FAR SIDE IMPACT INJURY RISK FOR BELTED OCCUPANTS IN AUSTRALIA AND THE UNITED STATES

Hampton C. Gabler
Virginia Tech
United States

Michael Fitzharris
James Scully
Brian N. Fildes
Monash University Accident Research Centre
Australia

Kennerly Digges
George Washington University
United States

Laurie Sparke
Holden Innovation
Australia

Paper No: 05-0420

ABSTRACT

This paper evaluates the risk of side crash injury for far side occupants in Australia and the United States. The study was based on the analysis of Australian data drawn from the Monash University Accident Research Center (MUARC) In-depth Data System (MIDS) and U.S. data extracted from the National Automotive Sampling System / Crashworthiness Data System (NASS/CDS). Over 100 cases of Australian far side struck occupants were examined from the MIDS database, and over 4500 cases of U.S. far side struck occupants were investigated from NASS/CDS 1993 - 2002. For both data sets, the analysis was restricted to three-point belted occupants of cars, light trucks, and vans. 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. The goal of this study was to develop priorities for developing far side impact injury countermeasures which would be effective in both countries.

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. However, occupants of the non-struck, or far side, of the vehicle are also at risk of injury (Digges and Dalmotas, 2001). The mechanism of far side impact injury is believed to be quite different than that 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 (Fildes et al, 2005). 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 study is to determine the risk of injury from far side impact crashes in Australia and 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 analysis presented in this paper was based on the examination of Australian data drawn from the MUARC In-depth Data System (MIDS) and U.S. data extracted from the National Automotive Sampling System / Crashworthiness Data System (NASS/CDS) files from 1993 - 2002.

DATA SOURCES

The MUARC In-depth Data System (MIDS) is comprised of in-depth accident investigation data from four crashed vehicle studies conducted by the MUARC: the Crashed Vehicle File (CVF) collected from 1989 – 1993; the study funded by FORS (now the Australian Transport Safety Bureau, ATSB) to evaluate ADR69 and conducted from 1995 – 2000, the Holden Crash Investigation project (1993 onwards) and the current Australian National Crash In-Depth Study (ANCIS)[1] from 2000 onwards.

The MIDS database contains weights which, when applied to individual cases, permitted national estimates of traffic crash injury in Australia. The MIDS weighting system uses key crash parameters that when used in combination result in 4032 possible covariate patterns, in order to adequately capture crash and injury characteristics. Principal variables for the weighting system are: Year of vehicle manufacture (pre/post-1990); Impact direction (e.g., front, left, or right side of vehicle); Seating position of occupant; Single vehicle crash or multiple vehicle crash; Speed zone (categories: ≤60, 70-90, 100+ km/h); Head injury AIS ≥ 3; Chest or Abdominal injury AIS ≥ 3; Lower extremity AIS ≥ 3. The year of manufacture is included as advances in vehicle safety have progressed rapidly, and, while crude, serves as a reasonable cut-point as the Australian fleet is on average 10 -12 years of age. The expected number of crashes in each of the 4032 covariate patterns was calculated for all fatality crashes in Australia and Victorian crash statistics for a three year period (1999-2001) with Victorian crashes adjusted and multiplied to approximate and equal, respectively, the Australian serious, minor and non-injury crashes. Weights were determined by expressing expected number of occupants per covariate pattern divided by the number of matching occupants in the MIDS. Analysis was conducted with and without weights applied.

NASS/CDS is a sample of 4,000 to 5,000 crashes investigated each year by the U.S. 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. Each case in NASS/CDS has corresponding weights which allow for computation of national estimates of traffic crash injury outcome.

FAR SIDE IMPACT DATA SET

The analysis which follows focuses exclusively on occupants of passenger vehicles subjected to far side impact. 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 front seat passenger would be considered to be on the far side of the car. Likewise, for impacts to the front passenger 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 the study.

As shown in Table 1 and Table 2, these selection criteria resulted in a final sample of 107 Australian cases and 4,518 U.S. cases of far side struck occupants. 10 of the Australian cases and 281 of the U.S. cases were seriously injured occupants. Seriously injured occupants were defined to be occupants with a maximum injury severity of AIS 3 or greater. Both files contained a small number of fatally-injured occupants which were included in the Harm calculation but not analyzed separately. In addition to the unweighted number of cases, these tables also present weighted counts of the number of occupants in each injury severity category. The

[1] The ANCIS partners include the Federal Department of Transport and Regional Services; Autoliv Australia; Ford Motor Company Australia Ltd.; Holden Ltd.; Mitsubishi Motors Australia Ltd.; Motor Accidents Authority of New South Wales; National Roads and Motorists' Association, Royal Automobile Club of Victoria Ltd.; Roads & Traffic Authority (New South Wales); Transport Accident Commission (Victoria); Toyota Motor Corporation; and VicRoads. The Federal Chamber of Automotive Industries and the Australian Automobile Association (AAA) are included as Observers.

weighted numbers were developed using the multipliers included in both MIDS and NASS to permit national estimates of injury in their corresponding countries. All analyses which follow were performed with weighed accident data.

