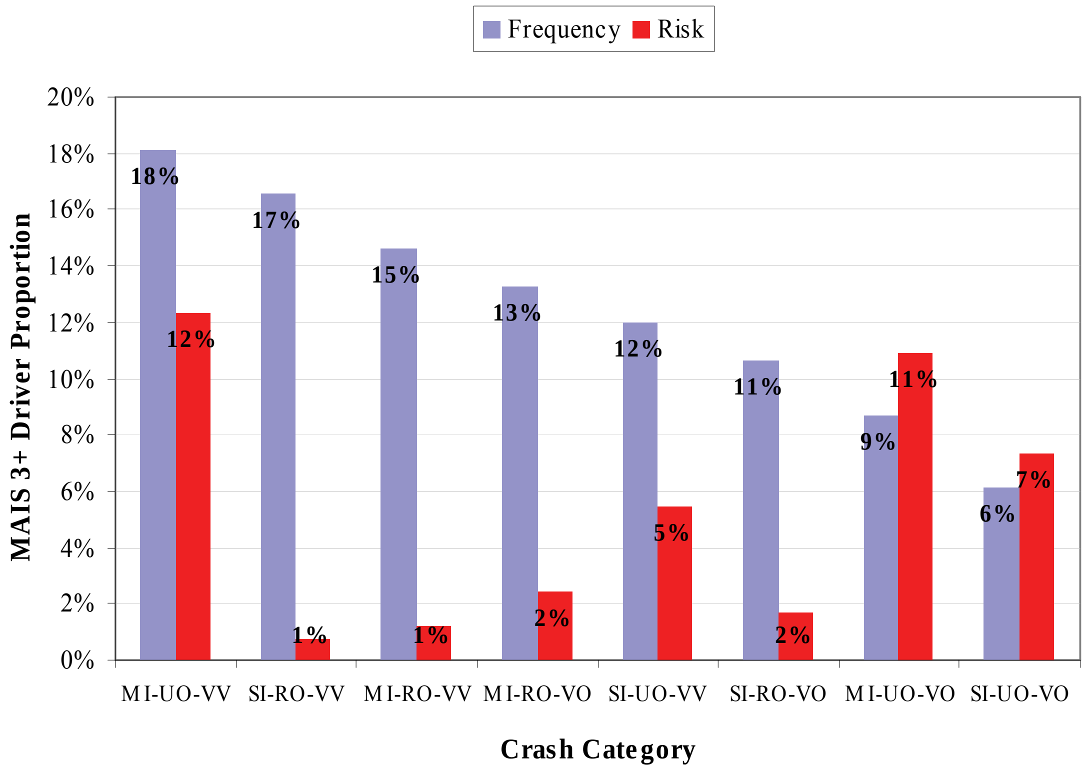
Table 4. Breakdown of MAIS3+ Drivers and FSP13+ by Number of Impacts, Restraint Use, and Crash Type (1997-2005 CDS)

Crash Category	Driver	FSP 13+
Multiple-Impact, Unrestrained, Vehicle-Vehicle	12,234	946
Single-Impact, Restrained, Vehicle-Vehicle	11,172	2,516
Multiple-Impact, Restrained, Vehicle-Vehicle	9,843	3,164
Multiple-Impact, Restrained, Vehicle-Object	8,956	1,323
Single-Impact, Unrestrained, Vehicle-Vehicle	8,090	1,303
Single-Impact, Restrained, Vehicle-Object	7,182	2,380
Multiple-Impact, Unrestrained, Vehicle-Object	5,849	1,436
Single-Impact, Unrestrained, Vehicle-Object	4,132	326
Total	67,458	13,394

Figures 5 and 6 illustrate the distribution of MAIS3+ drivers and FSP13+ and their risk of suffering MAIS3+ in each of the eight crash categories.*[1] Risk analysis of MAIS3+ show:

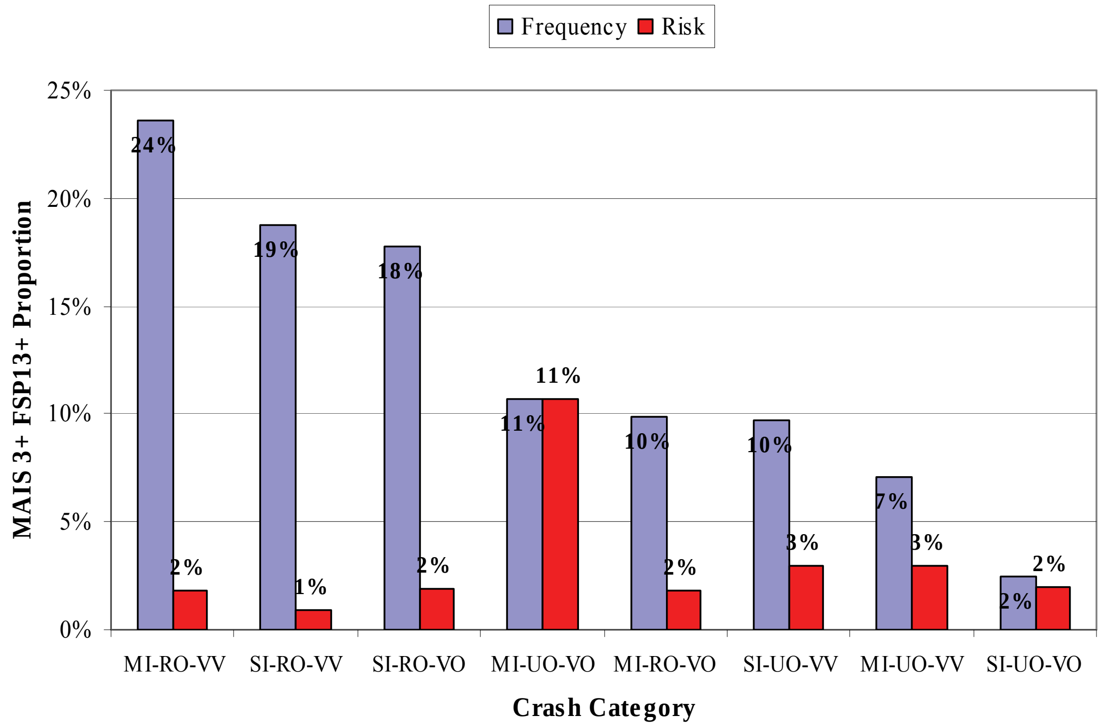
- Drivers are at their highest risk (11-12%) to sustain MAIS3+ when unrestrained in multi-impact crashes.
- Drivers are at their lowest risk (1%) to sustain MAIS3+ when restrained in vehicle-vehicle crashes.
- FSP13+ occupants are at their highest MAIS3+ risk (11%) when unrestrained in multiple-impact vehicle-object crashes.
- FSP13+ occupants are at their lowest MAIS3+ risk (1%) when restrained in single-impact vehicle-vehicle crashes.

* Computation of Frequency and Risk presented in Figure 5: There were 67,458 drivers with MAIS3+ in the target data set in all crash categories. Of these, there were 12,234 MAIS3+ drivers in MI-UO-VV crash category; thus, the frequency is (12,234/67,458)*100 = 0.18*100 = 18 percent. There were 99,028 drivers involved in MI-UO-VV crash category. Of these, 12,234 drivers suffered MAIS3+; thus, the risk is (12,234/99,028)*100 = 0.12*100 = 12 percent.



MI: Multiple Impacts, SI: Single Impact, UO: Unrestrained Occupant, RO: Restrained Occupant
VV: Vehicle-Vehicle, VO: Vehicle-Object

Figure 5. Distribution of MAIS3$^+$ Drivers in Front-Damage Vehicles and Their MAIS3$^+$ Risk in Different Crash Categories (1997-2005 CDS)



MI: Multiple Impacts, SI: Single Impact, UO: Unrestrained Occupant, RO: Restrained Occupant
VV: Vehicle-Vehicle, VO: Vehicle-Object

Figure 6. Distribution of MAIS3$^+$ FSP13$^+$ in Front-Damage Vehicles and Their MAIS3$^+$ Risk in Different Crash Categories (1997-2005 CDS)

2.4. Injured Body Region of Target Occupants in Front-Damage Vehicles

For each occupant, the maximum injury per body region is counted. For an occupant, with more than one injury occurring to the same body region at the maximum severity for that region, only one maximum injury to that body region is reported. In this way a maximum of eight unique body regions may be reported to sustain injury, per occupant.

Tables 5 and 6 provide the number of injured body regions by restraint use respectively for the driver and FSP13$^+$ populations in front-damage vehicles. Two injury categories are listed in these tables: MAIS1$^+$ counts the known injured body region and concomitant injury level from MAIS 1 through 6 while MAIS3$^+$ counts the known injured body region and concomitant injury level from MAIS 3 through 6. Driver statistics of injured body regions reveal that:

- Upper and lower extremities dominated respectively at 25 percent and 23 percent of all known injured body regions at MAIS1$^+$;
- Lower extremity and thorax were the most prevalent respectively at 32 percent and 24 percent of all known injured body regions at MAIS3$^+$;
- The head ranked third at 19 percent of all known injured body regions at MAIS3$^+$;

– Counting MAIS1$^+$, body regions other than extremities accounted for about 51 percent and 54 percent respectively for restrained and unrestrained drivers;
– Counting MAIS3$^+$, body regions other than extremities accounted for about 49 percent and 59 percent respectively for restrained and unrestrained drivers; and
– In both MAIS1$^+$ and MAIS3$^+$ counts, unrestrained drivers suffered substantially higher rates of head and face injuries than restrained drivers.

Table 6 statistics about FSP13$^+$ occupants show that:

– Lower extremity and face dominated respectively at 22 percent and 18 percent of all known injured body regions at MAIS1$^+$;
– Lower extremity and thorax were the most prevalent respectively at 44 percent and 28 percent of all known injured body regions at MAIS3$^+$;
– Upper extremity and head were equally ranked third at 11 percent of all known injured body regions at MAIS3$^+$;
– Counting MAIS1$^+$, body regions other than extremities accounted for about 62 percent and 56 percent respectively for restrained and unrestrained FSP13$^+$ occupants;
– Counting MAIS3$^+$, body regions other than extremities accounted for about 46 percent and 40 percent respectively for restrained and unrestrained FSP13$^+$ occupants; and
– In both MAIS1$^+$ and MAIS3$^+$ counts, unrestrained FSP13$^+$ occupants suffered substantially higher rates of head injury than restrained FSP13$^+$ occupants.

Table 5. Breakdown of Injured Body Regions by Restraint Use for Drivers in Front-Damage Vehicles (1997-2005 CDS)

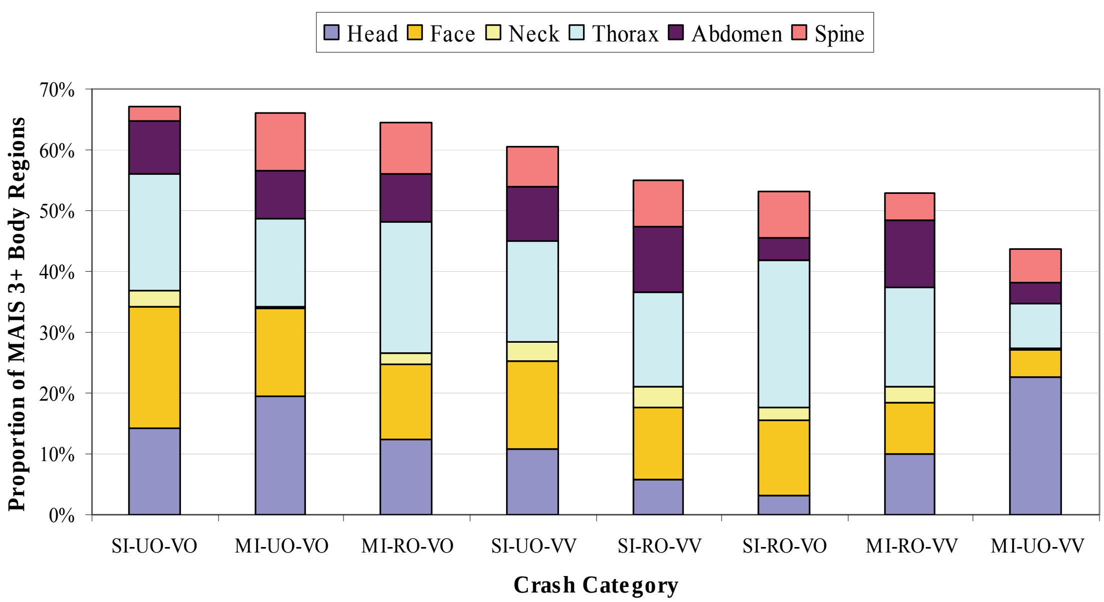
Body Region	MAIS1$^+$			MAIS3$^+$		
	Restrained	Unrestrained	Total	Restrained	Unrestrained	Total
Head	97,000	69,000	166,000	6,000	11,000	17,000
Face	300,000	78,000	378,000	-	1,000	1,000
Neck	71,000	4,000	75,000	-	-	-
Thorax	368,000	40,000	408,000	12,000	10,000	22,000
Abdomen	146,000	12,000	158,000	2,000	2,000	4,000
Spine	321,000	46,000	367,000	3,000	2,000	5,000
Upper Extremity	684,000	85,000	769,000	9,000	4,000	13,000
Lower Extremity	573,000	125,000	698,000	15,000	14,000	29,000
Total	2,560,000	459,000	3,019,000	47,000	44,000	91,000

Table 6. Breakdown of Injured Body Regions by Restraint Use for FSP13+ Occupants in Front-Damage Vehicles (1997-2005 CDS)

Body Region	MAIS1+			MAIS3+		
	Restrained	Unrestrained	Total	Restrained	Unrestrained	Total
Head	12,000	18,000	30,000	1,000	1,000	2,000
Face	72,000	43,000	115,000	1,000	-	1,000
Neck	20,000	1,000	21,000	-	-	-
Thorax	79,000	6,000	85,000	4,000	1,000	5,000
Abdomen	39,000	2,000	41,000	-	-	-
Spine	64,000	25,000	89,000	-	-	-
Upper Extremity	82,000	30,000	112,000	2,000	-	2,000
Lower Extremity	97,000	46,000	143,000	5,000	3,000	8,000
Total	465,000	171,000	636,000	13,000	5,000	18,000

Figure 7 illustrates the distribution of injured body regions, other than extremities, with MAIS3+ for drivers in front-damage vehicles by crash category. Based on Figure 7 data:

- The head accounted for the highest proportion of these injuries when the driver was unrestrained in multi-impact crashes. The thorax had the highest proportion of these injuries in other crash categories.
- The face was as high as the thorax when the driver was unrestrained in single-impact vehicle-object crashes.

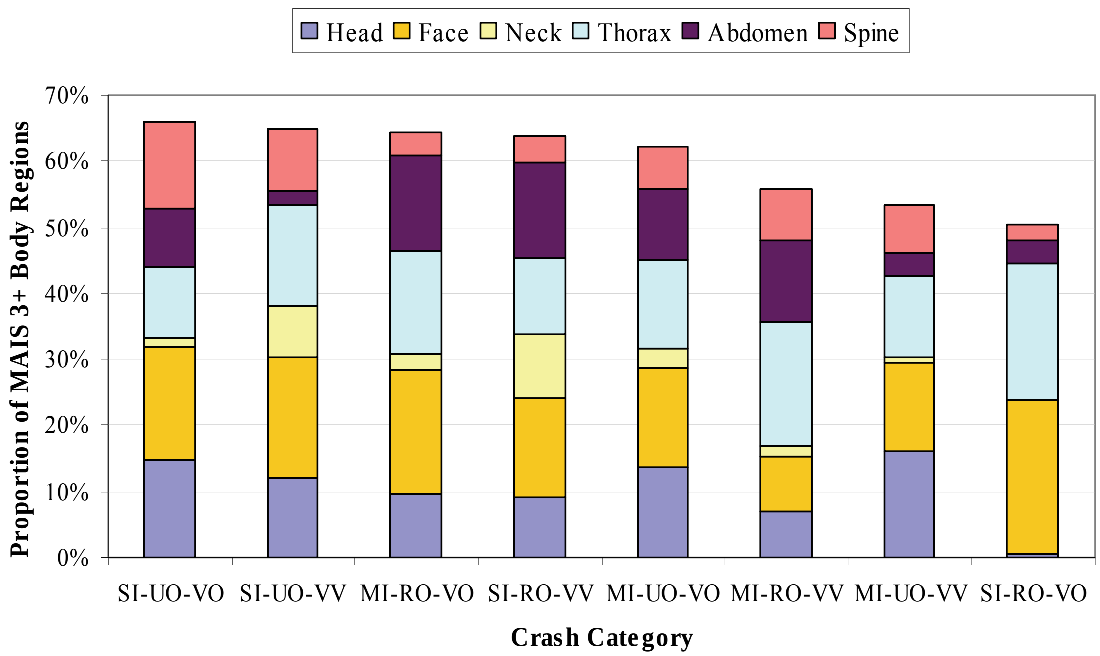


MI: Multiple Impacts, SI: Single Impact, UO: Unrestrained Occupant, RO: Restrained Occupant
VV: Vehicle-Vehicle, VO: Vehicle-Object

Figure 7. Breakdown of Driver MAIS3+ Body Regions Other Than Extremities by Crash Category in Front-Damage Vehicles (1997-2005 CDS)

Figure 8 illustrates the distribution of injured body regions, other than extremities, with MAIS3+ for FSP13+ occupants in front-damage vehicles by crash category. Based on Figure 8 statistics:

- The face accounted for the highest proportion of these injuries when the FSP13+ population was involved in single-impact crashes and in multi-impact vehicle-object crashes.
- The thorax had the highest proportion of these injuries when the FSP13+ population was restrained in multi-impact vehicle-vehicle crashes. On the other hand, the head dominated when the FSP13+ was unrestrained in multi-impact vehicle-vehicle crashes.



MI: Multiple Impacts, SI: Single Impact, UO: Unrestrained Occupant, RO: Restrained Occupant
VV: Vehicle-Vehicle, VO: Vehicle-Object

Figure 8. Breakdown of FSP13+ MAIS3+ Body Regions Other Than Extremities by Crash Category in Front-Damage Vehicles (1997-2005 CDS)

3. PRIORITIZATION OF TARGET CRASHES

Target ARS crashes were identified and prioritized based on the number of fatalities and FYL. A top-down analysis was conducted using the 2002-2006 FARS, 2006 GES, and 1997-2006 CDS crash databases. This analysis focused on vehicles with frontal damage from the first harmful impact or event because ARS will be enabled by forward-looking sensors that would detect and potentially interpret the first event. Target vehicles were light vehicles (e.g., passenger cars, vans or minivans, light pickup trucks, and sport utility vehicles) belonging to $MY98^{+}$. Target occupants included drivers and $FSP13^{+}$. Target occupants also suffered a maximum crash injury of $MAIS3^{+}$. This analysis correlated pre-crash scenarios with the impact mode. In contrast with Section 2, this top-down analysis did not distinguish between belted and unbelted occupants.

