

Side Impact Injury Risk for Belted Far Side Passenger Vehicle Occupants

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ABSTRACT

In a side impact, the occupants on both the struck, or near side, of the vehicle and the occupants on the opposite, or far side, of the vehicle are at risk of injury. Since model year 1997, all passenger cars in the U.S. have been required to comply with FMVSS No. 214, a safety standard that mandates a minimum level of side crash protection for near side occupants. No such federal safety standard exists for far side occupants. The mechanism of far side injury is believed to be quite different than the injury mechanism for near side injury. Far side impact protection may require the development of different countermeasures than those which are effective for near side impact protection.

This paper evaluates the risk of side crash injury for far side occupants as a basis for developing far side impact injury countermeasures. Based on the analysis of NASS/CDS 1993-2002, this study examines the injury outcome of over 4500 car, light truck, and van occupants subjected to far side impact. The analysis was restricted to 3-point belted occupants. The paper evaluates the risk of far side impact injury as a function of struck body type, collision partner, delta-V, crash direction (PDOF), occupant compartment intrusion, and injury contact source. Injury risk is evaluated using the maximum injury severity for each occupant, by injury severity for each body region, and by Harm, a social cost measure.

INTRODUCTION

The primary objective of both side impact research and side impact regulation to date has been to protect occupants located on the struck side of a passenger vehicle. In a side impact, however, both the occupants of the struck, or near side, of the vehicle as well as occupants on the opposite, or far side, of the vehicle are at risk of injury (Digges and Dalmotas, 2001). The

mechanism of far side impact injury is believed to be quite different than the injury mechanism for near side impact injury. Far side impact protection may require the development of different countermeasures than those which are effective for near side impact protection.

In early 2004, an international consortium of universities and crashworthiness research groups, led by the Monash University Accident Research Centre (MUARC), began to examine the problem of far side impact injury risk. The goal of this research program is to investigate far side impact injury to occupants of passenger cars, light trucks and vans. The specific objectives of the project are to establish an improved understanding of the biomechanics of far side impact injury, develop a test procedure for evaluating the potential of injury in a far side impact, and explore new countermeasure approaches for far side impact injury prevention. This paper presents some of the first findings of this project.

OBJECTIVE

The goal of this paper is to determine the risk of injury from far side impact crashes in the United States. The specific objectives are to determine the priorities for injury countermeasure development, and to characterize those impact conditions which lead to far side impact injury as a first step toward the development of a far side impact test procedure.

APPROACH

The findings presented in this paper were based on the analysis of the National Automotive Sampling System / Crashworthiness Data System (NASS/CDS) from 1993 - 2002. NASS/CDS is a national sample of 4,000 to 5,000 crashes investigated each year by the National Highway Traffic Safety Administration (NHTSA) at up to 27

locations throughout the United States. For a crash to be included in NASS/CDS, at least one of the vehicles in the accident had to be towed from the scene.

The analysis was limited to passenger cars, light trucks, and vans subjected to a side impact. For this study, side impact was defined to be a crash in which the general area of damage in the most harmful event was to the left or right side of the car. Any cases in which the vehicle rolled over were excluded. A far side occupant was defined to be either an outboard occupant on the opposite side of a crash or a center seated occupant. For impacts to the driver side of the car, for example, a right front seat occupant would be considered to be on the far side of the car. Likewise, for impacts to the right side of the car, the driver would be considered to be the far side occupant. Only occupants that were restrained by a three-point safety belt were included in this study.

MEASURING SOCIAL COST WITH HARM

Harm is one of several methods of measuring the social cost of traffic accidents. Two other more common measures are number of fatalities and number of injuries. Both fatality and injury counts however provide unrealistic snapshots of social cost. Fatal accidents are extremely rare, and unrepresentative of the majority of traffic accidents. Determining research priorities based upon fatal accidents can bias a study to consider only the most catastrophic accident modes – at the expense of potentially more prevalent accident modes which are disabling but non-fatal. On the other hand, basing research priorities upon total number of injuries ignores the fact that most injuries are minor abrasions and bruises, and present no significant threat to life.

Recognizing the need for a social cost metric that balanced the number of injuries with the severity of the injuries, Malliaris et al (1982) developed the Harm metric. The Harm metric determines social cost based upon injury severity. Severity is measured using the Abbreviated Injury Scale (AIS) which describes the relative threat to life of an injury (AAAM, 1990). AIS levels range from 0 for no injury to 6 for unsurvivable, or fatal, injuries. The social cost includes both medical costs and indirect costs such as loss of wages.

When a person suffers multiple injuries, the Malliaris Harm metric bases the social cost upon the body region with the maximum AIS level. This method can underestimate the overall AIS level as multiple injuries aggravate the total threat to a crash victim's life. Fildes et al (1994) developed an enhanced Harm metric, presented below and used in this study, which more correctly accounts for the social cost of persons with multiple injuries.

$$Harm = \sum_{i=1}^{NumInjuries} Cost_i (bodyregion, AIS)$$

This method assigns a social cost to each injury, and sums these costs to estimate a total social cost of injury. In this study, $Cost_i$, the social cost of an injury i as defined by Fildes et al (1994) was used as a measure of social cost. $Cost_i$ is a function of the injury severity as measured by the AIS scale, and the body region which has been injured. The cost components include not only treatment and rehabilitation costs but also all other costs to society such as loss or wages and productivity, medical and emergency service infrastructure costs, legal and insurance costs, legal and insurance charges, family and associated losses and allowances for pain and suffering.