Table 1. Number of Australian Belted Far Side Struck Occupants – MIDS

	Weighted	Unweighted
Occupants	5,894	107
Seriously Injured Occupants (AIS3+)	39	10
Fatalities	4	1

Table 2. Number of U.S. 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

One analytical challenge of this study was how to combine the Australian and U.S. data. The U.S, far side impact data set is many times larger than the corresponding Australian data set. Our approach was to use the Australian and U.S. data to compare and contrast the higher level characteristics of the far side impact problem, e.g. body region priorities for injury reduction. The larger U.S. data set was then used to determine the detailed injury mechanisms of far side impact injury. At the time of this paper, the number of cases from the MIDS database was too small to perform a similar analysis with Australian data alone.

MEASURING SOCIAL COST WITH HARM

Our study used the Harm metric to measure the social cost of traffic accidents. The Harm metric was first developed by Malliaris et al (1982) as a means of balancing number of injuries with the severity or cost of an injury. Using the Malliaris Harm metric, each AIS level has a prescribed social cost. This social cost includes both medical costs and indirect costs such as loss of wages. For each injured person, the Harm is the social cost which corresponds to their maximum AIS injury level.

This original Harm metric was a remarkable new method of injury assessment, but had two weaknesses. First, social cost is not a function exclusively of AIS level. The social cost of injury varies by body region as well as by injury severity. For example, an AIS 3 head injury has a higher social cost than an AIS 3 leg injury. Second, the original Harm metric assigned a cost to only the injury of highest severity. This approach can underestimate the total social cost of a person who suffers multiple injuries as multiple injuries can aggravate the total threat to a crash victim's life.

Fildes et al (1994) developed an improved Harm metric which addressed these two issues. The improved 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.

Our 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. The costs proposed by Fildes et al (1994) were normalized to cost of a fatality and are presented in Table 3.

COMPARISON OF AUSTRALIAN AND U.S. FAR SIDE CRASHES

The traffic safety environments in Australia and the United States share many common vehicle types and similar safety regulations, but also differ in several important aspects. Differences in fleet composition, driver seating position, and rural-to-urban driving mix may have an influence on the priorities for countermeasure development. Our initial step in the analysis was to compare and contrast the risk of far side impact injury in Australia and the United States.

Table 3. 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

Figure 1 and Figure 2 present the relative injury risk of near and far side impact for Australia and the U.S. As illustrated in Figure 2, a side struck occupant in the U.S. 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. In Australia, however, the MIDS database predicts a very different distribution. 60% of side struck occupants were on the near side of the car and the remaining fraction were on the far side of the car.

On the other hand, the ratio of near side to far side occupant injuries was very similar in both countries. Both the Australian and the U.S. accident data show that near side impact carries a significantly higher injury risk. Near side crashes accounted for approximately 80% of the seriously injured side struck persons in Australia and 78% in the U.S. Near side struck occupants incurred 76% of the side impact Harm in Australia, and 71% of the side impact Harm in the U.S.

Far side struck occupants have a significant risk of injury in both Australia and the United States. As a fraction of all occupants who experienced a side impact, far side struck occupants accounted for approximately 20% of the seriously injured persons and 24-29% of the Harm.

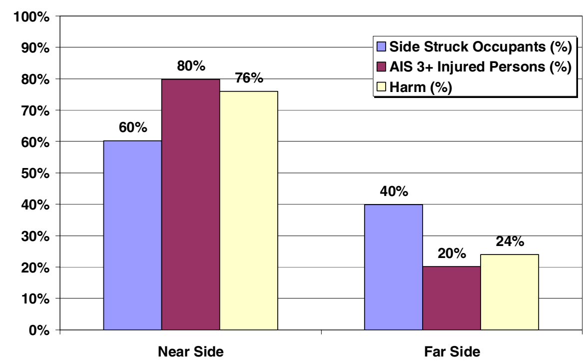

Figure 1. Distribution of Australian Near vs. Far Side Impact Injuries for 3-Pt Restrained Occupants