3.1. Harm Measure and National Crash Databases

Societal harm of motor vehicle crashes was expressed by the functional years lost measure that weighs and integrates the MAIS level of all people involved. This is a non-monetary measure that sums the years of life lost to fatal injury and the years of functional capacity lost to nonfatal injury.[11] A year of functional capacity covers 24 hours/day and 365 days/year. Functional capacity loss is defined as impairment along any of the following seven dimensions: mobility, cognitive, self care, sensory, cosmetic, pain, and ability to perform household responsibilities and wage work. The FYL measure does not mirror the monetary economic cost.[14] It assigns a different value to the relative severity of injuries suffered from motor vehicle crashes as listed in Table 7. The FYL measure was selected over other measures such as equivalent lives in order to harmonize with automakers who have adopted this measure in their crash avoidance research.[15] [16]

Table 7. Functional Years Lost by MAIS Per-Unit Basis

MAIS	Severity	Functional Years Lost
1	Minor	0.07
2	Moderate	1.1
3	Serious	6.5
4	Severe	16.5
5	Critical	33.1
6	Fatal	42.7

The FARS crash database is a census of fatal crashes occurring on roadways in the United States. At least one crash participant must expire as a result of a motor vehicle crash within 30 days of the incident. In addition to vehicle occupants, FARS also accounts for pedestrians, pedalcyclists, or other conveyances involved in fatal crashes. The crash detail, however, is limited to the information furnished by the police officer during the course of writing the incident report. The GES and CDS crash databases comprise the National Automotive Sampling System. The GES estimates the national crash population based on police accident reports by sampling approximately 55,000 crashes annually. These crashes involve all vehicle types and all injury levels. This provides a broad overview of vehicle and occupant involvement and the general crash environment. As previously mentioned in this report, the CDS samples about 4,500 crashes per year and is designed to fill the comprehensive crash void of the GES. This crash database includes light vehicles towed from the crash scene due to damage. On-scene investigators collect forensic evidence relevant to crash location, vehicle deformation, occupant kinematics, demography, and injury outcomes. A crash timeline chronology is established, although not quantitative, thereby defining a crash into unique events with injuries reported at the crash unit level.

The GES does not provide information on injury severity based on the AIS coding scheme. Instead, the GES records injury severity by crash victim on the KABCO scale from police accident reports. Police reports in almost every state use KABCO to classify crash victims as K – killed, A – incapacitating injury, B – non-incapacitating injury, C – possible injury, O – no apparent injury, or ISU – Injury Severity Unknown. The KABCO coding scheme allows non-medically trained persons to make on-scene injury assessments without a hands-on examination. However, KABCO ratings are imprecise and inconsistently coded between States and over time. To estimate injuries based on the MAIS coding structure, a translator derived from 1982–1986 NASS data was applied to the GES police-reported injury profile.[17] Table 8 shows the matrix equation with the multiplicative factors used to convert injury severity from KABCO to MAIS.

Table 8. Conversion Matrix of KABCO to MAIS Injury Severity

$$\begin{bmatrix} \text{MAIS0} \\ \text{MAIS1} \\ \text{MAIS2} \\ \text{MAIS3} \\ \text{MAIS4} \\ \text{MAIS5} \\ \text{MAIS6} \end{bmatrix} = \begin{bmatrix} 0 & 0.01516 & 0.04938 & 0.19919 & 0.92423 & 0.07523 \\ 0 & 0.49183 & 0.79229 & 0.71729 & 0.07342 & 0.70581 \\ 0 & 0.27920 & 0.12487 & 0.06761 & 0.00206 & 0.15708 \\ 0 & 0.16713 & 0.03009 & 0.01509 & 0.00029 & 0.04343 \\ 0 & 0.02907 & 0.00267 & 0.00064 & 0.00001 & 0.01712 \\ 0 & 0.01762 & 0.00069 & 0.00018 & 0.00000 & 0.00134 \\ 1 & 0 & 0 & 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} \text{K} \\ \text{A} \\ \text{B} \\ \text{C} \\ \text{O} \\ \text{ISU} \end{bmatrix}$$

3.2. Crash Analysis Framework

Figure 9 illustrates a crash analysis approach that yielded two major crash types: vehicle-object and vehicle-vehicle crashes. They were simply distinguished by the type of obstacle struck during the first harmful event based on whether or not the obstacle is a vehicle in transport. Vehicle-object crashes were characterized by a vehicle in transport contacting a “not vehicle in transport” obstacle. Ten obstacle categories were recognized: tree, pole, ground, structure, person, vehicle, animal, not-fixed object, non-collision, and unknown. Attention was paid to whether the target vehicle was involved in a single- or multi-impact crash. In single-vehicle crashes, the target vehicle did not hit a vehicle in transport. However, in a multi-impact crash, it was very important to identify the object type that was contacted during the first harmful event. In multi-vehicle crashes, the target vehicle contacted a vehicle in transport. In the case of multiple impacts, it is possible for the target vehicle to strike an object first before hitting another vehicle in transport. Thus, the analysis separated multi-vehicle crashes based on the first harmful event into vehicle-object and vehicle-vehicle crashes as seen in Figure 9.

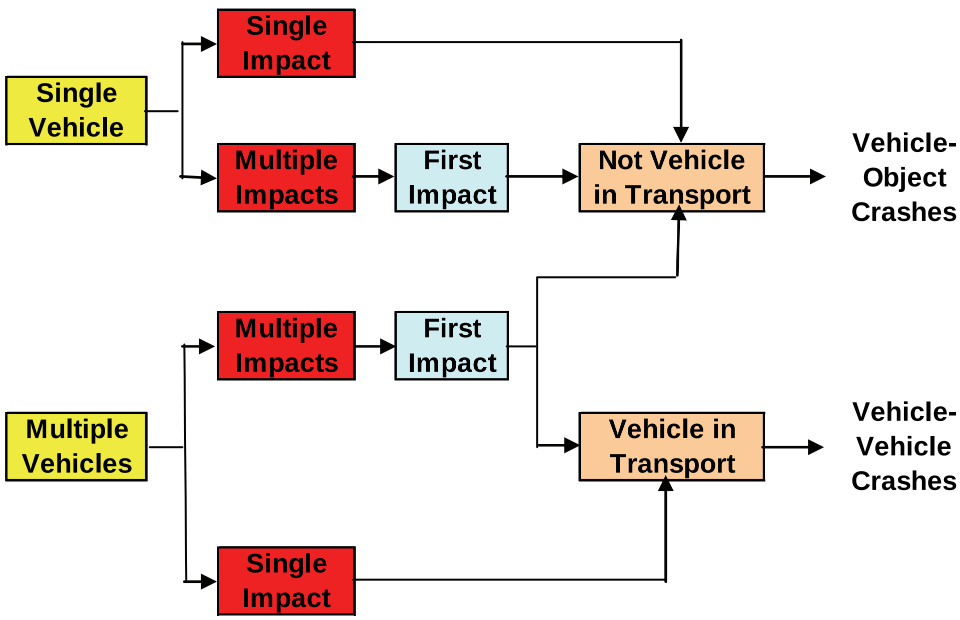


Figure 9. Block Diagram of Crash Analysis Framework

The analysis of FARS crash database applied the following filters to identify target vehicles and occupants.[18]:

- Target vehicles - Vehicle Level:
  - Light vehicle: Body Type = 1 – 49
  - Model year ≥ 1998: Vehicle Model Year ≥ 1998
  - Frontal damage: Impact Point-Initial = 1, 11, or 12
- Target occupants - Person Level:
  - Driver: Seating Position = 11
  - FSP13$^+$: Seating Position =13 and Age ≥ 13

The following GES variables and codes were used to analyze target crashes.[7]:

- Light vehicle - Vehicle Data Set: BDYTYP_H = 01 – 49

- First event producing property damage or personal injury - Event Data Set: EVENTNUM = 1
- Front damage - Event Data Set: VEHNUM and GAD = 1, 11, or 12
- Impact type in first event - Event Data Set:
  - Object type: OBJCONT = 121 – 159
  - Vehicle impact: OBJCONT = 1 – 100 and OBJGAD
- Occupant type and injury - Person Data Set:
  - Driver: SEAT_H = 11
  - FSP 13^{+}: SEAT_H = 13 and AGE_H ≥ 13
  - Injury severity: INJSEV_H
- Object contacted:
  - Tree: OBJCONT = 144 or 145
  - Pole: OBJCONT = 137
  - Ground: OBJCONT = 131, 138, 139, or 140
  - Structure: OBJCONT = 132, 133,134, 135, 136, 141, 142, 143, 146, 158, or 159
  - Person: OBJCONT = 121, 122, or 127
  - Vehicle: OBJCONT = 123 or 126
  - Animal: OBJCONT = 124
  - Not Fixed: OBJCONT = 110, 128 or 129
  - Non-collision: OBJCONT = 101 – 109
  - Unknown: OBJCONT = 999

The CDS crash database contains similar variables to the GES listed above, which can be used to identify target crashes.[8]:

- Light vehicle – General Vehicle form: BODYTYPE = 1 – 49
- Single-impact, vehicle-object crash – Accident form: VEHFORMS = 1 and Accident form: EVENTS = 1 and Vehicle Exterior form: OBJCONT1 = 41-89
- Single-impact, vehicle-vehicle crash – VEHFORMS = 2 and EVENTS = 1 and OBJCONT1 = 1-30
- Multi-impact, vehicle-vehicle crash – EVENTS ≠ 1 and OBJCONT1 = 1-30
- Multi-impact, vehicle-object crash – EVENTS ≠ 1 and OBJCONT1 = 41-89
- Occupant type and injury
  - Driver: Occupant Assessment form: ROLE = 1 and SEATPOS = 11
  - FSP 13^{+}: ROLE = 2 and SEATPOS = 13 and AGE ≥ 13
  - Injury severity: MAIS
- Object contacted:
  - Tree: OBJCONT1 = 41-43
  - Pole: OBJCONT1 = 45-53
  - Ground: OBJCONT1 = 44 and 61
  - Structure: OBJCONT1 = 54-60 and 62-69
  - Person/animal: OBJCONT1 = 72-76
  - Parked Vehicle: OBJCONT1 = 70 and 71

- Other Not Fixed Object: OBJCONT1 = 77-89
- Other: OBJCONT1 = 98 and 99

Both GES and CDS databases also have similar pre-crash variables that allow the identification of pre-crash scenarios. This report defines pre-crash scenarios as combinations of movements and dynamics of vehicles and critical events prior to driver attempted maneuvers to avoid the crash.[6] Appendices A and B present coding schemes respectively for single-vehicle and multi-vehicle pre-crash scenarios using CDS variables and codes. Unfortunately, this type of analysis cannot be performed with FARS since it does not contain the same set of pre-crash variables. Thus, this report provides results of target crashes in terms of the impact mode for FARS and in terms of pre-crash scenario and impact mode combinations for GES and CDS.

3.3. Analysis of Vehicle-Object Crashes

Analysis results of vehicle-object crashes are presented below based on data from FARS, GES, and CDS respectively.

3.3.1. FARS Vehicle-Object Crashes

The 2002-2006 FARS crash databases were queried to identify target vehicle-object crashes for advanced restraints. Target crashes involved at least one fatal injury in target vehicles by the driver or $FSP13^+$. Target vehicles included all $MY98^+$ light vehicles that experienced front damage from the first harmful event. Table 9 lists the number of driver and $FSP13^+$ fatalities in target vehicle-object crashes by obstacle category from 2002 through 2006. The number of fatalities increased in almost each category over time due to the greater number of $MY98^+$ vehicles in the vehicle fleet in the United States.

Table 9. Driver and $FSP13^+$ Fatalities in Vehicle-Object Crashes (2002-2006 FARS)

Obstacle	2002	2003	2004	2005	2006	Total	% Total
Ground	553	708	868	991	1,178	4,298	28.3%
Structure	577	694	757	872	1,000	3,900	25.7%
Tree	551	614	679	818	868	3,530	23.2%
Pole	308	334	385	427	506	1,960	12.9%
Non-Collision	81	99	110	161	195	646	4.3%
Vehicle	83	83	118	121	122	527	3.5%
Animal	20	34	29	35	40	158	1.0%
Not-Fixed	17	34	34	38	34	157	1.0%
Pedestrian	-	4	5	4	3	16	0.1%
Unknown	1	-	1	-	1	3	0.0%
Cyclist	1	2	-	-	-	3	0.0%
Total	2,192	2,606	2,986	3,467	3,947	15,198	100.0%

Figure 10 illustrates the trend of target vehicle-object crashes from 2002 through 2006 by normalizing the number of drivers and FSP13$^+$ fatalities by the number of target vehicles. Ground, structure, tree, and pole were the dominant obstacles in crashes over the 5-year period in a descending order. There was a slight increase in killed drivers and FSP13$^+$ as a result of target vehicles striking ground or structure. Appendix C provides details of the structure, ground, non-collision, and not-fixed obstacle categories.

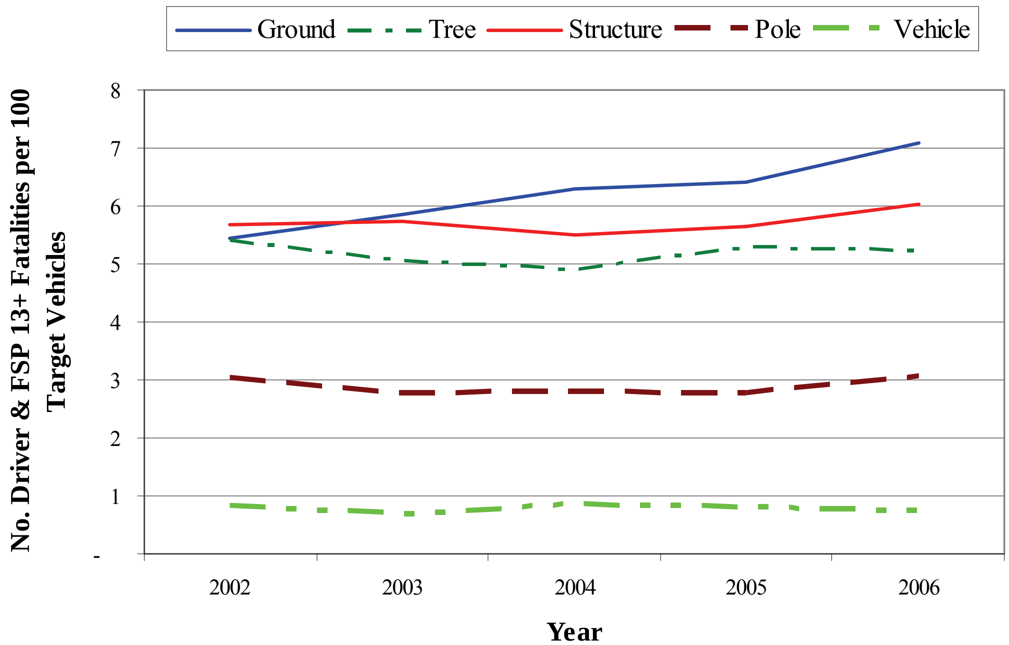


Figure 10. Driver and FSP13$^+$ Fatalities Normalized by the Number of Target Vehicles Involved in Vehicle-Object Crashes (2002-2006 FARS)

3.3.2. GES Vehicle-Object Crashes

Table 10 lists in a descending order the pre-crash scenarios of target vehicle-object crashes in terms of the FYL measure by the driver and FSP13$^+$, independent of the struck obstacle type. This FYL measure was computed by counting the maximum injury suffered by the driver and FSP13$^+$ at MAIS3$^+$. MAIS levels of 0-2 were not included in this FYL measure. These statistics are based on the 2006 GES crash database. Table 11 lists in a descending order the FYL harm by obstacle category, independent of the pre-crash scenario. Table 12 correlates the pre-crash scenarios by the struck obstacle type and lists the more prevalent combinations. Less common pre-crash scenario and obstacle type combinations are included in "Other Scenarios" in Table 12. For example, Table 10 lists 127,125 functional years lost from all road departure pre-crash scenarios. On the other hand, Table 12 lists 127,075 functional years lost from road departure correlated with ground, structure, tree, pole, not fixed, and vehicle. The difference of 50 functional years lost between Table 10 and Table 12 is due to road departure pre-crash scenarios with vehicle striking person, animal, or unknown obstacle, which are included in "Other Scenarios."

As seen in Table 10, road departure pre-crash scenarios accounted for over 60 percent of functional years lost. Control loss scenarios follow at a distant second with only 20 percent of functional years lost. Ground, structure, tree, and pole were the dominant obstacles in target vehicle-object crashes in terms of the FYL harm in a descending order.

Table 10. Functional Years Lost by Driver and FSP13^{+} in Target Vehicle-Object Pre-Crash Scenarios (2006 GES)

Pre-Crash Scenario	Functional Years Lost	% Functional Years Lost
Road Departure	127,125	61.0%
Control Loss	41,742	20.0%
Other	15,239	7.3%
Cyclist	11,990	5.8%
Animal	5,858	2.8%
Opposite Direction	2,053	1.0%
Pedestrian	1,340	0.6%
Object	1,215	0.6%
Rear-End	1,078	0.5%
Straight Crossing Paths	595	0.3%
Turning	281	0.1%
Total	208,515	100.0%

Table 11. Functional Years Lost by Driver and FSP13^{+} in Target Vehicle-Object Crashes by Obstacle Type (2006 GES)

Obstacle	Functional Years Lost	% Functional Years Lost
Ground	59,741	28.7%
Structure	55,473	26.6%
Tree	41,000	19.7%
Pole	25,491	12.2%
Person	13,343	6.4%
Not Fixed	5,818	2.8%
Vehicle	5,311	2.5%
Animal	2,092	1.0%
Unknown	247	0.1%
Total	208,515	100.0%

Table 12. Functional Years Lost by Driver and FSP13+ in Target Vehicle-Object Pre-Crash Scenarios by Obstacle Type (2006 GES)

Pre-Crash Scenario	Obstacle	Functional Years Lost	% Functional Years Lost
Road Departure	Ground	35,859	17.2%
Road Departure	Structure	35,388	17.0%
Road Departure	Tree	28,496	13.7%
Road Departure	Pole	17,788	8.5%
Control Loss	Ground	17,640	8.5%
Control Loss	Structure	13,418	6.4%
Cyclist	Person	11,985	5.7%
Control Loss	Pole	5,589	2.7%
Other	Structure	5,183	2.5%
Road Departure	Not Fixed	5,145	2.5%
Control Loss	Tree	4,810	2.3%
Road Departure	Vehicle	4,399	2.1%
Other	Ground	4,354	2.1%
Other	Tree	4,280	2.1%
Animal	Animal	2,092	1.0%
Other Scenarios		12,089	5.8%
	Total	208,515	100.0%

3.3.3. CDS Vehicle-Object Crashes

Table 13 lists in a descending order the pre-crash scenarios of target vehicle-object crashes in terms of the FYL measure by the driver and FSP 13+ based on 1997-2006 CDS databases. This FYL measure was computed by counting the maximum injury suffered by the driver and FSP13+ at MAIS3+. This computation excluded MAIS levels of 0-2. Table 13 also shows the number of target vehicles involved in these crashes by sample count and weighted frequency. Table 14 lists the FYL harm by obstacle category. Table 15 correlates the pre-crash scenarios by the struck obstacle category.