Table 1. Average Cost per Injury (Normalized to the Cost of a Fatal Injury)

BODY REGION	INJURY SEVERITY						
	Minor (AIS = 1)	Moderate (AIS = 2)	Serious (AIS = 3)	Severe (AIS = 4)	Critical (AIS = 5)	Maximum (AIS = 6)	Unknown
External	0.0045	0.0250	0.0698	0.1135	0.1646	1.0000	0.0045
Head	0.0063	0.0295	0.1213	0.2796	0.9877	1.0000	0.0045
Face	0.0063	0.0295	0.1213	0.1601	0.3277	1.0000	0.0045
Neck	0.0063	0.0295	0.1213	0.1601	0.3277	1.0000	0.0045
Chest	0.0045	0.0250	0.0698	0.1135	0.1646	1.0000	0.0045
Abdomen	0.0045	0.0250	0.0698	0.1135	0.1646	1.0000	0.0045
Pelvis	0.0045	0.0250	0.0698	0.1135	0.1646	1.0000	0.0045
Spine	0.0045	0.0250	0.1631	1.4054	1.6804	1.0000	0.0045
Upper Extremity	0.0063	0.0433	0.1026				0.0045
Lower Extremity	0.0045	0.0433	0.1303	0.1926	0.3277		0.0045

This study uses a variation of the Fildes method for computation of Harm. In some cases, there may be multiple injuries to a single body region. In our methodology, the maximum injury to a single body region is used when assigning costs as costs are typically assigned to treat a single body region not individual injuries of that body region. For purposes of this comparison, this study will also present the number of seriously injured persons (AIS 3 or greater) and the Malliaris Harm Metric. The costs used for the Fildes Harm metric were normalized to cost of a fatality and are presented in Table 1.

As another measure of injury outcome, our analysis also computed the number of serious injuries. Serious injuries are defined to be injuries of AIS level 3 or greater. Like the Harm metric, the use of serious injuries as a metric avoids the biases associated with the use of fatality or total injury counts. Both Harm and number of serious injuries are frequently set as targets for reduction through countermeasure development.

COMPARISON OF NEAR AND FAR SIDE IMPACT

The initial step in the analysis was to compare the relative injury risk of near and far side impact. This analysis included only passenger vehicles of model year 1997 or later to capture the effect of the more recently introduced countermeasures likely to be in future fleets. By model year 1997, all U.S. passenger cars were required to meet the dynamic side impact protection provisions of FMVSS No. 214. Likewise, by model year 1997, all passenger cars in the U.S. were required to have both driver and passenger airbags. Similar provisions for dynamic side impact protection and mandatory airbags were required for all light trucks and vans by model year 1999.

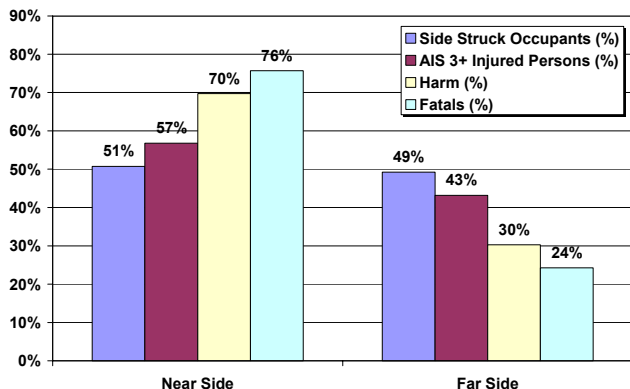


Figure 1. Comparison of Near and Far Side Impact Injuries for 3-Point Belted Occupants in Passenger Vehicles of Model Year 1997 and later (NASS/CDS 1997-2002 and FARS 1997-2002)

As illustrated in Figure 1, a side struck occupant has a nearly equal probability of being seated on the near or

far side of the vehicle. Approximately half of the side struck occupants were on the near side, and half were on the far side. Near side impact however carries a significantly higher injury risk. Near side impact resulted in 57% of seriously injured side struck occupants, 70% of the Harm, and 76% of the side impact fatalities. Far side impact accounted for 30% of the Harm, 43% of the seriously injured persons, and 24% of the side impact fatalities. The fatality counts for this figure were obtained from the 1997-2002 Fatal Analysis Reporting System (FARS) database.

ANALYSIS OF RISK OF INJURY IN FAR SIDE IMPACT

The analysis which follows will focus exclusively on occupants of passenger vehicles subjected to far side impact. The analysis is based upon the NASS/CDS database from 1993-2002. All model years are included. Following the approach described above, only cases with a general area of damage of left or right side are included. Rollovers were excluded. Only 3-point restrained occupants were included in the analysis.