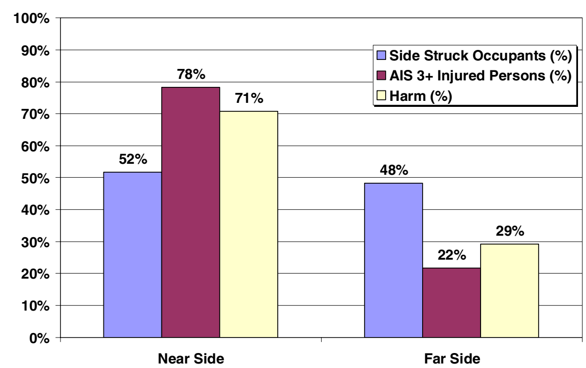

Figure 2. Comparison of U.S. Near and Far Side Impact Injuries for 3-Pt Restrained Occupants

As seen in Figure 3, the distribution of far side impact injury by body region is very similar in both Australia and the U.S. Head injuries accounted for approximately one-fourth of all Harm, the largest fraction of total Harm. The largest differences in injury outcome were for the chest and the spine. The chest incurred 13% of all Harm in the U.S. and only 7% of all Harm in Australia. Spine injuries accounted for 15% of all Harm in Australia, but only 10% of Harm in the U.S. Protection of the head, chest, and spine are priorities for countermeasure development. These three body regions accounted for approximately half of all the Harm attributed to far side impact in both countries.

Injuries to the upper and lower extremities combined for approximately 40% of the far side impact Harm in both countries – a surprisingly large fraction. 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. One difference between NASS and MIDS should be noted here: in the MIDS database pelvic injuries were grouped with the abdominal injuries while in NASS/CDS pelvic injuries were grouped with lower extremity injuries.

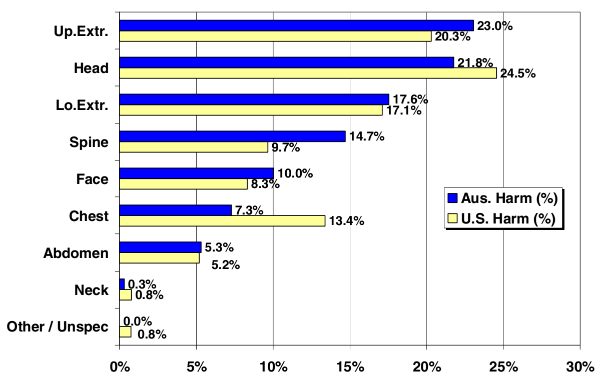

Figure 3. Distribution of Far Side Impact Harm by Body Region – Australia vs. United States

In both Australia and the U.S. the distribution of Harm by seating location was very similar. As shown in Figure 4 and Figure 5, in both Australia and the U.S. drivers composed just under three-fourths of the far side struck occupants and incurred just over three-fourths of the Harm. Front passengers accounted for approximately 20% of the far side struck occupants, and 14-20% of the Harm. Rear passengers comprised only 7% of the total far side struck occupants and only 3-6% of the Harm. A test procedure which focuses on the front seat occupants would capture over 90% of the Harm.

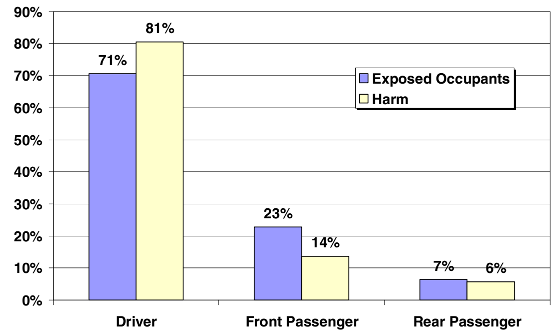

Figure 4. Australian Far Side Injuries to Belted Occupants by Seating Position

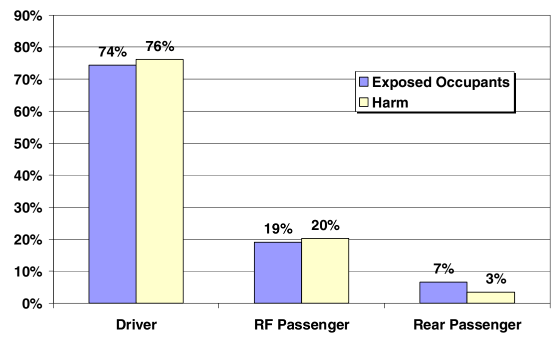

Figure 5. U.S. Far Side Injuries to Belted Occupants by Seating Position

The composition of the Australian and U.S. passenger vehicle fleets are very different. The Australian fleet is primarily composed on passenger cars. The U.S. fleet is characterized by a growing segment of light trucks and vans (LTVs) now estimated to account for 40% of registered light vehicles and 50% of all light vehicle sales in the U.S. The LTV category includes pickup trucks, sport utility vehicles, vans, and minivans.