As seen in Table 13, road departure crashes are the dominant pre-crash scenarios accounting for about 80 percent of functional years lost by the driver and FSP13+ in target vehicles. As for obstacle type, Table 14 shows that pole, structure, ground, and tree contribute to similar functional years lost between 21 percent and 25 percent each. Table 15 provides additional details about the road departure pre-crash scenarios where the road departure-no vehicle maneuver scenario is the most dominant resulting between 17 percent and 19 percent of functional years lost in each of the four common obstacle types. No vehicle maneuver refers to a vehicle passing, parking, turning, changing lanes, merging, or successful corrective action to a previous critical event prior to any attempted evasive maneuver by the driver. In contrast, the control loss-no vehicle action scenario produces only between 2 percent and 5 percent of functional years lost in each of the four prevalent obstacle types. No vehicle action denotes a vehicle decelerating, accelerating, starting, passing, parking, turning, backing up, changing lanes, merging, and successful corrective action to a previous critical event prior to any attempted evasive maneuver by the driver.

Table 13. Functional Years Lost by Driver and FSP13[+] in Target Vehicle-Object Pre-Crash Scenarios (1997-2006 CDS)[*]

Pre-Crash Scenario	Vehicle Count	Vehicle Weight	Functional Years Lost	% Functional Years Lost
Road Departure	2,169	821,677	594,841	79.9%
Control Loss	999	437,475	118,471	15.9%
Lane Change	115	50,303	9,623	1.3%
Animal	198	152,356	7,644	1.0%
Object	41	13,349	3,505	0.5%
Vehicle Failure	49	13,285	3,311	0.4%
Opposite Direction	54	15,417	3,004	0.4%
Straight Crossing Paths	24	3,860	1,377	0.2%
Turning	37	20,092	1,268	0.2%
Rear-End	39	7,952	1,114	0.1%
Evasive Action	23	21,494	294	0.0%
Other	34	14,935	170	0.0%
Total	3,782	1,572,197	744,623	100.0%

Table 14. Functional Years Lost by Driver and FSP13[+] in Target Vehicle-Object Crashes by Obstacle Category (1997-2006 CDS)

Obstacle	Vehicle Count	Vehicle Weight	Functional Years Lost	% Functional Years Lost
Pole	776	321,163	184,948	24.8%
Structure	1,256	427,995	175,193	23.5%
Ground	610	327,322	164,187	22.0%
Tree	630	188,438	156,793	21.1%
Not Fixed	83	31,246	41,526	5.6%
Vehicle	293	153,661	14,977	2.0%
Person	18	11,425	5,082	0.7%
Animal	116	110,946	1,915	0.3%
Total	3,782	1,572,197	744,622	100.0%

[*] In tables presenting CDS statistics, the "Vehicle Count" column represents the raw vehicle or case counts while the "Vehicle Weight" column represents the weighted number of vehicles using CDS weights for each case.

Table 15. Functional Years Lost by Driver and FSP13+ in Target Vehicle-Object Pre-Crash Scenarios by Obstacle Category (1997-2006 CDS)

Pre-Crash Scenario	Obstacle	Vehicle Count	Vehicle Weight	Functional Years Lost	% Functional Years Lost
Road Departure - No Vehicle Maneuver	Pole	495	190,719	138,066	18.5%
Road Departure - No Vehicle Maneuver	Ground	337	179,567	133,379	17.9%
Road Departure - No Vehicle Maneuver	Structure	552	163,005	126,765	17.0%
Road Departure - No Vehicle Maneuver	Tree	369	85,668	124,062	16.7%
Road Departure - No Vehicle Maneuver	Not Fixed	31	10,871	37,730	5.1%
Control Loss - No Vehicle Action	Structure	374	154,448	35,928	4.8%
Control Loss - No Vehicle Action	Pole	121	65,501	33,615	4.5%
Control Loss - No Vehicle Action	Tree	149	64,147	23,006	3.1%
Control Loss - No Vehicle Action	Ground	148	61,259	13,797	1.9%
Road Departure - Vehicle Maneuver	Ground	27	17,572	11,409	1.5%
Road Departure - No Vehicle Maneuver	Vehicle	219	128,996	9,038	1.2%
104 Other Scenarios		960	450,444	57,826	7.8%
	Total	3,782	1,572,197	744,622	100.0%

3.3.4. Priority Vehicle-Object Crashes

Based on 2002-2006 FARS data, about 90 percent of driver and FSP13+ fatalities in MY98+ light vehicles with frontal damage were attributed to crashes in which the vehicle first struck the ground, a structure, a tree, or a pole in descending order. Specifically, the top five obstacles struck first were a tree, a ditch, a guardrail face, an embankment, or a pole in descending order. These five specific obstacles accounted for 55 percent of the fatalities.

Similar to FARS data, 2006 GES statistics identified the same order of prevalent obstacle types in terms of functional years lost. Ground, structure, tree, or pole were cited as first obstacle struck in vehicle-object crashes and accounted for 87 percent of functional years lost. In addition, 2006 GES statistics revealed that road departure and control loss pre-crash scenarios led to 81 percent of functional years lost in vehicle-object crashes. Target vehicles first striking the ground, a structure, a tree, or a pole in road departure pre-crash scenarios dominated vehicle-object crashes in this order at 56 percent of functional years lost.

Similar to GES statistics, 1997-2006 CDS statistics identified road departure and control loss pre-crash scenarios in the same order yielding 96 percent of functional years lost. However, CDS statistics showed a different order of obstacle types in terms of functional years lost where pole was the leading first obstacle struck and was followed by structure, ground, and tree. These four major obstacle types accounted for 91 percent of functional years lost according to CDS statistics. Target vehicles first striking ground, pole, structure, or tree in road departure pre-crash scenarios dominated vehicle-object crashes in this order at 73 percent of functional years lost. Table 16 lists the priority obstacle types and pre-crash scenarios in vehicle-object crashes, and ranks them in terms of their crash harm in FARS, GES, and CDS.

Table 16. Priority and Order of Target Vehicle-Object Crashes

Crash Scenario		FARS	GES	CDS
Obstacle	Pole	4	4	1
	Structure	2	2	2
	Ground	1	1	3
	Tree	3	3	4
Pre-Crash Scenario	Road Departure (RD)		1	1
	Control Loss		2	2
Pre-Crash Scenario - Obstacle	RD - Ground		1	1
	RD - Pole		4	2
	RD - Structure		2	3
	RD - Tree		3	4

3.4. Analysis of Vehicle-Vehicle Crashes

Analysis results of vehicle-vehicle crashes are presented below based on data from FARS, GES, and CDS respectively.

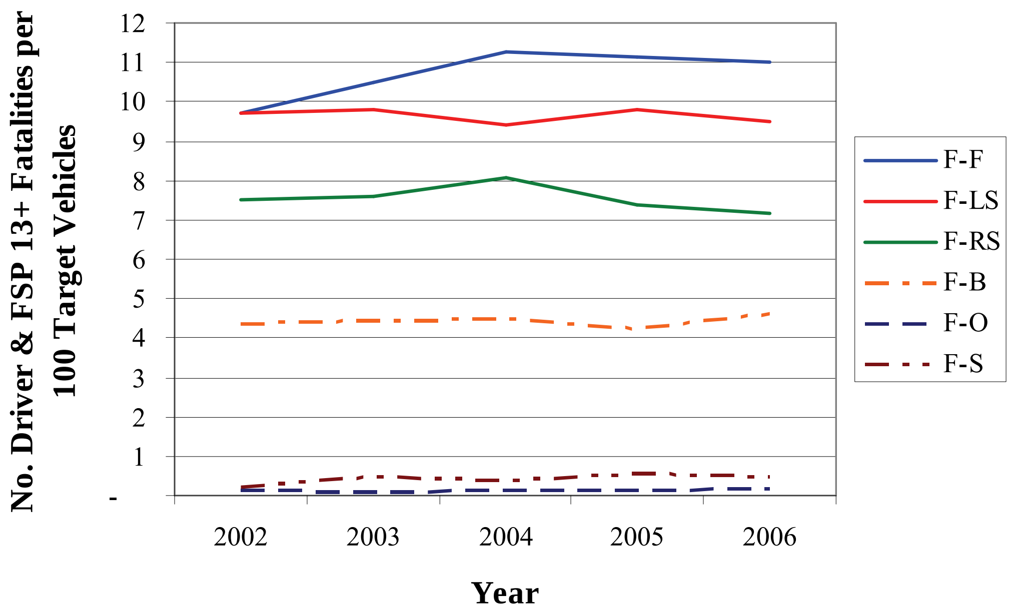
3.4.1. FARS Vehicle-Vehicle Crashes

Table 17 lists in descending order the number of driver and FSP13^{+} fatalities in vehicle-vehicle crashes by impact mode based on 2002-2006 FARS crash databases. Front-to-front impacts were the most fatal at one-third of all target occupant fatalities. Front-to-left side impacts came in close second at 29 percent of all fatalities. Figure 11 shows the trend of driver and FSP13^{+} fatalities over the 5-year period, normalized by the number of target vehicles. The fatality rate in front-to-front impacts rose from 10 percent in 2002 and leveled off at 11 percent since 2004. While the fatality rate in front-to-left side impacts remained almost constant at an average of 9.6 percent over the five-year period, the rate of fatalities in front-to-right side impacts decreased slightly from 8.1 percent in 2004 to 7.2 percent in 2006.

Table 17. Driver and FSP13$^+$ Killed in Target Vehicle-Vehicle Crashes (2002-2006 FARS)

Impact Mode	2002	2003	2004	2005	2006	Total	% Total
Front - Front	989	1,270	1,551	1,722	1,831	7,363	32.7%
Front - Left Side	988	1,187	1,295	1,520	1,579	6,569	29.2%
Front - Right Side	765	922	1,111	1,145	1,190	5,133	22.8%
Front - Back	444	541	617	658	769	3,029	13.5%
Front - Side*	22	60	53	86	79	300	1.3%
Front - Other	11	9	18	23	30	91	0.4%
Total	3,219	3,989	4,645	5,154	5,478	22,485	100.0%

*: Unknown what side of the vehicle was struck first in multi-impact crashes



F-F: Front-Front; F-LS: Front-Left Side; F-RS: Front-Right Side; F-O: Front-Other;
F-B: Front-Back; F-S: Front-Side

Figure 11. Trends in Driver and FSP13$^+$ Fatalities in Target Vehicle-Vehicle Crashes (2002-2006 FARS)

3.4.2. GES Vehicle-Vehicle Crashes

Table 18 lists in descending order the pre-crash scenarios of target vehicle-vehicle crashes in terms of functional years lost computed from MAIS3$^+$ injuries by involved drivers and FSP13$^+$. Table 19 shows the same statistics for the impact mode and Table 20 correlates the pre-crash scenarios to the impact mode.

Opposite direction pre-crash scenarios were the most prevalent scenarios by accounting for about 28 percent of functional years lost. In these scenarios, a vehicle is typically going straight, drifts at a non-junction, and then encroaches into another vehicle traveling in the opposite direction. The vehicle could also be negotiating a curve or passing. There were four other dominant pre-crash scenarios:

- Rear-end: vehicle is typically going straight and then closes in on a lead vehicle that could be stopped, decelerating, accelerating, or moving at slower constant speed. Moreover, a vehicle could be starting in traffic, changing lanes, passing, or turning and then closes in on a lead vehicle.
- Turning: these scenarios refer to any crossing-paths turning maneuvers other than left turn across path/opposite direction.
- Straight crossing paths: vehicle is going straight through a junction and then cuts across the path of another straight crossing vehicle from lateral direction. Vehicle could also stop and proceed against crossing traffic or both vehicles first stopping and then proceeding on straight crossing paths.
- Left turn across path/opposite direction (LTAP/OD): vehicle is turning left at a junction and then cuts across the path of another vehicle traveling from the opposite direction. It should be noted that the target vehicle, suffering frontal damage from the first harmful event, could be turning or going straight in turning crossing-path pre-crash scenarios.

Front-to-front impacts resulted in about 37 percent of functional years lost as listed in Table 19. Front-to-back impacts fell in second and superseded front-to-side impacts. There were two dominant pre-crash scenario and impact mode combinations: opposite direction pre-crash scenarios leading to front-to-front impacts and rear-end pre-crash scenarios ending in front-to-back impacts. These two combinations accounted for about 38 percent of functional years lost as can be derived from Table 20. It should be noted that opposite direction pre-crash scenarios also involved front-to-side impacts.

Table 18. Functional Years Lost by Driver and FSP13^{+} in Target Vehicle-Vehicle Pre-Crash Scenarios (2006 GES)

Pre-Crash Scenario	Functional Years Lost	% Functional Years Lost
Opposite Direction	69,942	27.8%
Rear-End	43,791	17.4%
Turning*	39,977	15.9%
Straight Crossing Paths	33,927	13.5%
LTAP/OD	32,176	12.8%
Other	9,783	3.9%
Lane Change	9,775	3.9%
Control Loss	6,440	2.6%
Road Departure	4,932	2.0%
Backing	818	0.3%
Total	251,560	100.0%

LTAP/OD: Left Turn Across Path from Opposite Directions
*: Turning refers to any crossing-paths turning maneuver other than LTAP/OD

Table 19. Functional Years Lost by Driver and FSP13+ in Target Vehicle-Vehicle Crashes by Impact Mode (2006 GES)

Impact Mode	Functional Years Lost	% Functional Years Lost
Front - Front	92,521	36.8%
Front - Back	55,921	22.2%
Front - Left Side	52,380	20.8%
Front - Right Side	44,856	17.8%
Front - Other	5,883	2.3%
Total	251,560	100.0%

Table 20. Functional Years Lost by Driver and FSP13+ in Target Vehicle-Vehicle Pre-Crash Scenarios by Impact Mode (2006 GES)

Pre-Crash Scenario	Impact Mode	Functional Years Lost	% Functional Years Lost
Opposite Direction	Front - Front	55,163	21.9%
Rear-End	Front - Back	40,726	16.2%
LTAP/OD	Front - Front	18,165	7.2%
Straight Crossing Paths	Front - Left Side	16,514	6.6%
Straight Crossing Paths	Front - Right Side	13,209	5.3%
Turning*	Front - Back	12,401	4.9%
LTAP/OD	Front - Right Side	11,178	4.4%
Turning*	Front - Left Side	11,040	4.4%
Turning*	Front - Right Side	9,654	3.8%
Opposite Direction	Front - Left Side	8,351	3.3%
Turning*	Front - Front	6,847	2.7%
Opposite Direction	Front - Right Side	6,095	2.4%
Lane Change	Front - Left Side	6,079	2.4%
Other	Front - Front	5,184	2.1%
Road Departure	Front - Other	4,266	1.7%
Control Loss	Front - Left Side	4,122	1.6%
Straight Crossing Paths	Front - Front	4,032	1.6%
Other	Front - Left Side	3,391	1.3%
LTAP/OD	Front - Left Side	2,588	1.0%
Other Scenarios		12,556	5.0%
	Total	251,560	100.0%

LTAP/OD: Left Turn Across Path from Opposite Directions
*: Turning refers to any crossing-paths turning maneuver other than LTAP/OD

3.4.3. CDS Vehicle-Vehicle Crashes

Table 21 lists in descending order the pre-crash scenarios of target vehicle-vehicle crashes in terms of functional years lost computed from MAIS3$^+$ by drivers and FSP13$^+$ based on 1997-2006 CDS databases. Table 22 shows the same statistics for the impact mode and Table 23 correlates the pre-crash scenarios to the impact mode.

Opposite direction pre-crash scenarios were the most dominant scenarios by accounting for about 45 percent of functional years lost based on CDS statistics. This rate was much higher than the 28 percent rate found in GES statistics. Front-to-front impacts also resulted in higher rate than the GES as seen in Table 22.