As shown in Table 2, these selection criteria resulted in a final sample of over 4500 far side struck occupants. 281 of these occupants were seriously injured. 80 of these occupants were fatally injured. In addition to the unweighted number of cases, the table presents or weighted counts of the number of occupants in each injury severity category. The weighted numbers were developed using the multipliers developed by NASS to permit national estimates of injury. Seriously injured occupants were defined to be occupants with a maximum injury severity of AIS 3 or greater. The fatalities category is a count of occupants whose NASS Treatment variable was fatal. As not all fatally injured occupants die of AIS 6 (unsurvivable) injuries, this approach provides a more accurate count of fatalities than simply counting occupants with a maximum AIS = 6. Fatalities unrelated to the crash were not included in the count of fatalities.

Table 2. Number of Belted Far Side Struck Occupants – NASS/CDS 1993-2002

	Weighted	Unweighted
Occupants	2,386,633	4,518
Seriously Injured Occupants	21,982	281
Fatalities	5,175	80
Harm	20,492	

Figure 2 presents the distribution of far side impact injuries by body region. The chest was the body region most likely to suffer a serious injury and incurred approximately one-third of all serious injuries (33%).

Head injuries were the second most likely region to suffer a serious injury and accounted for over a quarter of all serious injuries (27%). Head injuries accounted for one-fourth of all Harm, the largest fraction of total Harm. Surprisingly, the upper and lower extremities accounted for a combined one-third of the Harm and one-fourth of the serious injuries. These injuries may be due to the flailing motion of the limbs as the occupant is thrown across the car in a far side impact.

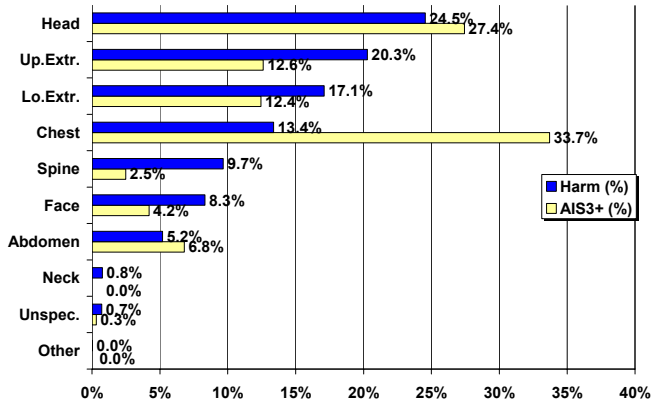


Figure 2. Distribution of Injuries by Body Region

As shown in Figure 3, drivers accounted for approximately three-fourths of the far side struck occupants as well as three-fourths of the seriously injured occupants and Harm. Right front passengers accounted for approximately 20% of the far side struck occupants, 20% of the Harm, and 25% of the seriously injured occupants. Rear passengers comprised only 7% of the total far side struck occupants and only 3% of the Harm. A test procedure which focuses on the front seat occupants would capture 98% of the seriously injured occupants and 97% of the Harm.

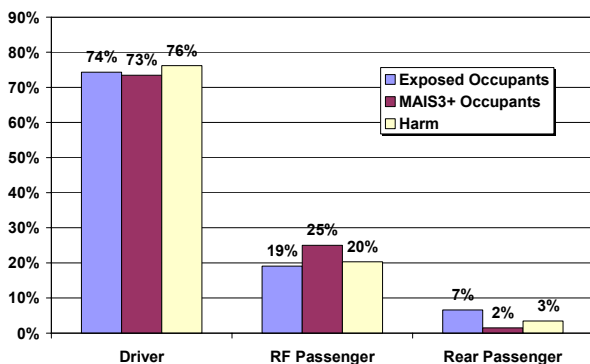


Figure 3. Distribution of Injuries by Occupant Seating Position

A far side impact is much more dangerous for a car occupant than for the occupant of a light truck or van (LTV). Figure 4 presents the distribution of injuries by struck body type. Approximately three-fourths (76%) of the side struck occupants were drivers or passengers of a car. The remaining persons were occupants of an LTV. The LTV category includes pickup trucks, sport

utility vehicles, vans, and minivans. Although car occupants accounted for 76% of side struck persons, car occupants accounted for 83% of the seriously injured persons and 84% of the Harm.