Reflecting this fleet composition, the Australian dataset contained only passenger car data. The U.S. dataset however contained cases of both car and LTV occupants involved in far side impact. Figure 6 presents the distribution of injuries by struck body type in the U.S. Approximately three-fourths (76%) of the side struck occupants in the U.S. were drivers or passengers of a car. The remaining persons were occupants of an LTV. A far side impact is much more dangerous for a car occupant than for the occupant of a light truck or van (LTV). Although car occupants accounted for 76% of side struck persons in the U.S., car occupants accounted for 83% of the seriously injured persons and 84% of the Harm.

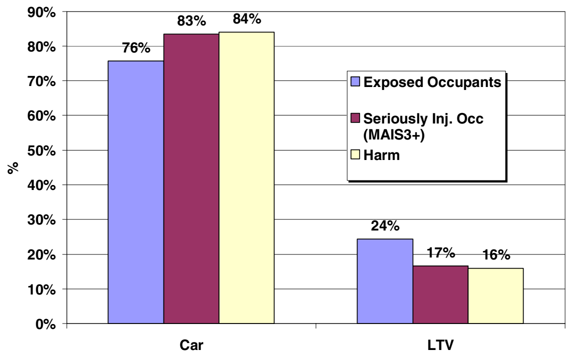

Figure 6. U.S. Far Side Impact Injuries by Body Type of Struck Vehicle

Finding that a substantial proportion of the far side harm in the U.S. is incurred by LTV occupants, we next examined whether car and LTV occupants might require different injury countermeasures. As seen in Figure 7, the Harm distributions for car and LTV occupants are not identical. Nevertheless, the head, chest, and spine are still the most urgent targets for Harm reduction. For both car and LTV occupants, the largest contributor to Harm was head injuries. Chest injuries resulted in much more Harm for car occupants (14%) than for LTV occupants (10%). In contrast, upper and lower extremity injuries were somewhat more important for LTV occupants than for car occupants. Injuries to the arms and legs accounted for 44% of LTV occupant Harm, but only 36% of car occupant Harm.

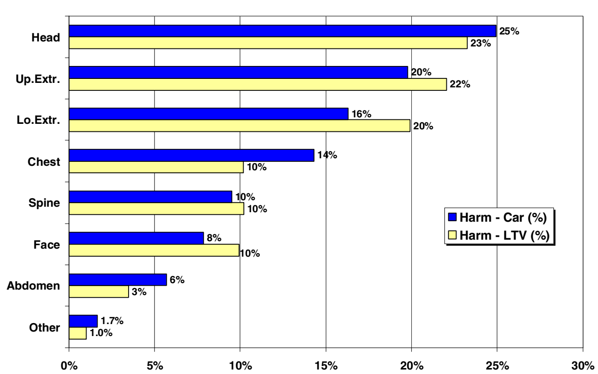

Figure 7. Distribution of Serious Injuries by Type of Struck Vehicle Type and Body Region Injured in the U.S.

The distribution of Australian and U.S. far side injuries by striking vehicle were next evaluated to determine the influence of differing fleet composition. As shown in Table 4, however there were too few cases in the Australian data to disaggregate the data to this level. This table does however show that the primary striking vehicle was a passenger car or a passenger car-derivative denoted as Ute below.

Table 4. Number of Australian Belted Far Side Struck Occupants – MIDS

Striking Vehicle or Object	Weighted		Unweighted	
	Occupants	AIS3+	Occupants	AIS3+
Car / UTE	3,892	28	63	5
4WD	264	-	5	
Van	91	-	3	
Hvy Truck / Bus	169	-	4	
Other Vehicle	1,063	-	6	
Pole	139	2	11	2
Tree	251	9	14	3
Other Object	26	-	1	
Total	5,894	39	107	10

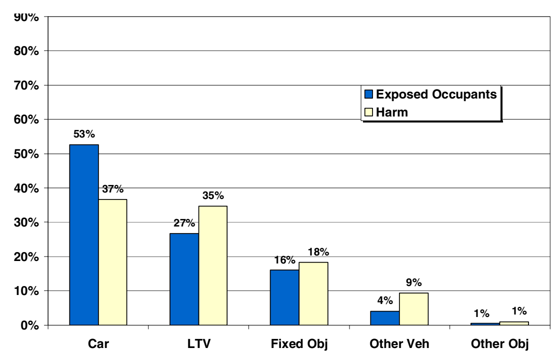

Figure 8. Distribution of Far Side Injuries by Striking Vehicle Type in U.S.