The top two dominant pre-crash scenario and impact mode combinations were similar in the CDS and GES databases: opposite direction pre-crash scenarios leading to front-to-front impacts and rear-end pre-crash scenarios ending in front-to-back impacts. However, these two combinations accounted for about 59 percent of functional years lost in the CDS as opposed to 38 percent in the GES. The CDS also revealed one more prevalent combination over 10 percent of functional years lost. Overall, there were three dominant combinations based on 1997-2006 CDS statistics:

- Opposite direction with front-to-front impact: FYL = 36.9 percent
- Rear-end with front-to-back impact: FYL = 21.8 percent
- LTAP/OD with front-to-front impact: FYL = 10.4 percent

Table 21. Functional Years Lost by Driver and FSP13$^+$ in Target Vehicle-Vehicle Pre-Crash Scenarios (1997-2006 CDS)

Pre-Crash Scenario	Vehicle Count	Vehicle Weight	Functional Years Lost	% Functional Years Lost
Opposite Direction	1,422	337,402	328,017	44.8%
Rear-End	2,485	1,663,401	170,861	23.4%
LTAP/OD	2,605	1,087,197	93,907	12.8%
Turning*	1,419	751,193	42,085	5.8%
Straight Crossing Paths	2,041	806,643	38,275	5.2%
Road Departure	41	11,665	18,532	2.5%
Lane Change	476	218,125	17,177	2.3%
Control Loss	209	95,448	11,874	1.6%
Other	104	43,514	8,068	1.1%
Turning Right	191	123,635	2,895	0.4%
Total	10,993	5,138,223	731,692	100.0%

LTAP/OD: Left Turn Across Path from Opposite Directions

*: Turning refers to any crossing-path turning maneuver other than LTAP/OD or turning right

Table 22. Functional Years Lost by Driver and FSP13+ in Target Vehicle-Vehicle Crashes by Impact Mode (1997-2006 CDS)

Impact Mode	Vehicle Count	Vehicle Weight	Functional Years Lost	% Functional Years Lost
Front - Front	3,058	985,482	394,769	54.0%
Front - Back	2,578	1,711,705	171,580	23.4%
Front - Left Side	2,623	1,216,066	89,279	12.2%
front - Right Side	2,697	1,194,371	75,689	10.3%
Front - Other	37	30,600	375	0.1%
Total	10,993	5,138,223	731,692	100.0%

Table 23. Functional Years Lost by Driver and FSP 13+ in Target Vehicle-Vehicle Pre-Crash Scenarios by Impact Mode (1997-2006 CDS)

Pre-Crash Scenario	Impact Mode	Vehicle Count	Vehicle Weight	Functional Years Lost	% Functional Years Lost
Opposite Direction - No Vehicle Maneuver	Front - Front	1,020	211,323	225,093	30.8%
LVS - No Vehicle Maneuver	Front - Back	1,453	1,036,489	117,888	16.1%
LTAP/OD	Front - Front	1,350	472,496	76,218	10.4%
Opposite Direction - Vehicle Maneuver	Front - Front	52	11,315	44,575	6.1%
Opposite Direction - No Vehicle Maneuver	Front - Left Side	160	61,001	32,237	4.4%
LVM - No Vehicle Maneuver	Front - Back	305	139,320	25,205	3.4%
Opposite Direction - No Vehicle Maneuver	Front - Right Side	162	46,512	23,913	3.3%
Turning*	Front - Left Side	798	389,585	23,327	3.2%
Straight Crossing Paths	Front - Left Side	1,014	414,400	18,731	2.6%
Road Departure - No Vehicle Maneuver	Front - Front	20	1,254	17,991	2.5%
Straight Crossing Paths	Front - Right Side	991	386,839	17,520	2.4%
LTAP/OD	Front - Right Side	1,064	491,903	16,334	2.2%
Turning*	Front - Front	374	210,298	9,956	1.4%
Turning*	Front - Right Side	235	146,109	8,802	1.2%
Rear-End - Vehicle Maneuver	Front - Back	156	95,164	8,491	1.2%
LVD - No Vehicle Maneuver	Front - Back	478	352,547	7,764	1.1%
99 Other Scenarios		1,361	671,666	57,648	7.9%
	Total	10,993	5,138,223	731,692	100.0%

LVS: Lead Vehicle Stopped
LTAP/OD: Left Turn Across Path From Opposite Directions
LVM: Lead Vehicle Moving at Slower Constant Speed
LVD: Lead Vehicle Decelerating
*: Turning refers to any crossing-path turning maneuver other than LTAP/OD or turning right

3.4.4. Priority Vehicle-Vehicle Crashes

Based on 2002-2006 FARS data, about 98 percent of driver and FSP13^{+} fatalities in MY98^{+} light vehicles with frontal damage were attributed to crashes in which the front of the target vehicle first struck the front, left side, right side, or back of another vehicle in descending order. This order of impact mode in FARS was different than 2006 GES and 1997-2006 CDS statistics. Both the GES and CDS identified the following order of impact mode: front, back, left side, and right side.

The top five pre-crash scenarios were also common between the GES and CDS in terms of functional years lost. They include opposite direction, rear-end, turning at junction, straight crossing paths, and LTAP/OD pre-crash scenarios. All five pre-crash scenarios accounted for 87 percent and 92 percent of functional years lost respectively in the GES and CDS.

The top five pre-crash scenario and impact mode combinations in the GES contributed to about 57 percent of functional years lost. On the other hand, the top five combinations in the CDS resulted in 75 percent of functional years lost. Table 24 lists the priority impact modes and pre-crash scenarios in vehicle-vehicle crashes, and ranks them in terms of their crash harm in FARS, GES, and CDS.

Table 24. Priority and Order of Target Vehicle-Vehicle Crashes

Crash Scenario		FARS	GES	CDS
Impact Mode	Front - Front (FF)	1	1	1
	Front - Back (FB)	4	2	2
	Front - Left Side (FLS)	2	3	3
	Front - Right Side (FRS)	3	4	4
Pre-Crash Scenario	Opposite Direction		1	1
	Rear-End		2	2
	LTAP/OD		5	3
	Turning		3	4
	Straight Crossing Paths		4	5
Pre-Crash Scenario - Impact Mode	Opposite Direction - FF		1	1
	Rear-End - FB		2	2
	LTAP/OD - FF		3	3
	Turning - FLS		8	4
	Straight Crossing Paths - FLS		4	5
	Straight Crossing Paths - FRS		5	6

LTAP/OD: Left Turn Across Path From Opposite Directions

4. EXAMINATION OF TARGET CRASHES

This section presents results from a detailed examination of individual crash cases deemed as a priority for intervention opportunities by new advanced restraints with pre-crash sensing capability. Section 3 identified five crash scenarios of interest based upon their societal harm in terms of fatalities and functional years lost by the driver and $FSP13^+$. Target vehicles encompassed light vehicles of $MY98^+$ with frontal damage from the first harmful event. Selection of $MY98^+$ light vehicles was due to the presence of second generation air bags. This analysis included target vehicles in which the driver or $FSP13^+$ suffered an injury level of $MAIS3^+$. All relevant cases belonging to the following five crash scenarios were selected from the 1997-2006 CDS databases for further examination:

- Opposite direction pre-crash scenarios with different impact modes;
- Rear-end pre-crash scenarios with front-to-back impact mode;
- LTAP/OD pre-crash scenarios with different impact modes;
- Road departure pre-crash scenarios; and
- Control loss pre-crash scenarios.

4.1. Selection and Review of Vehicle and Occupant Cases

All relevant cases from the CDS were divided and assigned to different reviewers from NHTSA and its contractors. Cases lacking clarity or missing information were subjected to a group review or discarded. After NHTSA examination, all cases were then reviewed by the private partners from the automotive industry to assess the reviewer dispositions. Reviewers were asked to consider coded, photographic, graphic, and supplementary unedited data sources, resident on the NASS CDS case access viewer. Instructions were given to reviewers prior to accessing this viewer to encourage uniformity in consideration and synthesis of analysis. In addition, a tool called BARCAP was developed for this analysis to pull down relevant information from the CDS and guide the review process.[12] The goal of the tool is to associate injuries to the relevant restraint usage and project the injury mitigation to which the occupant might have been helped in the presence of an advanced restraint. This tool also serves as a synthesis instrument allowing for easy summarization and interpretation of reviewer results.

During the review, consideration was given to the role of active and passive restraint systems resident in the target vehicle. Further, the applicability of newer generation restraint systems was assessed in terms of their potential capability to mitigate or avoid injuries produced in the various crash types. In each vehicle case, the driver and $FSP13^+$ with $AIS3^+$ injuries were examined separately. This examination focused on injured occupants who were restrained using a lap and shoulder belt and their air bag was deployed. All $AIS3^+$ injuries were included; however, many lower extremity cases exist in which the present restraint or an advanced restraint would have been superfluous based upon the specific crash parameters. Consideration, however, was given to the potential presence of knee air bags and their role in injury mitigating or prevention. Each body region was analyzed separately if a driver or $FSP13^+$ had $AIS3^+$ injuries to more than one body region. If a single body region sustained multiple AIS3^{+} injuries, the analysis then concentrated on the most severe injury.

Injury information was based on vehicle inspection and injury assessment records. Vehicle inspection involved an examination of the vehicle and evidence of relevant occupant contact. This was tempered by a review of medical records and vehicle contact assessment. The case reviewer consulted the various photographs taken in support of the crash investigation, scene diagram, and the unedited text version of crash events. Table 25 lists the number of relevant vehicle and occupant files reviewed and disaggregates them by reviewer disposition. Counts of vehicles and occupants were weighted to reflect national CDS representation. These dispositions were assessed relevant to the injuries sustained and the applicability of a restraint system. It should be noted that the majority of relevant occupants was submitted to the automotive partners as candidate members of advanced restraints systems. Overall, 71 percent of the weighted number of vehicles and occupants (63 percent of counts) were accepted for further examination.

Table 25. Number of Relevant Vehicles and Occupants by Reviewer Disposition

Reviewer Disposition	Vehicles		Occupants	
	Weighted	Count	Weighted	Count
Accepted	32,134	389	33,006	407
Rejected	12,739	226	13,434	239
Questionable	145	1	145	1
Total	45,018	616	46,585	647

4.2. Examination of Vehicles

The following analyses were conducted on target vehicles that were accepted by case reviewers as candidates for ARS applications. Based on weighted case counts, these analyses looked into the frequency breakdown of vehicles by crash scenario and number of impact events, Delta V, rotation as a result of collision, and frontal damage location and offset percentage.

4.2.1. Breakdown of Vehicles by Crash Scenario and Number of Events

Figure 12 shows a breakdown of the weighted number of accepted vehicle cases by the five crash scenarios. About 62 percent of the vehicles were involved in single-vehicle crashes: road departure and control loss. Of these single-vehicle crashes, 72 percent of the vehicles had a single impact or a multi-impact crash in which the first event was the most harmful. In contrast, 93 percent of the vehicles involved in multi-vehicle crashes experienced a single impact or a most harmful first event in a multi-impact crash. In general, only 20 percent of target vehicles were involved in multi-impact crashes where the most harmful event resulted from secondary impacts.

Figure 13 shows the breakdown of target vehicle cases by the crash scenario and event category. The following results can be observed:

- Opposite direction crashes had the highest rate of single events (58%);
- Rear-end crashes had the highest rate of multi-impact, most harmful first events (57%); and
- Road departure crashes had the highest rate of multi-impact, most harmful secondary events (30%).

In multi-impact crashes in which the most harmful event happened in secondary events, about 87 percent of the target vehicles experienced frontal damage in the most severe event. Damage to the undercarriage was reported as the most severe event in 6 percent of the vehicles. The remaining 7 percent of the vehicles had even split between right and left damage areas in the most severe event. Overall, 98 percent of the target vehicles suffered frontal damage in the most harmful event in single- and multi-impact crashes. Thus, the remainder of this section presents results independent of the number of impact events. The reader is referred to Appendix D for examination results broken down by single-impact crashes, multi-impact first most harmful event crashes, and multi-impact secondary most harmful event crashes.

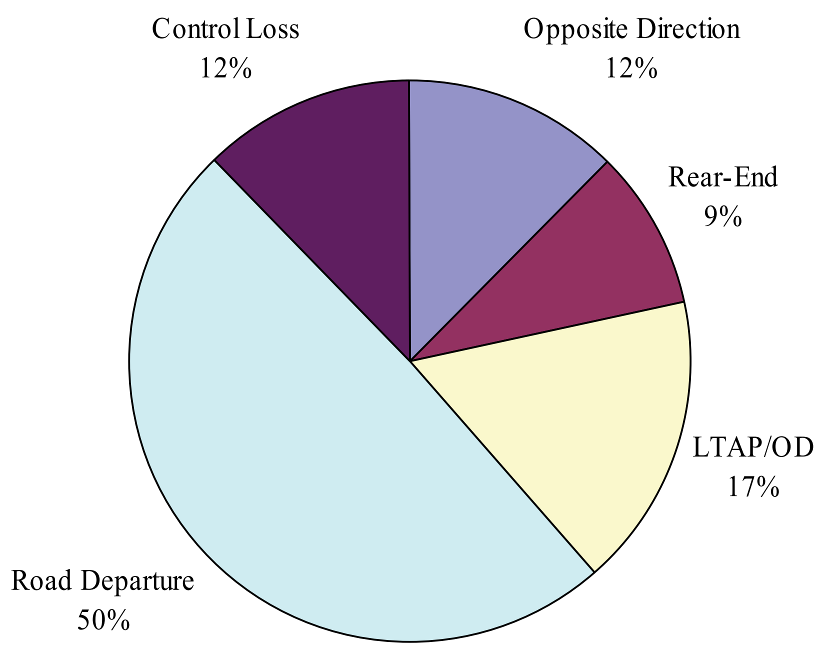


Figure 12. Breakdown of Weighted Vehicle Cases by Crash Scenario

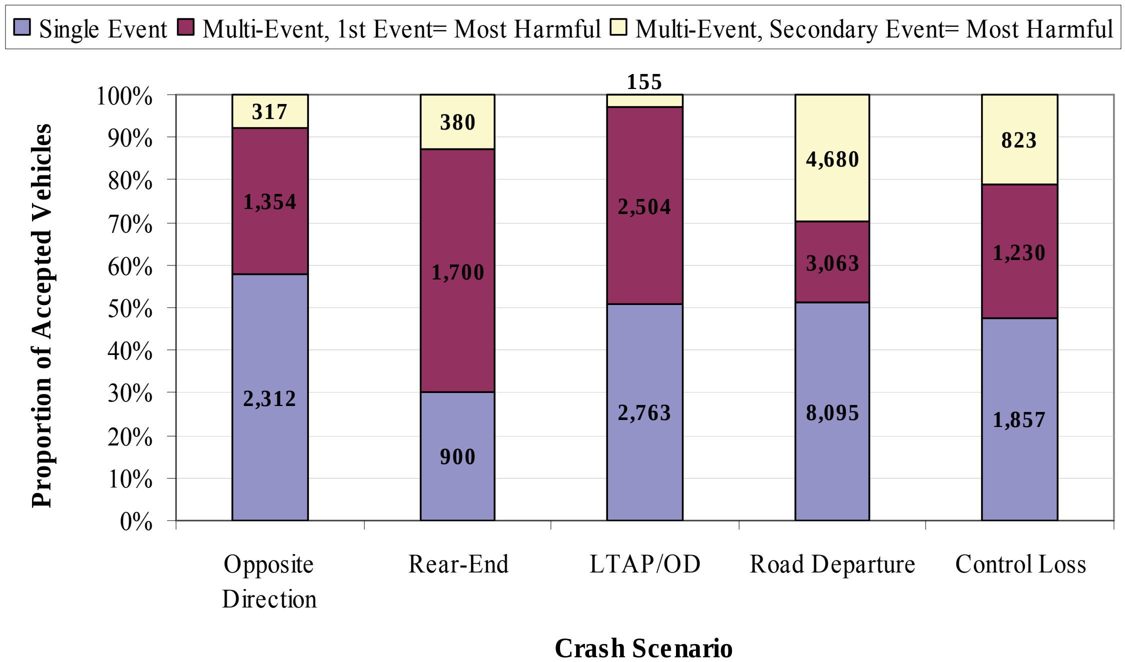


Figure 13. Breakdown of Weighted Vehicle Cases by Crash Scenario and Event

4.2.2. Breakdown of Vehicles by Delta V

Figure 14 shows a cumulative distribution of accepted vehicle cases by delta V (ΔV). This parameter quantifies the change in velocity as a result of the impact. This is a crash severity indicator for planar crashes. NASS CDS tow-away crashes are divided into units called events. Each event contains basic information. The event producing the highest ΔV in the crash is ranked as the most severe event. In addition, the most severe event is identified as planar or rollover. Upon being elevated to the most severe or second most severe event, crush measurements are taken for the damaged plane. Precise orientations of the crush are taken for each damaged plane. Then, ΔV is calculated from planar events for which meaningful crush measurements can be taken. For planar crashes without adequate crush measurements to calculate ΔV, a quantitative or qualitative estimate of ΔV can be made by the researcher. The experience of the researcher and the evidence of the crash will dictate the estimate made.

The plot in Figure 14 represents a redistribution of vehicles with calculated ΔV values. Not included were 24 percent of the vehicles that had other or unknown information coded in the CDS. About 96.5 percent of the vehicles experienced ΔV below 70 km/h. Moreover, 50.2 percent of the vehicles had ΔV values below 30 km/h.

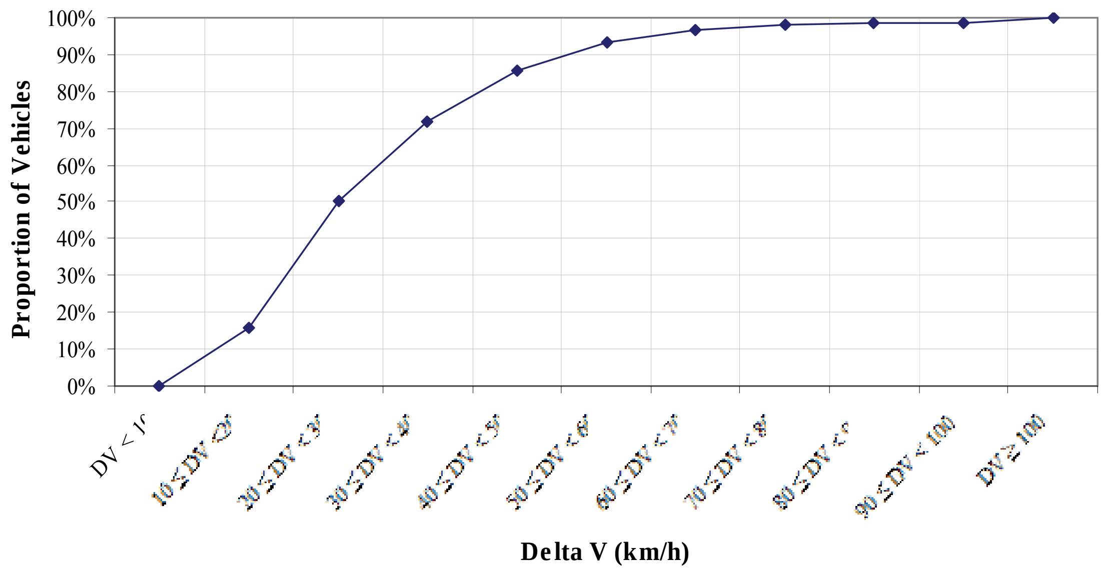


Figure 14. Cumulative Distribution of Vehicles by Delta V

4.2.3. <u>Breakdown of Vehicles by Rotation</u>

Figure 15 shows the distribution of vehicles by rotation and direction, excluding cases with unknown information. There were about 36 percent of the vehicles with unavailable information about rotation as a result of the crash. By excluding unknown cases and proportionally redistributing known cases, about 11 percent of the vehicles did not spin as a result of the collision, 50 percent rotated counter-clockwise (CCW), and 39 percent rotated clockwise (CW).

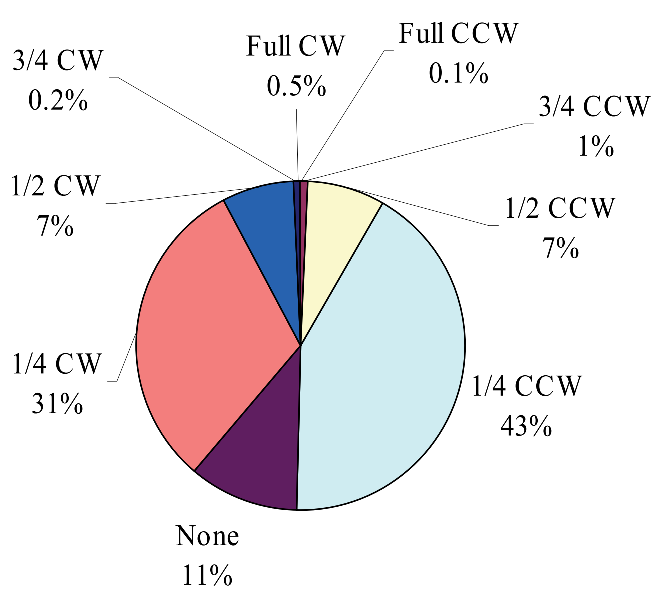


Figure 15. Distribution of Vehicles by Rotation and Direction

4.2.4. Breakdown of Vehicles by Damage Location and Offset

Figure 16 illustrates a breakdown of the number of vehicles by damage location and offset percentage. The offset percentage is the ratio of the damage width to the undeformed end width of the vehicle. Center, right, and left indicates the frontal plane section of the vehicle that was damaged. The DVD variable in the CDS was used to identify the location, in centimeters, as follows: center = 0, right = 1 → 300, and left = -1 → -300. The three-dimensional plot shows that:

- 51 percent of the vehicles sustained left frontal damage with offset percentage of 50 percent or less;
- 23 percent of the vehicles suffered center frontal damage with offset percentage greater than 50 percent; and
- 17 percent of the vehicles experienced right frontal damage with offset percentage of 50 percent or less.