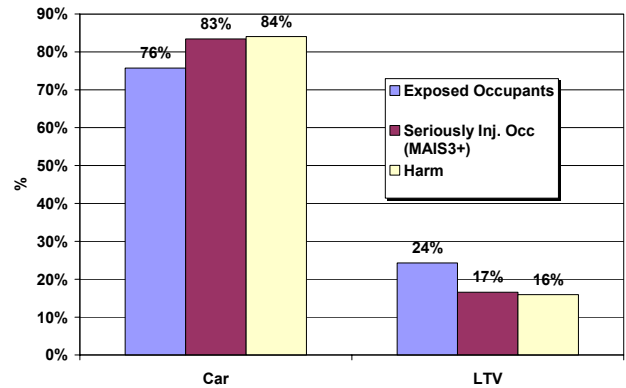


Figure 4. Distribution of Injuries by Body Type of Struck Vehicle

Furthermore far side struck car occupants were injured in a different manner than far side struck LTV occupants. As seen in Figure 5, the serious injuries suffered by car occupants were most likely to be chest (35%) and head (29%) injuries. Upper and lower extremity injuries each accounted for only 11% of serious injuries. In contrast, serious injuries to LTV occupants were almost uniformly distributed among head, chest, upper extremity, and lower extremity injuries. This suggests that passenger car occupants may require a different set of countermeasures than LTV occupants.

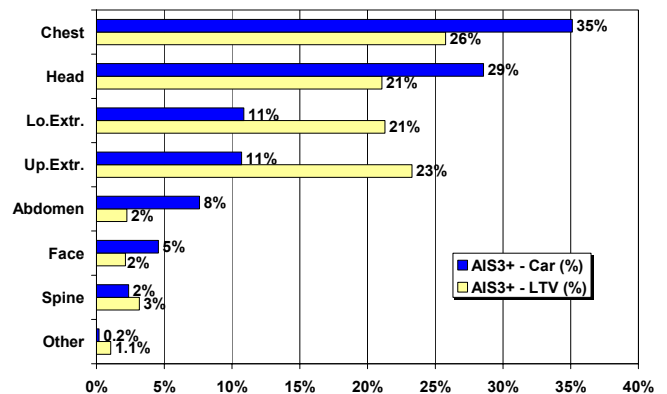


Figure 5. Distribution of Serious Injuries by Type of Struck Vehicle Type and Body Region Injured

Figure 6 depicts the distribution of far side injuries as a function of the striking vehicle type. Several studies have showed that light trucks and vans are incompatible with cars in traffic collisions [Summers et al, 2001; Gabler and Hollowell, 1998; IIHS, 1998]. The incompatibility is particularly an issue when the striking vehicle is an LTV and the struck vehicle is a passenger car. This observation is confirmed in Figure 6. The striking vehicle for over half of the side struck occupants

was a passenger car, yet this collision partner accounted for only 31% of the Harm and 37% of the fatalities. In contrast, 27% of the occupants were struck by an LTV, but these collisions resulted in 35% of the Harm and fatalities. Particularly dangerous, but fortunately rare, were collisions with 'Other' vehicles – a category which includes heavy trucks, buses, and motorcycles. Collisions with fixed objects, e.g. trees and poles, accounted for 16% of the side struck occupants, 19% of the fatalities and 18% of the Harm.

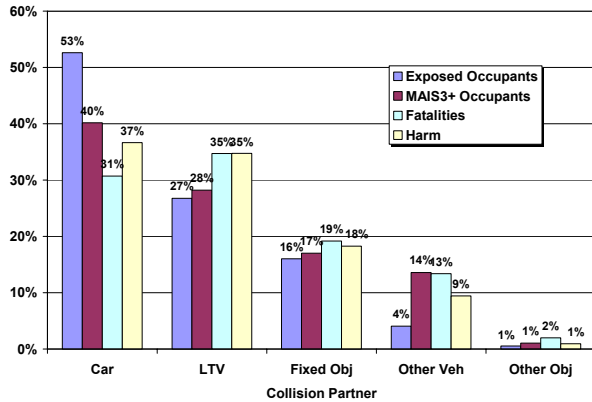


Figure 6. Distribution of Injuries by Striking Vehicle Type

As shown in Figure 7, the injury patterns differ by collision partner. Occupants struck by LTVs were more likely to suffer head and chest injuries than were occupants struck by passenger cars. The fraction of head and chest Harm for occupants struck by LTVs was 41% whereas head and chest harm was 33% of all harm for all occupants struck by cars. For occupants involved in a far side impact with a fixed object, 45% of the Harm is accounted for by head and face injuries. These differences may be due to the greater intrusion associated with LTV and fixed object collisions or simply to differences in impacting geometry between these three categories of collision partners.

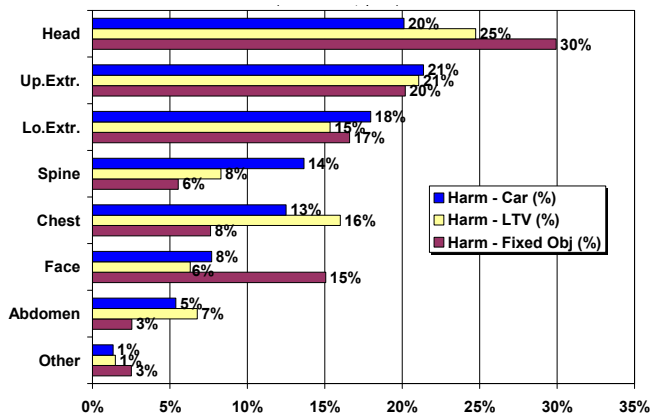


Figure 7. Distribution of Injuries by Striking Vehicle Type and Injured Body Region

A traffic accident does not always involve just a single collision. A crash may be composed of multiple collisions with several different vehicles or objects. This study considers the outcome of a crash to be the result of the event judged by NASS investigators to be the most harmful event. Figure 8 presents the distribution of injury by the number of events in which the side struck vehicle was involved. Over 60% of the sides struck occupants were involved in only a single event collision. Single event collisions accounted for over half of the seriously injured occupants and Harm. As the remaining 40% of the side struck occupants incurred approximately one half of the serious injuries, multiple event collisions, as might be expected, carry a higher risk of serious injury than do single event collisions.