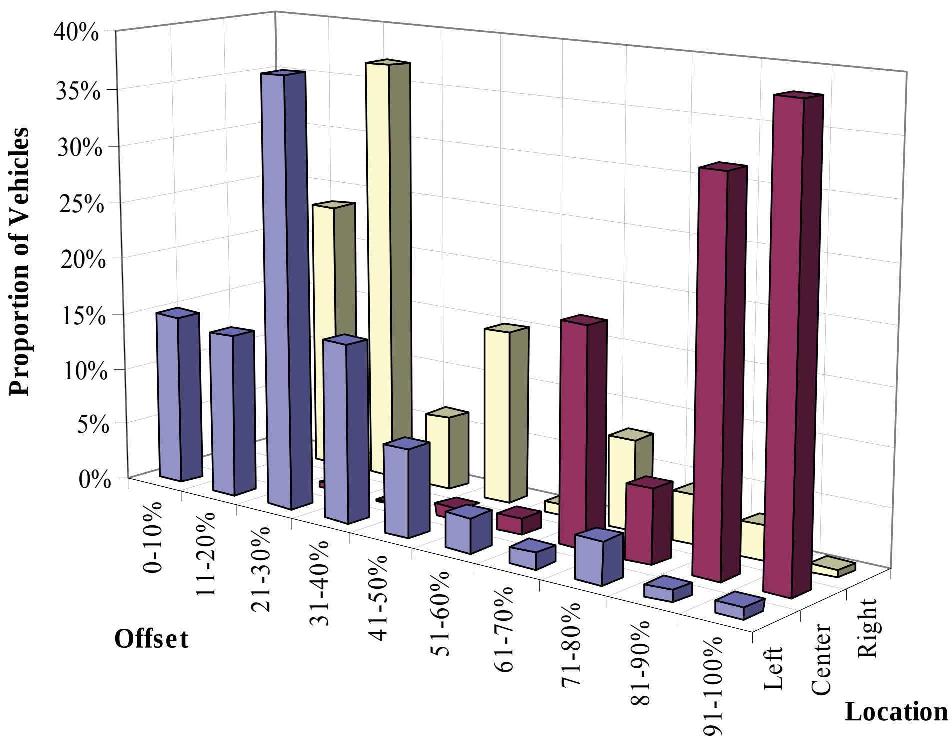


Figure 16. Distribution of Vehicles by Damage Location and Offset

4.3. Examination of Occupants

The following analyses were conducted on target occupants who were accepted by case reviewers as candidates for ARS applications. Based on weighted case counts, these analyses looked into the frequency breakdown of occupants by crash scenario and number of impact events, delta V, vehicle rotation as a result of collision, and frontal damage location and offset percentage.

4.3.1. Breakdown of Occupants by Crash Scenario and Number of Events

Figure 17 shows a breakdown of the weighted number of accepted occupant cases by the five crash scenarios. About 61 percent of the occupants were traveling in vehicles that were involved in single-vehicle crashes: road departure and control loss. Of these occupants involved in single-vehicle crashes, 72 percent of the occupants were in a single impact or a multi-impact crash in which the first event was the most harmful. In contrast, 93 percent of the occupants who were involved in multi-vehicle crashes were traveling in vehicles sustaining a single impact or a most harmful first event in a multi-impact crash. In general, only 20 percent of target occupants were involved in multi-impact crashes where the most harmful event resulted from secondary impacts.

Figure 18 shows the breakdown of target occupant cases by the crash scenario and event category. The following results can be observed:

- Opposite direction crashes had the highest rate of occupants in single events (59% of all occupants in opposite direction crashes);
- Rear-end crashes had the highest rate of occupants in multi-impact, most harmful first events (53% of all occupants in rear-end crashes); and
- Road departure crashes had the highest rate of occupants in multi-impact, most harmful secondary events (30% of all occupants in road departure crashes)

In multi-impact crashes in which the most harmful event happened in secondary events, about 87 percent of the target occupants were in vehicles experiencing frontal damage in the most severe event. Damage to the undercarriage was reported as the most severe event for 6 percent of the occupants. The remaining 7 percent of the occupants were evenly split between right and left damage areas of the vehicles in the most severe event. Overall, 98 percent of the target occupants were in vehicles suffering frontal damage in the most harmful event in single- and multi-impact crashes. Thus, the remainder of this section presents occupant results independent of the number of impact events.

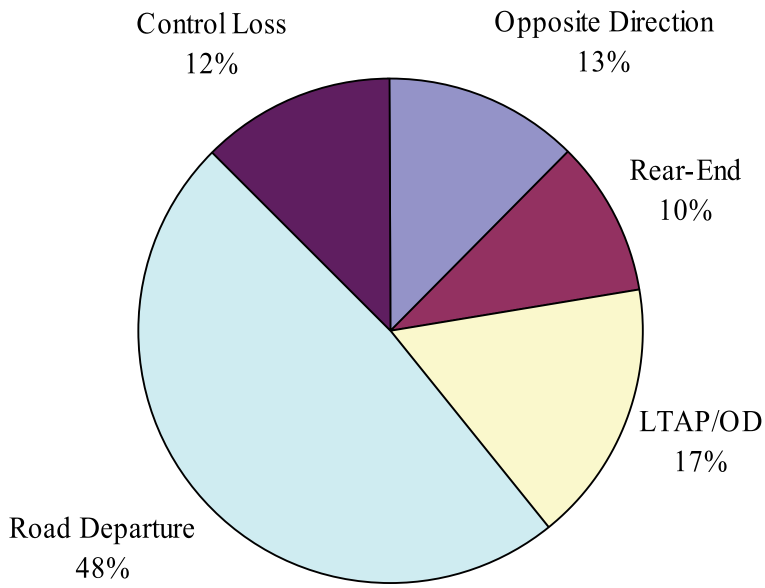


Figure 17. Breakdown of Weighted Occupant Cases by Crash Scenario

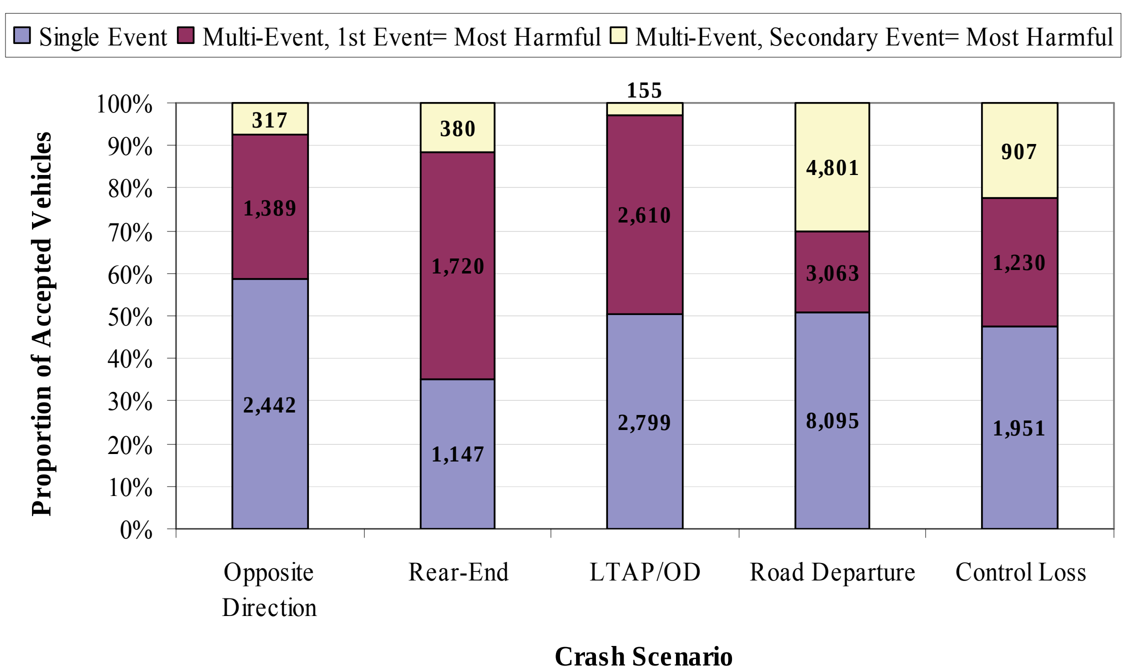


Figure 18. Breakdown of Weighted Occupant Cases by Crash Scenario and Event

4.3.2. Breakdown of Occupants by Vehicle Delta V

Figure 19 shows a cumulative distribution of accepted occupant cases by ΔV. The plot in Figure 19 represents a proportional redistribution of vehicles with only calculated ΔV values. Not included were 24 percent of the occupants in vehicles that had other or unknown information coded in the CDS. About 96.4 percent of the occupants were in vehicles that experienced ΔV below 70 km/h. Moreover, 48.9 percent of the occupants were in vehicles having ΔV values below 30 km/h.

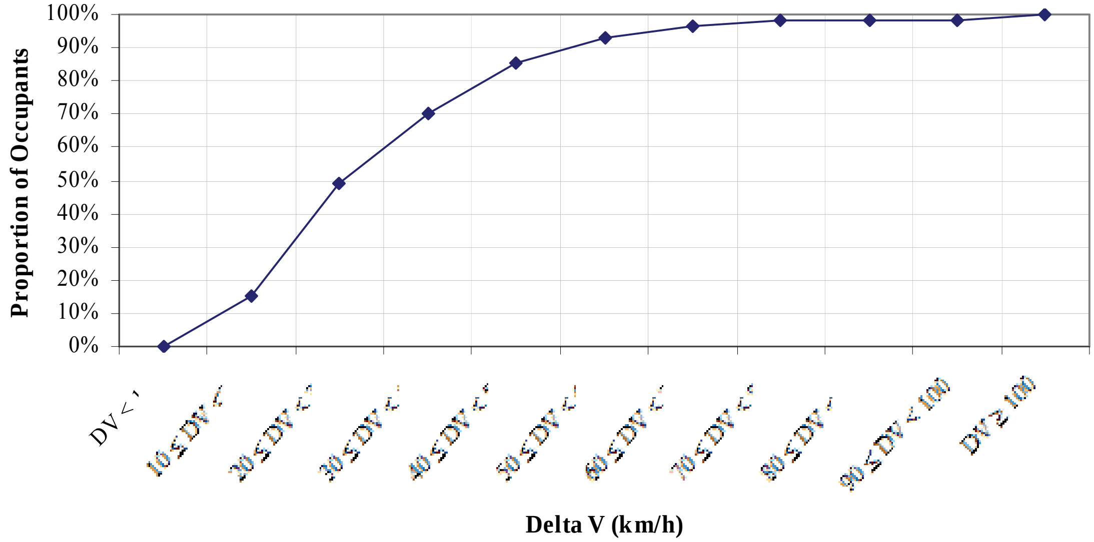


Figure 19. Cumulative Distribution of Occupants by Delta V

4.3.3. Breakdown of Occupants by Vehicle Rotation

Figure 20 shows the distribution of occupants by vehicle rotation and direction, excluding vehicle cases with unknown information. There were about 36 percent of the occupants in vehicles with unavailable information about rotation as a result of the crash. By excluding unknown cases and proportionally redistributing known cases, about 11 percent of the occupants were in vehicles that did not spin as a result of the collision. Moreover, 50 percent and 39 percent of the occupants were in vehicles that rotated respectively counter-clockwise and clockwise.

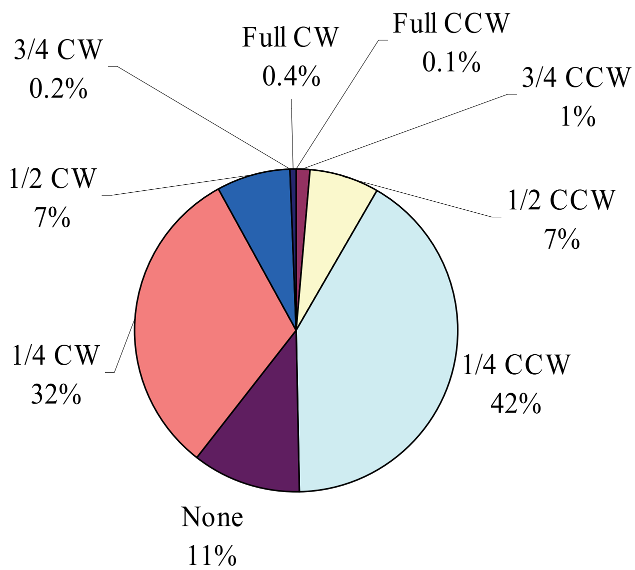


Figure 20. Distribution of Occupants by Vehicle Rotation and Direction

4.3.4. Breakdown of Occupants by Vehicle Damage Location and Offset

Figure 21 illustrates a breakdown of the number of occupants by vehicle damage location and offset percentage. The three-dimensional plot shows that:

- 50 percent of the occupants were in vehicles sustaining left frontal damage with offset percentage of 50 percent or less;
- 23 percent of the occupants were in vehicles suffering center frontal damage with offset percentage greater than 50 percent; and
- 17 percent of the occupants were in vehicles experiencing right frontal damage with offset percentage of 50 percent or less.

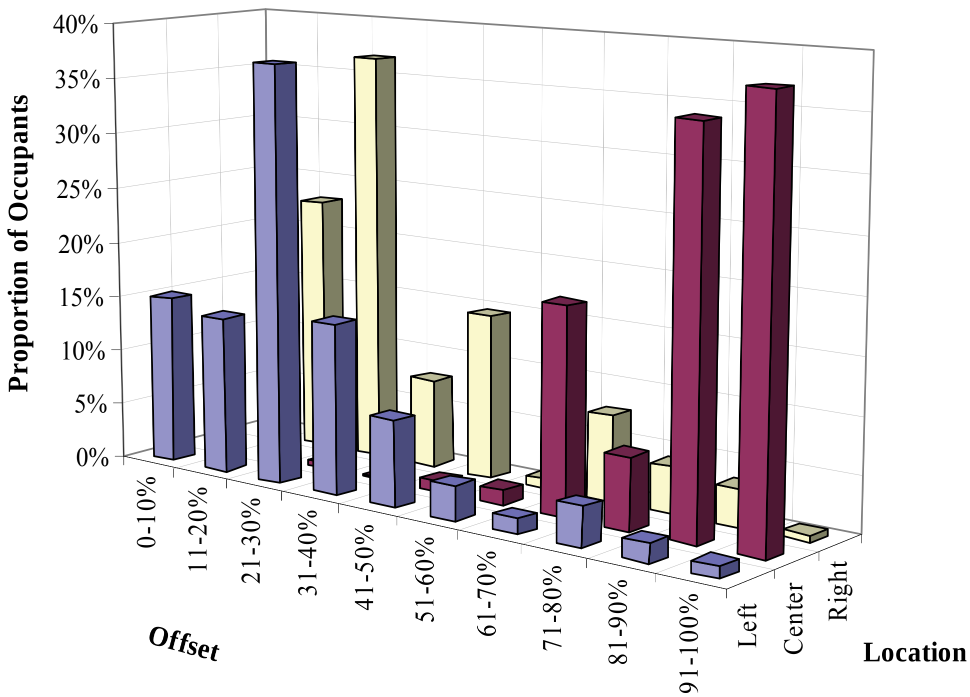


Figure 21. Distribution of Occupants by Vehicle Damage Location and Offset

4.4. Examination of Injuries

Approximately 33,000 target occupants in 32,000 target vehicles suffered an estimate of 42,000 injuries at MAIS3$^+$. Figure 22 shows a distribution of these injuries by injured body region. The highest injured body region was the chest at 36 percent of all MAIS3$^+$ injuries. This was followed by the lower extremity. About 48 percent of MAIS3$^+$ injuries were associated with extremities. Figure 23 provides a distribution of MAIS3$^+$ injuries by crash scenario. Road departure resulted in most MAIS3$^+$ injuries at 49 percent. Overall, single-vehicle crashes and multi-vehicle crashes accounted respectively for 61 percent and 39 percent of all MAIS3$^+$ injuries to target occupants. Table 26 lists the weighted counts of MAIS3$^+$ injuries by injured body region and crash scenario.

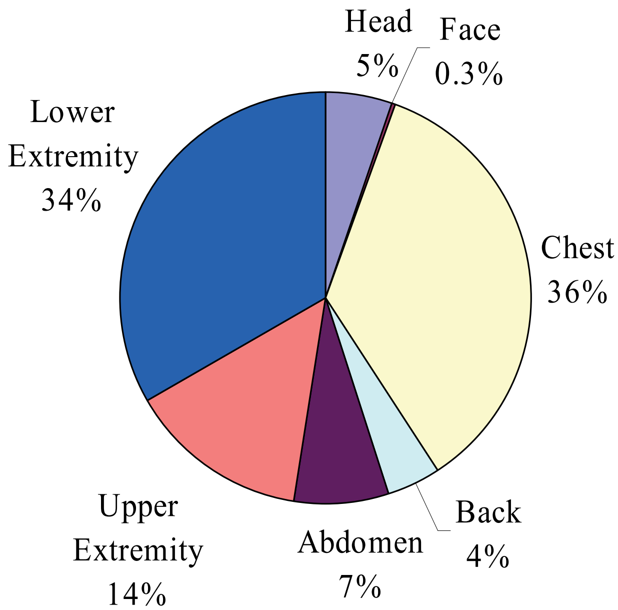


Figure 22. Distribution of MAIS3+ Injuries by Body Region

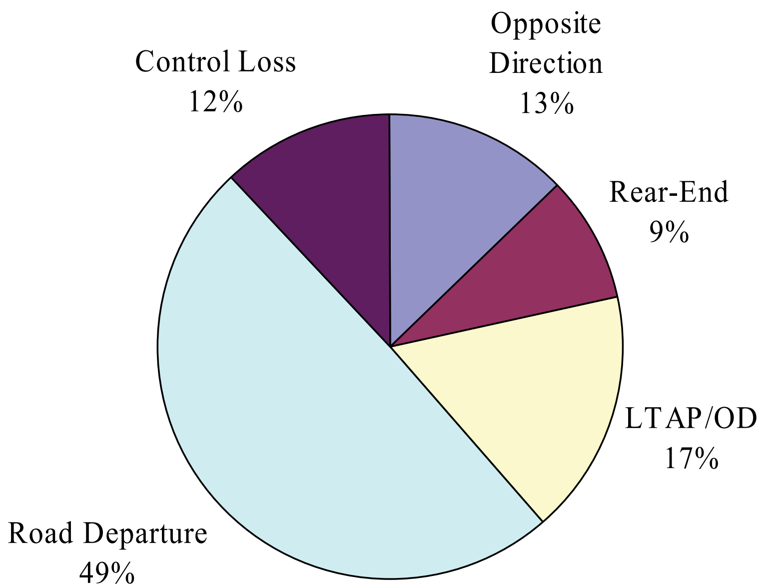


Figure 23. Distribution of MAIS3+ Injuries by Crash Scenario

Table 26. Breakdown on MAIS3$^+$ Injury Counts by Body Region and Crash Scenario

Crash Scenario	Head	Face	Chest	Back	Abdomen	Upper Extremity	Lower Extremity	Total
Opposite Direction	178	18	1,538	125	702	535	2,301	5,398
Rear-End	191	0	297	204	42	804	2,205	3,743
LTAP/OD	526	4	1,961	108	272	1,944	2,312	7,127
Road Departure	1,088	60	8,558	776	1,838	2,358	6,243	20,921
Control Loss	278	58	2,463	605	245	344	1,064	5,057
Total	2,262	140	14,817	1,817	3,099	5,985	14,125	42,246

4.4.1. Analysis of Concurrent Injuries

An analysis was conducted to identify the number of target occupants who sustained concurrent injuries each at MAIS3$^+$. The analysis considered the possibility that the occurrence of one injury with another might lead to different, if not more serious, outcome. It is also noted that MAIS, in this discussion, references the most severe injury by body region; therefore, the maximum injury for a given body region could fall below the maximum injury severity sustained by an occupant and no injury to a body region could exceed the maximum injury severity sustained by the occupant. The following three pairs of injuries were examined: head and chest, abdomen and chest, and neck and back. Results showed that 3.7 percent of the target occupants had concurrent MAIS3$^+$ abdomen and MAIS3$^+$ chest injuries. Similarly, concurrent MAIS3$^+$ head and MAIS3$^+$ chest injuries were observed in 3.1 percent of the occupants. There were no concurrent MAIS3$^+$ neck and MAIS3$^+$ back injuries. Figure 24 shows the percentage of occupants suffering concurrent MAIS3$^+$ injuries in each crash scenario. Concurrent MAIS3$^+$ head and chest injury rates were the highest in LTAP/OD and control loss crash scenarios. Single-vehicle crashes from road departure and control loss had the highest concurrent MAIS3$^+$ abdomen and chest injury rates.

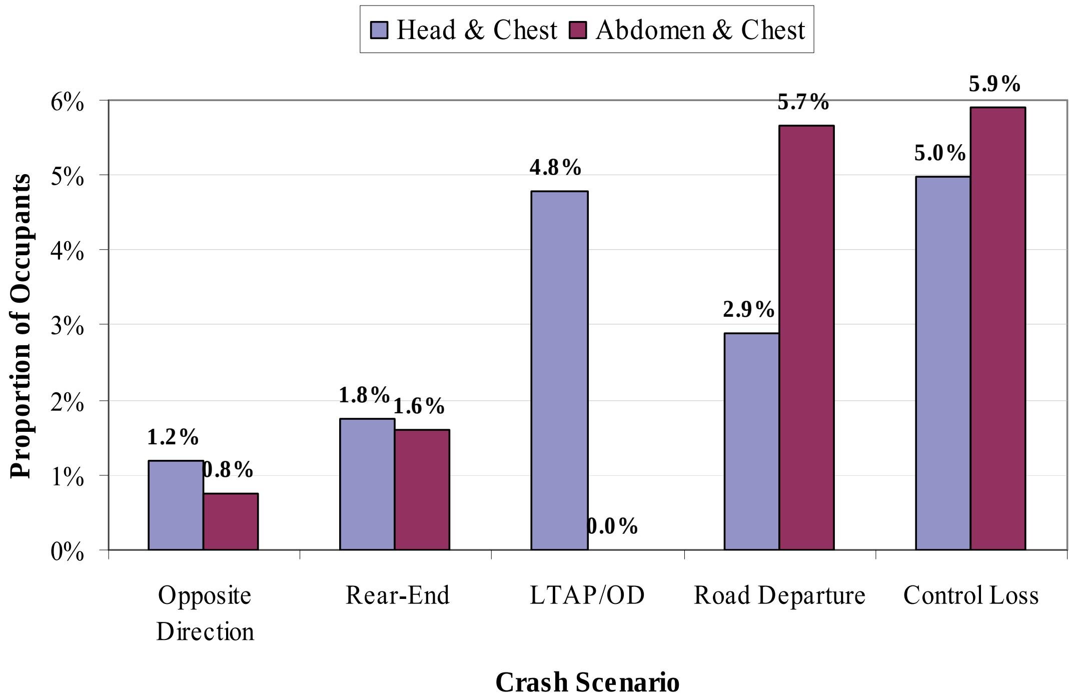


Figure 24. Rates of Concurrent MAIS3$^+$ Injuries by Crash Scenario

4.4.2. Analysis of Injury Sources

Figure 25 shows the distribution of MAIS3$^+$ injuries by the source of injury in the vehicle as identified by the case reviewer. Other non-specific sources of injury were reported as the highest rate at 23 percent of MAIS3$^+$ injuries. The instrument panel, a seat belt, and the steering wheel were the three other sources of injury reported each at a rate over 10 percent, respectively at 18 percent, 16 percent, and 15 percent of MAIS3$^+$ injuries. Air bags and knee bolsters followed respectively at 8 percent and 7 percent of MAIS3$^+$ injuries.

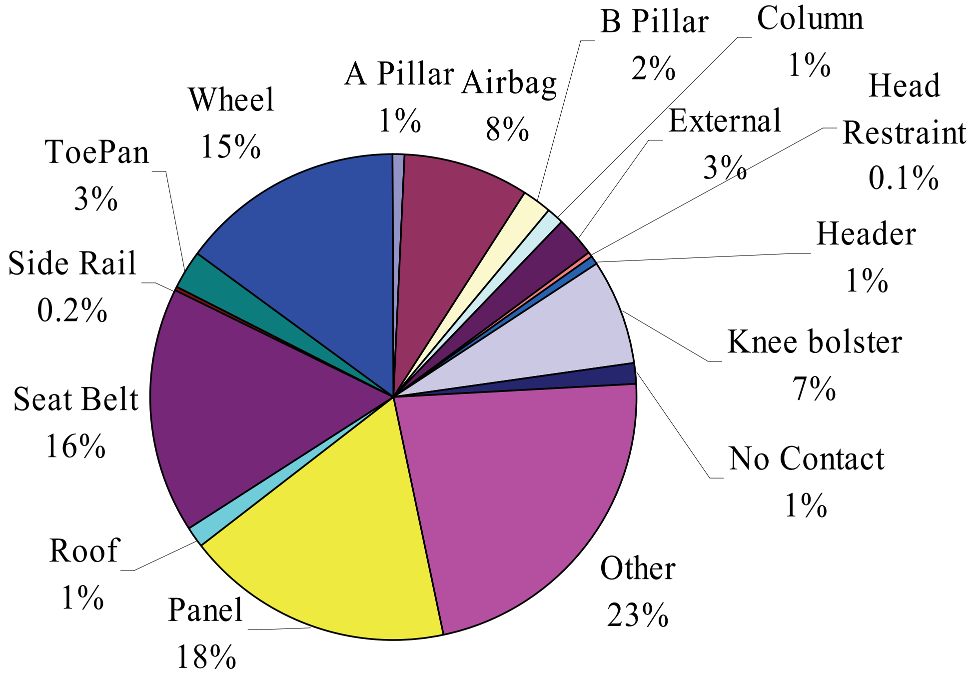


Figure 25. Distribution of $MAIS3^+$ Injuries by Source of Injury

Table 27 provides percentage values of $MAIS3^+$ injury source contribution rates to each body region. The highest rate to each body region is highlighted in yellow. The steering wheel had the highest contribution rate in chest, head, and upper extremity body regions. Injury to the abdomen was caused predominantly by the seat belt at an extreme rate of 83 percent. It should be noted that target occupants were all belted. Instrument panel caused the highest rate of injury to the lower extremity at 40 percent.

Table 28 provides percentage values of $MAIS3^+$ injury source contribution rates in each crash scenario. The highest rate to each body region is highlighted in yellow and the second highest rate is highlighted in tan. Injury sources indicated by the reviewers as “other” were the most dominant in multi-vehicle crashes. A seat belt was the second highest contributor to $MAIS3^+$ injury in opposite direction and rear-end crashes. On the other hand, a knee bolster was the second highest injury source in LTAP/OD crashes. It is interesting that the instrument panel was the most dominant injury source in road departure crashes while the steering wheel was the most prevalent in control loss crashes.

Table 27. Percentage of MAIS3+ Body Region Injuries by Injury Source

Injury Source	Abdomen	Back	Chest	Face	Head	Lower Extremity	Upper Extremity
A Pillar				20%	8%		2%
Air Bag		10%	19%		8%	3%	9%
B Pillar		7%			20%		1%
Column			4%				1%
External				35%	5%	2%	11%
Head Restraint					1%		
Header				10%	3%		3%
Knee bolster						19%	
No Contact		19%			3%		
Other	14%	24%	19%	19%	14%	28%	25%
Panel			1%		5%	40%	16%
Roof		22%			3%		
Seat Belt	83%	4%	28%		3%	1%	
Side Rail					3%		
ToePan						7%	
Wheel	3%	14%	29%	16%	23%	1%	33%
Total	100%	100%	100%	100%	100%	100%	100%

Table 28. Percentage of MAIS3+ Injuries in Crash Scenarios by Injury Source

Injury Source	Opposite Direction	Rear-End	LTAP/OD	Road Departure	Control Loss
A Pillar	2%		2%		1%
Air Bag	11%	10%	2%	12%	
B Pillar		1%	7%	1%	4%
Column	3%		1%		1%
External				3%	11%
Head Restraint					
Header	1%	5%			
Knee bolster	14%		25%		
No Contact	3%	9%			
Other	34%	50%	27%	13%	23%
Panel	3%	9%	10%	30%	11%
Roof				2%	2%
Seat Belt	16%	12%	11%	20%	14%
Side Rail			1%		
ToePan	5%	1%	6%	1%	3%
Wheel	6%	4%	9%	19%	30%
Total	100%	100%	100%	99%	100%

5. CONCLUSIONS

Crash analyses were performed to identify and prioritize crash scenarios and occupant injuries that could be amenable to the application of advanced restraints based on pre-crash sensors. These analyses targeted the driver and $FSP13^+$, traveling in light vehicles of $MY98^+$ that sustained frontal damage. Two types of crash analysis were conducted based on the first harmful event or the most harmful event in a crash. This distinction only impacts crashes with multiple events.

The first type of crash analysis involved data queries of the 1997-2005 CDS databases. This analysis correlated injured body regions and their concomitant injury severity levels to high-level crash scenarios. Injury data were reported based on the most harmful event in multi-impact crashes. High-level scenarios represented combinations of obstacle type struck, number of impacts, occupant type, and occupant restraint use. The following observations were made:

- 56 percent of all $MY98^+$ light vehicles suffered frontal damage from the most harmful event (target vehicles) based on 1997-2005 CDS statistics;
- 62 percent of target vehicles were involved in single-impact crashes and 73 percent of target vehicles were engaged in vehicle-vehicle crashes;
- 90 percent of drivers in target vehicles were belted. Drivers had the highest $MAIS3^+$ risk (12%) when unbelted in multi-impact crashes and the lowest (1%) when belted in vehicle-vehicle crashes;
- 86 percent of $FSP13^+$ in target vehicles were belted. $FSP13^+$ had the highest $MAIS3^+$ risk (11%) when unbelted in multi-impact vehicle-object crashes and the lowest (1%) when belted in single-impact vehicle-vehicle crashes;
- Of all known injured body regions by drivers at $MAIS3^+$, lower extremity and chest were the most prevalent respectively at 32 percent and 24 percent. The head ranked third at 19 percent;
- Lower extremity and chest were the most prevalent respectively at 44 percent and 28 percent of all known injured body regions by $FSP13^+$ at $MAIS3^+$. Upper extremity and head were equally ranked third at 11 percent;
- About 1.9 percent of all injured body regions (head, face, etc., with MAIS 1 or higher) by belted drivers and $FSP13^+$ sustained $MAIS3^+$ injuries. In contrast, this rate was 7.2 percent for unbelted drivers and $FSP13^+$; and
- Lower extremity, chest, upper extremity, and head accounted respectively for 33 percent, 27 percent, 18 percent, and 12 percent of all $MAIS3^+$ injuries by belted drivers and $FSP13^+$.

The second type of crash analysis involved a top-down analysis of the 2002-2006 FARS, 2006 GES, and 1997-2006 CDS data to identify and prioritize pre-crash scenarios and impact modes. The focus was on vehicles with frontal damage from the first harmful event. Data queries of the three national crash databases identified and prioritized target crashes for ARS applications based on the number of fatalities and FYL counting drivers and FSP13$^+$ with MAIS3$^+$ injuries only. This top-down crash analysis did not distinguish target occupants by belt use. Results from vehicle-object crashes were:

- Based on FARS data, 90 percent of target occupant fatalities in target vehicles were attributed to crashes in which the vehicle first struck the ground, a structure, atree, or a pole. A tree, ditch, guardrail face, embankment, or pole specifically accounted for 55 percent of the fatalities in this order.
- GES statistics identified ground, structure, tree, or pole as first obstacle struck, accounting for 87 percent of FYLs. Road departure and control loss pre-crash scenarios led to 81 percent of FYLs.
- CDS statistics identified road departure and control loss pre-crash scenarios yielding 96 percent of FYLs. Pole was the leading first obstacle struck and was followed by structure, ground, and tree. Target vehicles first striking ground, pole, structure, or tree in road departure scenarios dominated at 73 percent of FYLs.

General data queries of vehicle-vehicle crashes revealed the following:

- Based on FARS data, about 98 percent of target occupant fatalities in target vehicles were attributed to crashes in which the front of the target vehicle first struck the front, left side, right side, or back of another vehicle. GES and CDS identified the following order: front, back, left side, and right side.
- Opposite direction, rear-end, turning at junction, straight crossing paths, and LTAP/OD pre-crash scenarios were common between the GES and CDS. All five scenarios accounted for 87 percent and 92 percent of FYLs respectively in GES and CDS.
- The top five pre-crash scenario and impact mode combinations in the GES and CDS contributed respectively to 57 percent and 75 percent of FYLs.

Based on results from general data queries that prioritized pre-crash scenario and impact mode combinations, individual crash cases were selected from the 1997-2006 CDS for further examination to link occupant injuries to injury sources and pre-crash scenarios. These cases were reviewed for potential mitigation by ARS. Target occupants were restricted to belted drivers and FSP13$^+$ due to more intervention opportunities by near-term ARS technologies to improve occupant protection. Overall, 71 percent of the weighted number of vehicles and belted occupants were accepted for further examination. The raw numbers of CDS cases were 389 vehicles and 407 occupants. Results showed:

- 72 percent of occupants in single-vehicle crashes were in a single- or multi-impact crash in which the first event was the most harmful. In contrast, this rate was 93 percent in multi-vehicle crashes.
- 96 percent of occupants were in vehicles with ΔV below 70 km/h.
- 89 percent of occupants were in vehicles that spun around as a result of the collision.
- 50 percent and 17 percent of occupants were in vehicles sustaining left and right frontal damage, respectively, with offset percentage of 50 percent or less. The remaining 23 percent were in vehicles with center frontal damage at offset percentage greater than 50 percent.

- Single- and multi-vehicle crashes accounted respectively for 61 percent and 39 percent of all $MAIS3^+$ injuries to occupants.
- Chest was the highest injured body region at 36 percent of all $MAIS3^+$ injuries. 48 percent of $MAIS3^+$ injuries were associated with lower and upper extremities.
- 4 percent of occupants had concurrent $MAIS3^+$ abdomen and $MAIS3^+$ chest injuries. Concurrent $MAIS3^+$ head and $MAIS3^+$ chest injuries were observed in 3 percent of the occupants. There were no concurrent $MAIS3^+$ neck and $MAIS3^+$ back injuries.
- Other non-specific sources of injury were reported as the highest rate at 23 percent of $MAIS3^+$ injuries. Instrument panel, seat belt, and steering wheel followed respectively at 18 percent, 16 percent, and 15 percent of $MAIS3^+$ injuries. Air bag and knee bolster were noted at 8 percent and 7 percent of $MAIS3^+$ injuries.
- The steering wheel had the highest contribution rate to injury in chest, head, and upper extremity body regions. Injury to the abdomen was caused predominantly by the seat belt at an extreme rate of 83 percent. The instrument panel caused the highest rate of injury to the lower extremity at 40 percent.

Results from these crash analyses were used by the automotive partners and their supplier contacts to devise potential countermeasure concepts based on pre-crash sensing ARS and to develop preliminary functional requirements.[4] Development of objective test procedures and estimation of safety benefits constitute next research steps.