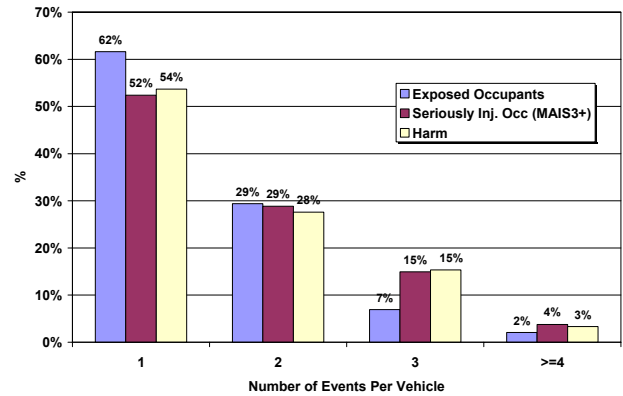


Figure 8. Distribution of Injuries by Number of Events

IMPACT CONFIGURATION

Impact speed, impact angle, and impact location are important parameters which must be identified in order to design a test procedure to evaluate far side impact injuries. This section provides an analysis of the accident data which investigates the impact configuration of a far side crash.

Figure 9 presents the distribution of far side injuries by total delta-V of the struck vehicle. Total delta-V is the resultant change in velocity, and includes both the lateral and longitudinal components of delta-V. The median total delta-V for all far side struck occupants was 15 km/hr. Half of the Harm occurred for total delta-V less than or equal to 24 km/hr. The median total delta-V for occupants with a maximum AIS injury level of 3 or higher was 32 km/hr.

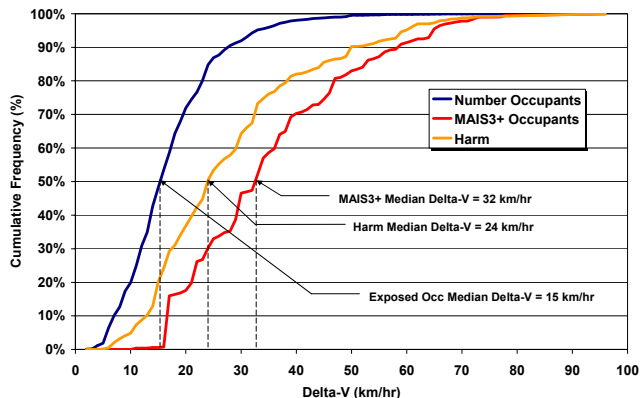


Figure 9. Distribution of Far Side Impact Injuries by Total Delta-V

Figure 10 examines the distribution of far side injuries by lateral delta-V of the struck vehicle. The median lateral delta-V for all far side struck occupants was 12 km/hr. Half of the Harm occurred for total delta-V less than or equal to 22 km/hr. The median lateral delta-V for occupants with a maximum AIS injury level of 3 or higher was 28 km/hr.

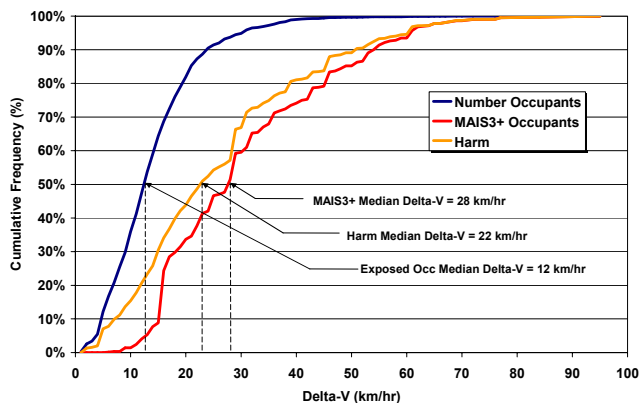


Figure 10. Distribution of Far Side Impact Injuries by Lateral Delta-V

For near side struck occupants, intrusion into the occupant compartment is known to increase the severity of impact injury. The effect of intrusion is not as obvious, however, for far side struck occupants. Our analysis used the SAE collision deformation extent, recorded by NASS crash investigators, as a measure of intrusion. As shown in Figure 11, the SAE collision deformation classification scheme divides the struck side of the car into nine zones. The boundary between the fifth and sixth zone corresponds to the centerline of the car.