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Appendix A. Pre-Crash Scenario Coding for Single-Vehicle Crashes

```
/*First Pass*/

if (VEHFORMS = 1 AND premove = 0) then sv_scen = 1; /*No driver
present*/

else if (VEHFORMS = 1 AND (1<=PREEVENT<=4)) then sv_scen = 2; /*Vehicle
failure*/

else if (VEHFORMS = 1 AND (5<=PREEVENT<=9) AND (premove
in(2,3,4,6,8,9,10,11,12) OR (15<=premove<=97))) then sv_scen = 3;
/*Control loss - vehicle action*/

else if (VEHFORMS = 1 AND (5<=PREEVENT<=9) AND (premove in(1,14))) then
sv_scen = 4; /*Control loss - no vehicle action*/

else if (VEHFORMS = 1 AND (5<=PREEVENT<=9) AND premove = 13) then
sv_scen = 5;/*Control loss - vehicle backing*/

else if (VEHFORMS = 1 AND (PREEVENT in(10,11,12,13,14)) AND (premove
in(6,8,9,10,11,12) OR (15<=premove<=97))) then sv_scen = 6;/*Road
departure – vehicle maneuver*/

else if (VEHFORMS = 1 AND (PREEVENT in(10,11,12,13,14)) AND (premove
in(1,2,3,4,14))) then sv_scen = 7;/*Road departure - no vehicle
maneuver*/

else if (VEHFORMS = 1 AND (10<=PREEVENT <=14) and premove = 13) then
sv_scen = 8;/*Road departure – vehicle backing*/

else if (VEHFORMS = 1 AND (80<=PREEVENT<=82) AND  (premove

/*Pedestrian – vehicle maneuver*/

else if (VEHFORMS = 1 AND  (80<=PREEVENT<=82) AND (premove
in(1,2,3,4,14))) then sv_scen = 10;/*Pedestrian - no vehicle maneuver*/

else if (VEHFORMS = 1 AND (83<=PREEVENT<=85) AND (premove
in(6,8,9,10,11,12) OR (15<=premove<=97))) then sv_scen = 11;/*Cyclist –
vehicle maneuver*/

else if (VEHFORMS = 1 AND (83<=PREEVENT<=85) AND (premove
in(1,2,3,4,14))) then sv_scen = 12;/*Cyclist - no vehicle maneuver*/

else if (VEHFORMS = 1 AND (87<=PREEVENT<=89) AND (premove
in(6,8,9,10,11,12) OR (15<=premove<=97))) then sv_scen = 13;/*Animal –
vehicle maneuver*/

else if (VEHFORMS = 1 AND  (87<=PREEVENT<=89) AND (premove
in(1,2,3,4,14))) then sv_scen = 14; /*Animal - no vehicle maneuver*/

else if (VEHFORMS = 1 AND (PREEVENT in(90,91,92)) AND (premove
in(6,8,9,10,11,12) OR (15<=premove<=97))) then sv_scen = 15;/*Object –
vehicle maneuver*/
```

```
else if (VEHFORMS = 1 AND (PREEVENT in(90,91,92)) AND (premove
in(1,2,3,4,14))) then sv_scen = 16;/*Object – no vehicle maneuver*/

else if (VEHFORMS = 1 AND  (80<=PREEVENT<=92) AND premove = 13) then
sv_scen = 17; /*Pedestrian, cyclist, animal, & object - vehicle
backing*/

else if (VEHFORMS = 1 AND (50<=PREEVENT <=52) AND (premove
in(6,8,9,10,11,12) OR (15<=premove<=97))) then sv_scen = 18;/*Rear-end
– vehicle maneuver*/

else if (VEHFORMS = 1 AND PREEVENT = 50 AND (premove in(1,2,3,4,14)))


else if (VEHFORMS = 1 AND PREEVENT = 51 AND (premove in(1,2,3,4,14)))


else if (VEHFORMS = 1 AND PREEVENT = 52 AND (premove in(1,2,3,4,14)))


else if (VEHFORMS = 1 AND (PREEVENT in(54,62,63)) AND (premove
in(6,8,9,10,11,12) OR (15<=premove<=97))) then sv_scen = 22;/*Opposite
direction – vehicle maneuver*/

else if (VEHFORMS = 1 AND (PREEVENT in(54,62,63)) AND (premove
in(1,2,3,4,14))) then sv_scen = 23;/*Opposite direction - no vehicle
maneuver*/

else if (VEHFORMS = 1 AND PREEVENT = 56) then sv_scen = 24;/*Other
vehicle backing*/

else if (VEHFORMS = 1 AND (PREEVENT in(60,61))) then sv_scen =


else if (VEHFORMS = 1 AND PREEVENT = 64) then sv_scen = 26;/*Other
vehicle from parking*/

else if (VEHFORMS = 1 AND PREEVENT = 16) then sv_scen = 27;/*Turn right
at intersection*/

else if (VEHFORMS = 1 AND (PREEVENT in(17,66,71))) then sv_scen =
29;/*SCP*/

else if (VEHFORMS = 1 AND PREEVENT = 15) then sv_scen = 30;/*Turn left
at intersection*/

else if (VEHFORMS = 1 AND (PREEVENT in(65,67,70,72))) then sv_scen =


else if (VEHFORMS = 1 AND PREEVENT = 74) then sv_scen = 34;/*Other


else if (VEHFORMS = 1 AND (PREEVENT in(53,55,59,68,73,78))) then
sv_scen = 36;/*Avoidance another vehicle*/

else if (VEHFORMS = 1) then sv_scen = 37;/*Other*/
```

```
/*Second Pass*/

else if (VEHFORMS = 1 AND ACCTYPE in(2,7) AND (premove
in(2,3,4,6,8,9,10,11,12,13) OR (15<=premove<=97))) OR (VEHFORMS = 1 AND
(ACCTYPE in (2,7)) AND (PREEVENT in (15,16,18))) then sv_scen =
3;/*Control loss - vehicle action*/

else if (VEHFORMS = 1 AND ACCTYPE in(2,7) AND (premove in(1,14))) then
sv_scen = 4;/*Control loss - no vehicle action*/

else if (VEHFORMS = 1 AND ACCTYPE in(2,7)) then sv_scen = 38;/*Control
loss – unknown vehicle action*/

else if (VEHFORMS = 1 AND (ACCTYPE in (1,6,11,14)) AND (premove
in(6,8,9,10,11,12) OR (15<=premove<=97))) then sv_scen = 6;/*Road
departure – vehicle maneuver*/

else if (VEHFORMS = 1 AND (ACCTYPE in(1,6,11,14)) AND (premove
in(1,2,3,4,5,7,14))) OR (VEHFORMS = 1 AND (ACCTYPE in(1,6,11,14)) AND
(PREEVENT in(10,11,12,13,14,17,18))) then sv_scen = 7;/*Road departure
- no vehicle maneuver*/

else if (VEHFORMS = 1 AND (ACCTYPE in(1,6,11,14)) and premove = 13)

backing*/

else if (VEHFORMS = 1 AND ACCTYPE = 12 AND (premove
in(6,8,9,10,11,12,13) OR (15<=premove<=97))) then sv_scen = 15;/*Object
– vehicle maneuver*/

else if (VEHFORMS = 1 AND ACCTYPE = 12 AND (premove
in(1,2,3,4,5,7,14))) then sv_scen = 16;/*Object – no vehicle maneuver*/

else if (VEHFORMS = 1 AND ACCTYPE = 13 AND e1 = 76 AND (premove
in(6,8,9,10,11,12,13) OR (15<=premove<=97))) then sv_scen = 13;/*Animal
– vehicle maneuver*/

else if (VEHFORMS = 1 AND ACCTYPE = 13 AND e1 = 76 AND (premove
in(1,2,3,4,5,7,14))) then sv_scen = 14; /*Animal - no vehicle
maneuver*/

else if (VEHFORMS = 1 AND ACCTYPE = 13 AND e1 = 72 AND (premove
in(6,8,9,10,11,12,13) OR (15<=premove<=97))) then sv_scen = 9;
/*Pedestrian – vehicle maneuver*/

else if (VEHFORMS = 1 AND ACCTYPE = 13 AND e1 = 72 AND (premove
in(1,2,3,4,5,7,14))) then sv_scen = 10;/*Pedestrian - no vehicle
maneuver*/

else if (VEHFORMS = 1 AND ACCTYPE = 13 AND e1 = 73 AND (premove
in(6,8,9,10,11,12,13) OR (15<=premove<=97))) then sv_scen =
11;/*Cyclist – vehicle maneuver*/

else if (VEHFORMS = 1 AND ACCTYPE = 13 AND e1 = 73 AND (premove
in(1,2,3,4,5,7,14))) then sv_scen = 12;/*Cyclist- no vehicle maneuver*/

else if (VEHFORMS = 1) then sv_scen = 37;/*Other*/
```

Appendix B. Pre-Crash Scenario Coding for Multi-Vehicle Crashes

```
/*First Pass*/

if (VEHFORMS GE 2 AND premove = 0) then mv_scen = 1; /*No driver
present*/

else if (VEHFORMS GE 2 AND (1<=PREEVENT<=4)) then mv_scen = 2;
/*Vehicle failure*/

else if (VEHFORMS GE 2 AND (5<=PREEVENT<=9) AND (premove
in(2,3,4,6,8,9,10,11,12) OR (15<=premove<=97))) then mv_scen = 3;
/*Control loss - vehicle action*/

else if (VEHFORMS GE 2 AND (5<=PREEVENT<=9) AND (premove in(1,14)))
then mv_scen = 4; /*Control loss - no vehicle action*/

else if (VEHFORMS GE 2 AND (5<=PREEVENT<=9) AND premove = 13) then
sv_scen = 5; /*Control loss - vehicle backing*/

else if (VEHFORMS GE 2 AND (PREEVENT in(12,13,14)) AND (premove
in(6,8,9,10,11,12) OR (15<=premove<=97))) then sv_scen = 6; /*Road
departure – vehicle maneuver*/

else if (VEHFORMS GE 2 AND (PREEVENT in(12,13,14)) AND (premove
in(1,2,3,4,14))) then sv_scen = 7; /*Road departure - no vehicle
maneuver*/

else if (VEHFORMS GE 2 AND (PREEVENT in(12,13,14)) and premove = 13)
then sv_scen = 8; /*Road departure – vehicle backing*/

else if (VEHFORMS GE 2 AND (80<=PREEVENT<=82) AND  (premove

/*Pedestrian – vehicle maneuver*/

else if (VEHFORMS GE 2 AND  (80<=PREEVENT<=82) AND (premove
in(1,2,3,4,14))) then sv_scen = 10; /*Pedestrian - no vehicle
maneuver*/

else if (VEHFORMS GE 2 AND (83<=PREEVENT<=85) AND (premove
in(6,8,9,10,11,12) OR (15<=premove<=97))) then sv_scen = 11; /*Cyclist
– vehicle maneuver*/

else if (VEHFORMS GE 2 AND (83<=PREEVENT<=85) AND (premove
in(1,2,3,4,14

else if (VEHFORMS GE 2 AND (87<=PREEVENT<=89) AND (premove
in(6,8,9,10,11,12) OR (15<=premove<=97))) then sv_scen = 13; /*Animal –
vehicle maneuver*/

else if (VEHFORMS GE 2 AND  (87<=PREEVENT<=89) AND (premove
in(1,2,3,4,14))) then sv_scen = 14; /*Animal - no vehicle maneuver*/
```

```
else if (VEHFORMS GE 2 AND (PREEVENT in(90,91,92)) AND (premove
in(6,8,9,10,11,12) OR (15<=premove<=97))) then sv_scen = 15;/*Object –
vehicle maneuver*/

else if (VEHFORMS GE 2 AND (PREEVENT in(90,91,92)) AND (premove
in(1,2,3,4,14))) then sv_scen = 16; /*Object – no vehicle maneuver*/

else if (VEHFORMS GE 2 AND  (80<=PREEVENT<=92) AND premove = 13) then
sv_scen = 17; /*Pedestrian, cyclist, animal, & object - vehicle -
backing*/

else if (VEHFORMS GE 2 AND (50<=PREEVENT <=52) AND (premove
in(6,8,9,10,11,12) OR (15<=premove<=97))) then sv_scen = 18; /*Rear-end
– vehicle maneuver*/

else if (VEHFORMS GE 2 AND PREEVENT = 50 AND (premove in(1,2,3,4,14)))
then sv_scen = 19; /*LVS – no vehicle maneuver*/

else if (VEHFORMS GE 2 AND PREEVENT = 51 AND (premove in(1,2,3,4,14)))
then sv_scen = 20; /*LVM – no vehicle maneuver*/

else if (VEHFORMS GE 2 AND PREEVENT = 52 AND (premove in(1,2,3,4,14)))
then sv_scen = 21; /*LVD – no vehicle maneuver*/

else if (VEHFORMS GE 2 AND (PREEVENT in(60,61))) then sv_scen = 25;


else if (VEHFORMS GE 2 AND (PREEVENT in(10,11)) AND (premove
in(6,15,16)) AND ((44<=ACCTYPE<=49) OR (70<=ACCTYPE<=73))) then sv_scen
= 25A; /*Vehicle changing lanes – same direction*/

else if (VEHFORMS GE 2 AND (PREEVENT in(10,11)) AND (premove
in(10,11,12)) AND ((44<=ACCTYPE<=49) OR (70<=ACCTYPE<=73))) then
sv_scen = 25B; /*Vehicle turning – same direction*/

else if (VEHFORMS GE 2 AND (PREEVENT in(10,11)) AND (premove in(1,2,3,
4,14)) AND ((44<=ACCTYPE<=49) OR (70<=ACCTYPE<=73))) then sv_scen =
25C; /*Vehicle drifting – same direction*/

else if (VEHFORMS GE 2 AND PREEVENT = 64) then sv_scen = 26; /*Other
vehicle from parking*/

else if (VEHFORMS GE 2 AND (PREEVENT in(10,11)) AND (premove in(8,9))
AND ((44<=ACCTYPE<=49) OR (70<=ACCTYPE<=73))) then sv_scen = 26A;
/*Vehicle parking – same direction*/

else if (VEHFORMS GE 2 AND (PREEVENT in(54,62,63)) AND
(50<=ACCTYPE<=67) AND (premove in(6,8,9,10,11,12) OR
(15<=premove<=97))) then sv_scen = 22; /*Opposite direction – vehicle
maneuver*/

else if (VEHFORMS GE 2 AND (PREEVENT in(10,11)) AND (50<=ACCTYPE<=67)
AND (premove in(6,8,9,10,11,12) OR (15<=premove<=97))) then sv_scen =
22; /*Opposite direction – vehicle maneuver*/
```

```
else if (VEHFORMS GE 2 AND (PREEVENT in(54,62,63)) AND
(50<=ACCTYPE<=67) AND (premove in(1,2,3,4,5,7,14))) then sv_scen = 23;
/*Opposite direction - no vehicle maneuver*/

else if (VEHFORMS GE 2 AND (PREEVENT in(10,11)) AND (50<=ACCTYPE<=67)
AND (premove in(1,2,3,4,5,7,14))) then sv_scen = 23; /*Opposite
direction - no vehicle maneuver*/

else if ((VEHFORMS GE 2 AND PREEVENT = 56) OR (VEHFORMS GE 2 AND
ACCTYPE = 93)) then sv_scen = 24; /*Other vehicle backing*/

else if (VEHFORMS GE 2 AND ACCTYPE = 92 AND premove = 13) then sv_scen
= 24A; /*Backing up into another vehicle*/

else if (VEHFORMS GE 2 AND PREEVENT = 16 AND (78<=ACCTYPE<=81)) OR
(VEHFORMS GE 2 AND premove = 10 AND (78<=ACCTYPE<=81)) then sv_scen =
27; /*Turn right at junction*/

else if (VEHFORMS GE 2 AND (PREEVENT in(65,67,70,72)) AND
(78<=ACCTYPE<=81)) OR (VEHFORMS GE 2 AND premove NE 10 AND
(78<=ACCTYPE<=81)) then sv_scen = 27A; /*Other vehicle turning right at
junction*/

else if (VEHFORMS GE 2 AND (86<=ACCTYPE<=91)) then sv_scen = 29;
/*SCP*/

else if (VEHFORMS GE 2 AND (ACCTYPE in(68,69))) then mv_scen = = 30A;
/*LTAP/OD*/

else if (VEHFORMS GE 2 AND (74<=ACCTYPE<=85)) then sv_scen = 32A;


else mv_scen = 37; /*Other*/

/*Second Pass*/

else if ((VEHFORMS GE 2 AND (20<=ACCTYPE<=43) AND (premove
in(6,8,9,10,11,12) OR (15<=premove<=97))) OR (VEHFORMS GE 2 AND
(20<=ACCTYPE<=43) AND PREEVENT in(10,11,12,13,15,16))) then sv_scen =
18; /*Rear-end – vehicle maneuver*/

else if ((VEHFORMS GE 2 AND (20<=ACCTYPE<=43) AND PREEVENT = 50) OR
(VEHFORMS GE 2 AND ACCTYPE = 20)) then sv_scen = 19; /*LVS – no vehicle
maneuver*/

else if ((VEHFORMS GE 2 AND (20<=ACCTYPE<=43) AND PREEVENT = 51) OR
(VEHFORMS GE 2 AND ACCTYPE = 24)) then sv_scen = 20; /*LVM – no vehicle
maneuver*/

else if ((VEHFORMS GE 2 AND (20<=ACCTYPE<=43) AND PREEVENT = 52) OR
(VEHFORMS GE 2 AND ACCTYPE = 28)) then sv_scen = 21; /*LVD – no vehicle
maneuver*/
```

```
else if (VEHFORMS GE 2 AND (50<=ACCTYPE<=67) AND (premove
in(6,8,9,10,11,12) OR (15<=premove<=97))) then sv_scen = 22; /*Opposite
direction – vehicle maneuver*/

else if ((VEHFORMS GE 2 AND (50<=ACCTYPE<=67) AND (premove
in(1,2,3,4,5,7,14))) OR (VEHFORMS GE 2 AND (PREEVENT in(10,11,17)) AND
(50<=ACCTYPE<=67)))then sv_scen = 23; /*Opposite direction - no vehicle
maneuver*/

else if (VEHFORMS GE 2 AND (premove in(1,2,3,4,5,7,14)) AND (PREEVENT
in(54,62,63))) then sv_scen = 23; /*Opposite direction - no vehicle
maneuver*/

else if (VEHFORMS GE 2 AND (ACCTYPE in(45,71,73))) then sv_scen = 25;
/*Other vehicle from adjacent lane - same direction*/

else if (VEHFORMS GE 2 AND (ACCTYPE in(74,75)) AND ((PREEVENT
in(15,16)) OR (premove in(10,11,12)))) then sv_scen = 25B; /*Vehicle
turning – same direction*/
```

Appendix C. Driver and FSP13[+] Fatalities in Vehicle-Object Crashes

Obstacle	First Harmful Event	2002	2003	2004	2005	2006	Total	% Total
Tree	Tree	540	603	665	796	851	3,455	22.7%
Ground	Ditch	151	168	232	273	405	1,229	8.1%
Structure	Guardrail Face	188	259	209	228	275	1,159	7.6%
Ground	Embank-Earth	116	137	181	194	223	851	5.6%
Pole	Utility Pole	117	150	157	170	203	797	5.2%
Ground	Embank-Unk	105	129	155	208	174	771	5.1%
Ground	Culvert	95	132	135	158	172	692	4.6%
Structure	Fence	100	109	111	145	153	618	4.1%
Pole	Hwy Sign Post	91	91	118	157	148	605	4.0%
Ground	Curb	62	110	132	135	164	603	4.0%
Non-Collision	Overturn	66	84	87	124	166	527	3.5%
Structure	Other Fixed Obj	86	89	76	68	103	422	2.8%
Vehicle	Park/Stop Mot Veh	62	63	92	100	104	421	2.8%
Structure	Concrete Barrier	63	79	65	91	105	403	2.7%
Pole	Other Post/Pole	74	60	73	59	103	369	2.4%
Structure	Mail Box	-	-	76	77	95	248	1.6%
Structure	Bridge Pier	37	40	46	48	48	219	1.4%
Structure	Bridge Rail	35	29	29	42	44	179	1.2%
Structure	Wall	22	26	41	40	44	173	1.1%
Animal	Animal	20	34	29	35	39	157	1.0%
Ground	Embank-Rock	24	32	33	23	40	152	1.0%
Not Fixed	Oth non-Fix Obj	16	34	31	36	34	151	1.0%
Pole	Light Support	18	26	22	27	40	133	0.9%
Structure	Guardrail End	-	-	36	35	50	121	0.8%
Non-Collision	Other non-Coll	9	12	16	27	21	85	0.6%
Tree	Shrubbery	11	11	14	22	17	75	0.5%
Structure	Building	9	15	16	17	15	72	0.5%
Structure	Boulder	11	12	5	24	18	70	0.5%
Structure	Other L-Barrier	8	7	12	20	19	66	0.4%
Vehicle	Rail Train	12	11	16	9	10	58	0.4%
Pole	Traf Sig Support	8	7	15	14	12	56	0.4%
Structure	Bridge Parapet	6	8	6	12	12	44	0.3%
Vehicle	Working vehicles	9	9	10	10	6	44	0.3%
Structure	Impact Attenuatr	2	6	7	6	7	28	0.2%
Structure	Snowbank	3	12	7	4	2	28	0.2%
Structure	Fire Hydrant	3	2	8	8	6	27	0.2%
Non-Collision	Immersion	3	1	3	5	4	16	0.1%
Pedestrian	Pedestrian	-	4	5	4	3	16	0.1%
Structure	Overhead Sign	4	1	4	2	4	15	0.1%
Structure	Bridge OH Struct	-	-	3	5	-	8	0.1%
Not Fixed	Obj Thrown/Fall	1	-	3	2	-	6	0.0%
Non-Collision	Pavemt Irregular	2	1	1	1	1	6	0.0%
Non-Collision	Fell from Veh	1	-	2	1	1	5	0.0%
Vehicle	Other Not ITMV	-	-	-	2	2	4	0.0%
Non-Collision	Fire/Explosion	-	1	1	1	-	3	0.0%
Cyclist	Pedalcycle	1	2	-	-	-	3	0.0%
Unknown	Unknown	1	-	1	-	1	3	0.0%
Non-Collision	Jackknife	-	-	-	2	-	2	0.0%
Non-Collision	Own veh strk occ	-	-	-	-	2	2	0.0%
Animal	Animal in Transp	-	-	-	-	1	1	0.0%
	Total	2,192	2,606	2,986	3,467	3,947	15,198	100.0%

Appendix D. Detailed Examination of Target Vehicles

D.1. Analysis of Single-Impact Crashes

Figure 26 shows a cumulative distribution of accepted target vehicle cases by delta V in single-impact crashes. Data in Figure 14 represent a proportional redistribution of vehicles with only calculated ΔV values. Not included were 19 percent of the vehicles that had other or unknown information coded in the CDS. About 95 percent of the vehicles experienced ΔV below 70 km/h and 47 percent of the vehicles had ΔV values below 30 km/h.

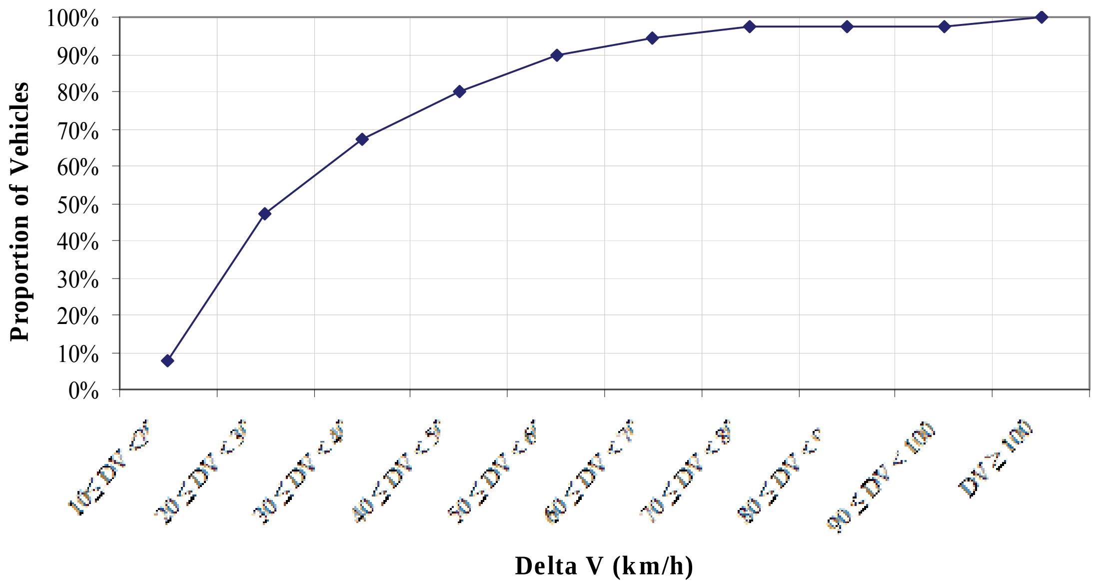

Figure 26. Cumulative Distribution of Vehicles by Delta V in Single-Impact Crashes

Figure 27 shows the distribution of vehicles by rotation and direction in single-impact crashes excluding cases with unknown information. There were about 30 percent of the vehicles with unavailable information about rotation as a result of the crash. In single-impact crashes, 11 percent of the vehicles did not spin, 40 percent rotated counter-clockwise, and 19 percent rotated clockwise.

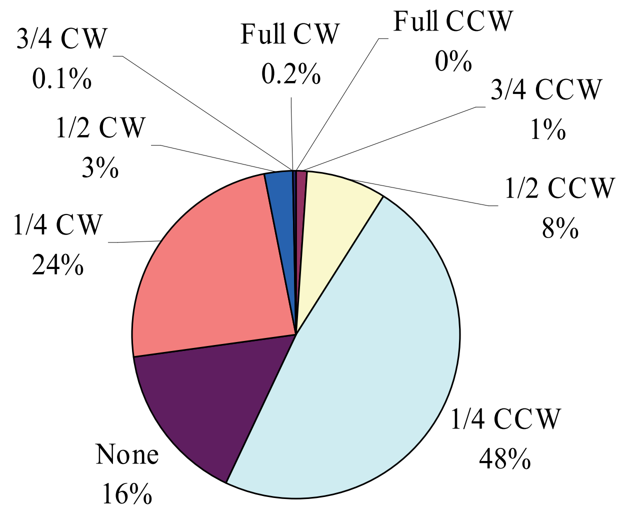

Figure 27. Distribution of Vehicles by Rotation and Direction in Single-Impact Crashes

Table 29 breaks down the number of vehicles involved in single-impact crashes by offset percentage and location. The offset percentage is the ratio of the damage width to the undeformed end width of the vehicle. Center (C), Left Center (LC), Right Center (RC), Left (L), and Right (R) indicate the side of the vehicle that was damaged. The DVD variable in the CDS was used to identify the location as follows: C= 0, LC= -1 → -35, L= -36 → -300, RC= 1 → 35, and R= 36 → 300. In single-impact crashes, nearly half (51%) of the vehicles suffered damage to the left side, 28 percent to right, and 21 percent to center.

Table 29. Distribution of Vehicles by Offset Percentage and Location in Single-Impact Crashes

Offset	L	LC	C	RC	R	Total
0-10%	239	-	-	-	-	239
11-20%	1,783	86	-	68	784	2,721
21-30%	265	3,329	-	2,065	115	5,774
31-40%	376	14	-	123	118	631
41-50%	470	325	57	13	306	1,170
51-60%	170	255	8	41	-	474
61-70%	-	56	651	459	40	1,205
71-80%	-	543	299	158	-	1,000
81-90%	-	159	1,315	167	-	1,642
91-100%	-	-	1,054	-	18	1,073
Total	3,302	4,767	3,384	3,093	1,381	15,928

L: Left, LC: Left Center, C: Center, R: Right, RC: Right Center

D.2. Analysis of Multi-Impact Most Harmful First Event Crashes

Figure 28 shows a cumulative distribution of accepted vehicle cases by ΔV in multi-impact crashes in which the first event was the most harmful. Not included in Figure 28 were 26 percent of the vehicles that had other or unknown ΔV information coded in the CDS. The plot represents a proportional redistribution of vehicles with only calculated ΔV values. About 96 percent of the vehicles experienced ΔV below 50 km/h and 56 percent of the vehicles had ΔV values below 30 km/h.

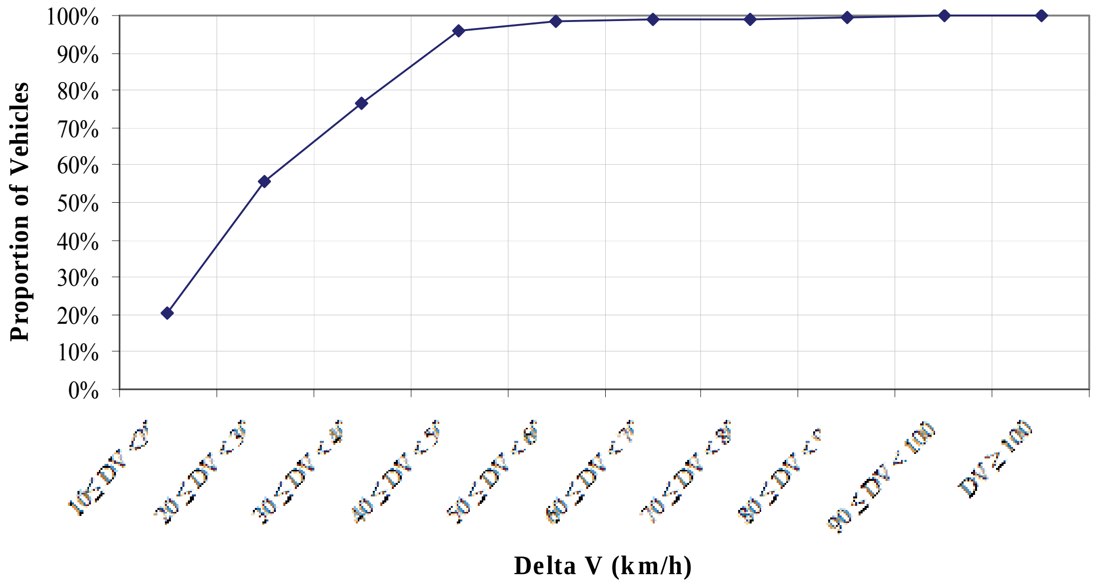

Figure 28. Cumulative Distribution of Vehicles by Delta V in Multi-Impact Most Harmful First Event Crashes

Figure 29 shows the distribution of vehicles by rotation and direction in multi-impact crashes in which the first event was the most harmful, excluding cases with unknown information. There were about 25 percent of the vehicles with unavailable information about rotation as a result of the crash. In multi-impact most harmful first event crashes, only 3 percent of the vehicles did not spin, 27 percent rotated counter-clockwise (CCW), and 44 percent rotated clockwise (CW).

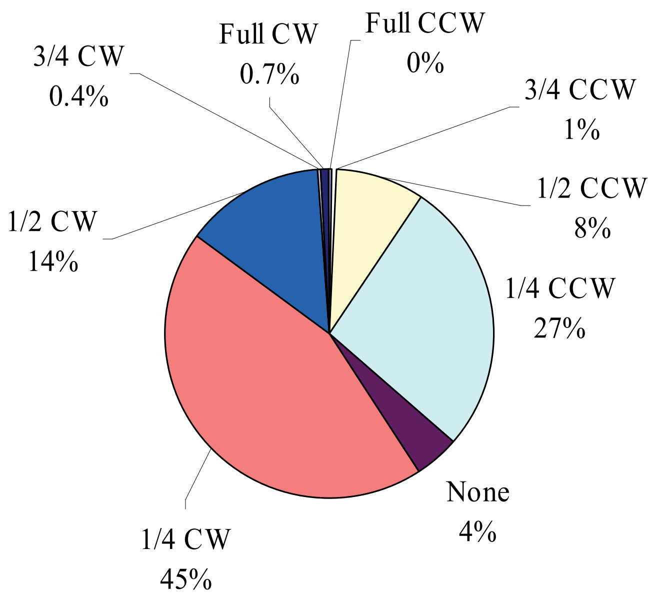

Figure 29. Distribution of Vehicles by Rotation and Direction in Multi-Impact Most Harmful First Event Crashes

Table 30 breaks down the number of vehicles involved in multi-impact crashes with first event being the most harmful by offset percentage and location. In these crashes, 66 percent of the vehicles suffered damage to the left side, 14 percent to the right, and 20 percent to center.

Table 30. Distribution of Vehicles by Offset Percentage and Location in Multi-Impact Most Harmful First Event Crashes

Offset	L	LC	C	RC	R	Total
0-10%	911	-	-	-	46	957
11-20%	377	-	-	386	96	858
21-30%	2,243	-	-	-	125	2,369
31-40%	2,109	85	10	123	-	2,326
41-50%	369	97	15	136	239	856
51-60%	4	117	94	18	-	232
61-70%	-	105	678	16	-	799
71-80%	63	9	96	120	-	288
81-90%	-	8	242	29	-	278
91-100%	21	26	817	13	10	888
Total	6,097	446	1,951	841	516	9,851

L: Left, LC: Left Center, C: Center, R: Right, RC: Right Center

D.3. Analysis of Multi-Impact Most Harmful Secondary Event Crashes

Figure 31 shows a cumulative distribution of accepted vehicle cases by ΔV in multi-impact crashes in which the most harmful event happened in secondary impacts. Not included in Figure 31 about one third of the vehicles that had other or unknown ΔV information coded in the CDS. The plot represents a proportional redistribution of vehicles with only calculated ΔV values. About 96 percent of the vehicles experienced ΔV below 60 km/h and 49 percent of the vehicles had ΔV values below 30 km/h.

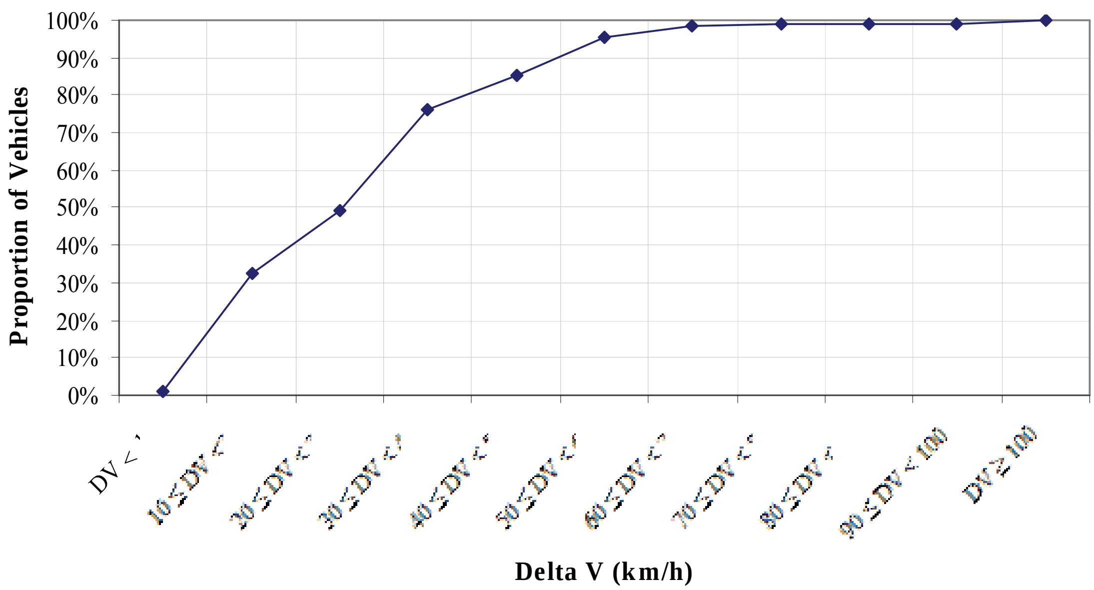

Figure 30. Cumulative Distribution of Vehicles by Delta V in Multi-Impact Most Harmful Secondary Event Crashes

Figure 31 shows the distribution of vehicles by rotation and direction in multi-impact crashes in which the most harmful was due to secondary event, excluding cases with unknown information. There were about 69 percent of the vehicles with unavailable information about rotation as a result of the crash. In multi-impact most harmful secondary event crashes, only 2 percent of the vehicles did not spin, 20 percent rotated counter-clockwise, and 9 percent rotated clockwise.

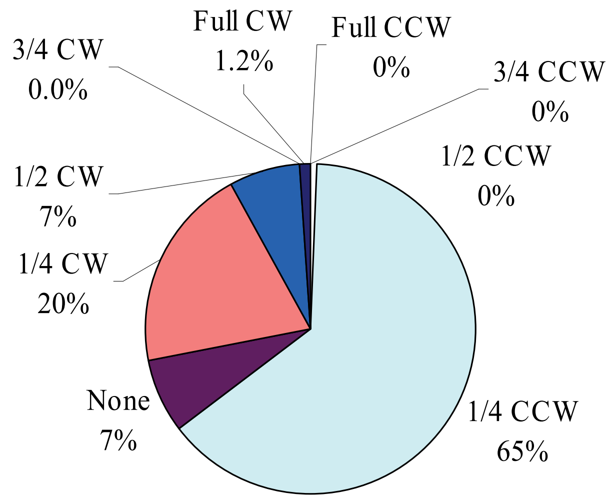

Figure 31. Distribution of Vehicles by Rotation and Direction in Multi-Impact Most Harmful Secondary Event Crashes

Table 31 breaks down the number of vehicles involved in multi-impact crashes with secondary events being the most harmful by offset percentage and location. In these crashes, 55 percent of the vehicles suffered damage to the left, 11 percent to right, and 34 percent to center.

Table 31. Distribution of Vehicles by Offset Percentage and Location in Multi-Impact Most Harmful Secondary Event Crashes

Offset	L	LC	C	RC	R	Total
0-10%	1,562	10	-	20	-	1,592
11-20%	155	182	-	79	130	546
21-30%	27	933	36	70	36	1,102
31-40%	54	170	-	34	21	280
41-50%	61	71	-	291	-	423
51-60%	-	-	-	-	-	-
61-70%	38	52	84	-	-	174
71-80%	-	41	84	-	-	126
81-90%	-	16	901	-	-	917
91-100%	145	-	1,048	-	-	1,193
Total	2,042	1,476	2,154	495	187	6,354

L: Left, LC: Left Center, C: Center, R: Right, RC: Right Center

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