As shown in Figure 12, 60% of all far side crashes resulted in damage extent involving only the first and second zones. This figure shows that serious injuries are strongly correlated with damage extent. Almost no serious injuries were observed for damage extent limited to the first two zones. However, 60% of the serious injuries were incurred by occupants of a vehicle with a damage extent to zones 3 or 4. However, as damage extent is also correlated with delta-V, it is unclear from

this figure if the injury was a result of intrusion or simply a higher inertial loading.

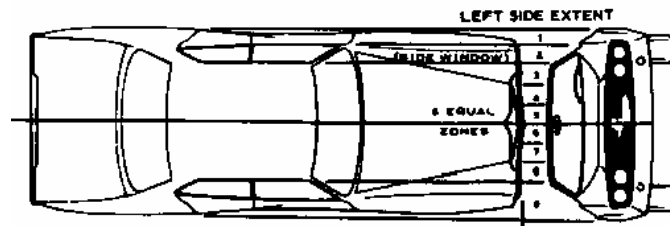


Figure 11. Side Crash Damage Extent

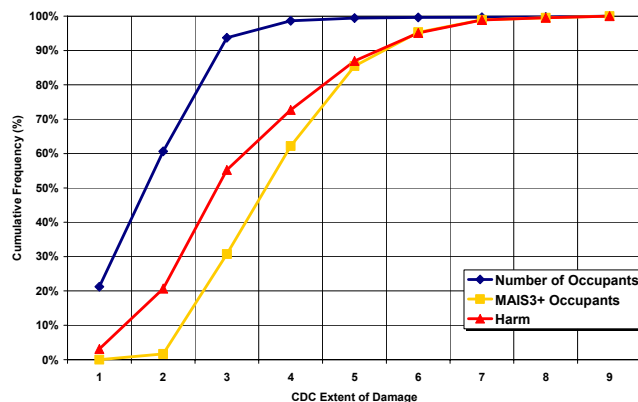


Figure 12. Distribution of Injuries by Damage Extent

Figure 13 presents the distribution of injuries by principal direction of force (PDOF). Zero degrees is the front of the struck car, 180 degrees is the rear of the struck car and 90 degrees is normal to the side of the struck car. In NASS, PDOF normally ranges from 0 to 360 degrees. For a side impact, a PDOF ranging from 0 to 180 degrees would correspond to a right side impact, while a PDOF ranging from 180 to 360 degrees would correspond to a left side impact. Note that for this analysis, the PDOF for both left and right side impacts have been collapsed into a set of values ranging from 0 to 180 degrees. Hence, a direction of force perpendicular to the side of either the left or right side of the vehicle would correspond to an angle of 90 degrees.

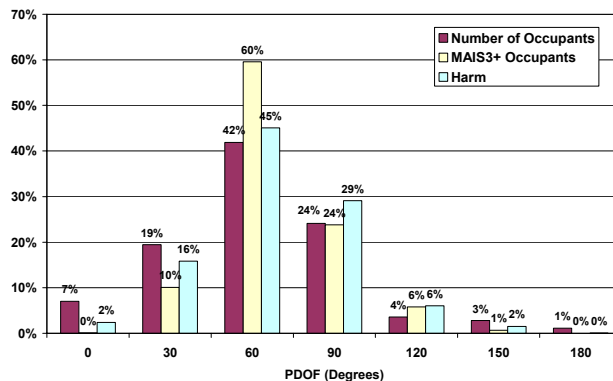


Figure 13. Distribution of Far Side Impact Injuries by Principal Direction of Force

As shown in Figure 13, the most likely principal direction of force in far side impacts was 60 degrees. A principal direction of force of 60 degrees, +/- 15 degrees, accounted for 60% of the seriously injured occupants, and 45% of the Harm. Little injury was observed either for PDOF below 30 degrees or for PDOF which exceeded 90 degrees.

Figure 14 shows the definition of impact region used in this analysis. The NASS categories Y (front 2/3 of the car side), P (center 1/3 of the car side), Z (rear 2/3 of the car side), and D (distributed), all involve impact to the occupant compartment. An impact to the occupant compartment may result in intrusion which is known to increase the injury severity for near side struck occupants. Intrusion may also affect the injury outcome for a far side struck occupant.

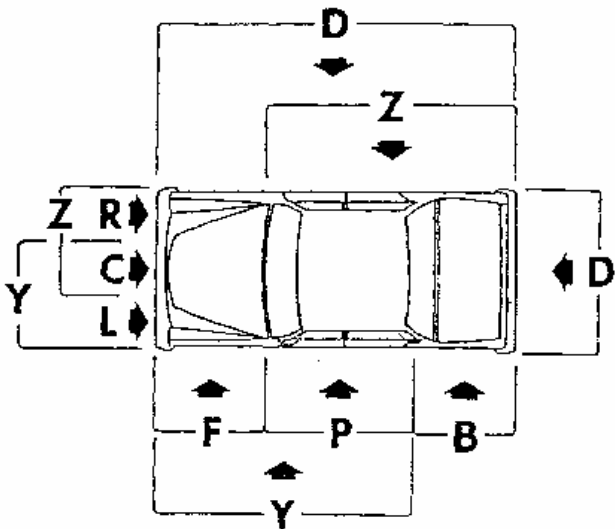


Figure 14. Side Crash Impact Locations

Figure 15 shows that the front 2/3 of the vehicle was the most likely damage location for the vehicles in our sample. Impacts to this region also accounted for the largest fractions of seriously injured occupants (42%) and Harm (39%). Collisions which involved the occupant compartment were observed to be result in a disproportionate amount of serious injuries and Harm. The side damage locations P, Y, Z, and D in the figure above accounted for 66% of the side struck occupants, but 86% of both the seriously injured occupants and the Harm.

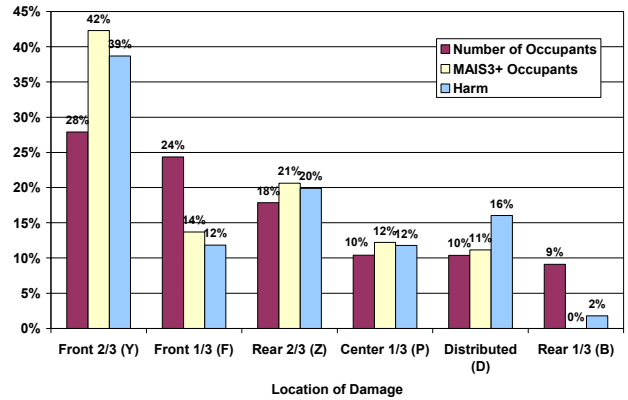


Figure 15. Distribution of Far Side Impact Injuries by Location of Impact

INJURY SOURCES

The following charts present the distribution of far side injuries by injury source. These figures identify potential targets for the development of countermeasures to prevent or reduce the severity of far side injuries. Because the number of AIS3+ cases in each category can be very small when disaggregating the data in this way, these figures report injuries at the AIS 2 level and higher. Harm was computed using only injuries of severity AIS 2 and greater.

As shown in Figure 16, the leading sources of head injury were contact with the right interior, roof, center panel, and right roof rail. Twenty per cent of the head Harm results from contact with the right interior surfaces of the vehicle. Because the head is free to flail about in the vehicle, we also note that unlike other, more constrained body regions, the head suffers impact with a large number of different contact sources.

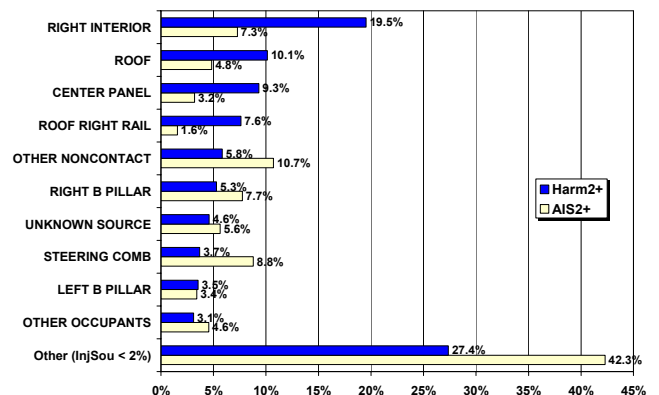


Figure 16. Distribution of Head Injuries by Injury Source

As shown in Figure 17, the leading sources of chest injury were contact with the seat back, the belt webbing or buckle, the right interior, and other occupants. Almost half of the AIS 2+ injuries result from contact with the

seat back of the vehicle. Analysis of high speed video of side impact crashes reveals that in a side impact the near side seat is frequently deformed out of position and into the trajectory of a far side occupant. Injuries induced by the safety belt or buckle accounted for approximately one-fourth of AIS 2+ injuries. As shown in Figure 18, most of the serious chest injuries occurred as a result of impacts with a PDOF of 60 degrees

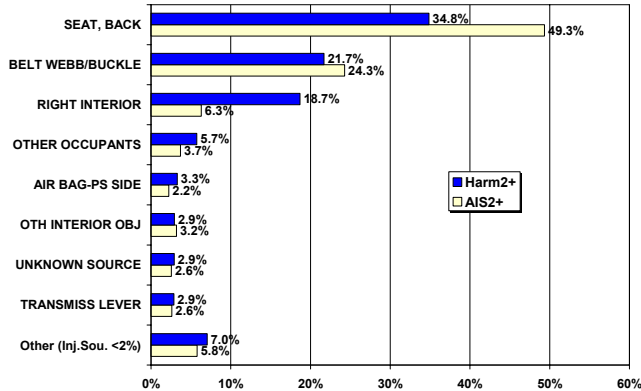


Figure 17. Distribution of Chest Injuries by Injury Source

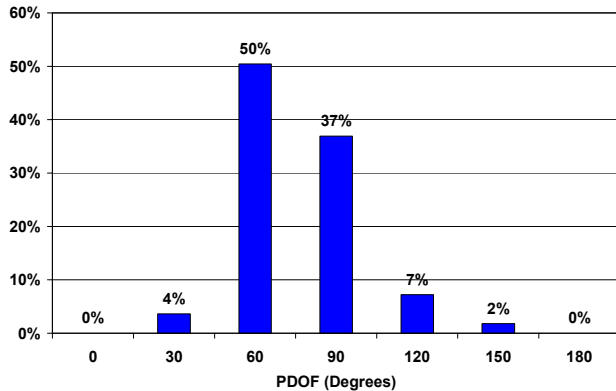


Figure 18. Distribution of Serious Chest Injuries (AIS 3+) by PDOF

As show in Figure 19, 86% of the AIS 2+ injuries and 73% of the Harm were the result of abdominal contact with either the safety belt or buckle. Current safety belt designs appear to interact very poorly with the abdomen of far side struck occupants. As shown in Figure 20, most of the serious abdominal injuries occurred at a PDOF of 90 degrees. A perpendicular PDOF is consistent with the investigator's observation that the belt or belt buckle was the injury source rather than another component such as the center console. The accident data suggest that improvement of safety belt loading should be a priority for both abdominal and chest injury reduction.

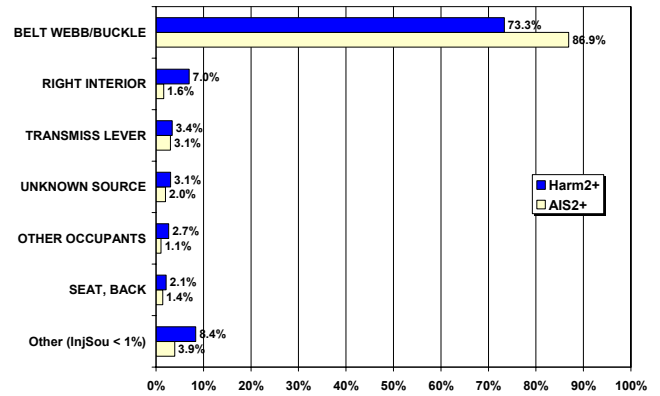


Figure 19. Distribution of Abdominal Injuries by Injury Source

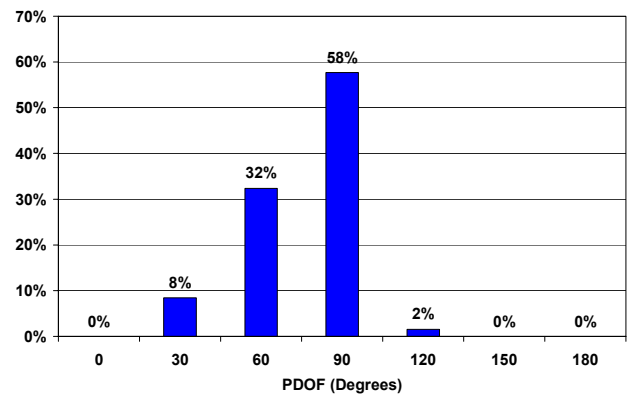


Figure 20. Distribution of Serious Abdominal Injuries (AIS 3+) by PDOF

CONCLUSIONS

This paper has evaluated the risk of injury from far side impact crashes in the United States. Our analysis was based upon an examination of over 4500 far side struck occupants of passenger cars, light trucks and vans which were extracted from the NASS/CDS 1993-2002 crash investigations database. The findings of the study were used to establish priorities for injury countermeasure development.

Specific conclusions are as follows:

- Far side struck occupants have a significant risk of injury. As a fraction of all occupants who experienced a side impact, far side struck occupants accounted for 43% of the seriously injured persons and 30% of the Harm.
- Protection of the head and chest are priorities for countermeasure development. These two body regions accounted for over half of all serious injuries suffered from far side impact.

- The study identified the vehicle interior components most frequently associated with injury in current vehicles. Nearly half of all AIS 2+ injuries to the chest were the result of contact with the seat back. Particularly surprising was the finding that 86% of the AIS 2+ abdominal injuries were the result of contact with either the safety belt or buckle.
- Car occupants may require different countermeasures than LTV occupants. In far side impact, passenger car occupants and LTV occupants experience very different injury outcome patterns.
- Confirming other studies on the aggressivity of LTVs, far side injuries were found to be more severe when the striking vehicle was an LTV than when the striking vehicle was a car.

As a first step toward the development of a far side impact test procedure, the analysis has investigated the impact conditions which lead to far side impact injury. Specific findings are as follows:

- The median lateral delta-V for occupants exposed to far side impact was 12 km/hr. The median lateral delta-V for Harm was 22 km/hr while the median lateral delta-V for serious injuries was 28 km/hr.
- A principal direction of force of 60° was most likely to be associated with serious injury. A PDOF of 60° +/- 15° was experienced by 60% of the seriously injured persons and resulted in 45% of the Harm.
- Impact damage location involving the occupant compartment was most likely to produce far side injuries. Impacts involving the occupant compartment accounted for 86% of the seriously injured persons and 86% of the Harm. Early indications are that this may be due to the effect of intrusion on the far side occupant.

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