The analysis presented in Figure 8 depicts the distribution of far side injuries as a function of the striking vehicle type in the U.S. 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 8. The striking vehicle for over half of the side struck occupants was a passenger car, yet this collision partner accounted for only 37% of the Harm. In contrast, 27% of the occupants were struck by an LTV, but these collisions resulted in 35% of the Harm. 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 and 18% of the Harm.

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. Because of the small number of Australian cases, the analysis which follows is based exclusively upon U.S. accident data.

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.

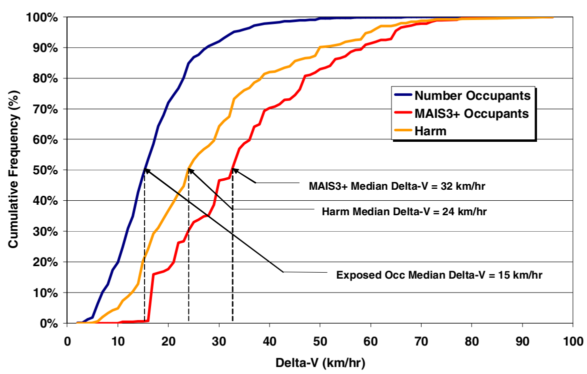

Figure 9. Distribution of Far Side Impact Injuries by Total Delta-V

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.

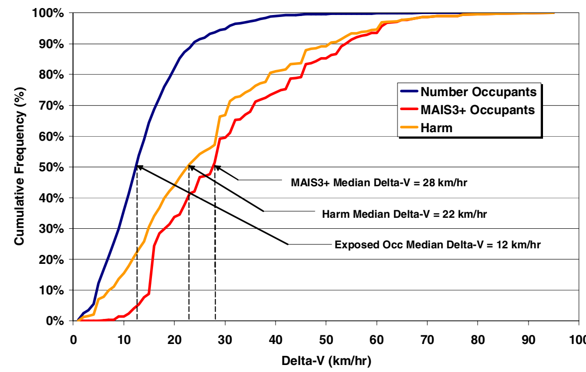

Figure 10. Distribution of Far Side Impact Injuries by Lateral Delta-V

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 struck occupants were exposed to crashes with a 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.

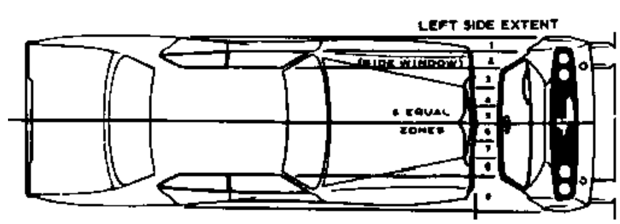

Figure 11. Side Crash Damage Extent

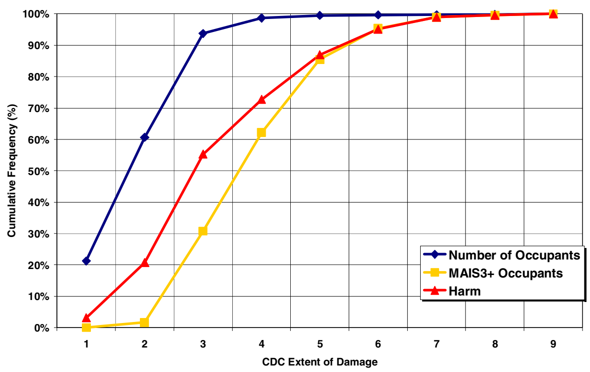

Figure 12. Distribution of Injuries by Damage Extent

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.

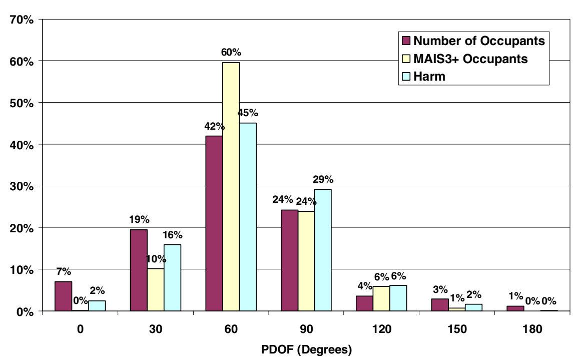

Figure 13. Distribution of Far Side Impact Injuries by Principal Direction of Force

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.

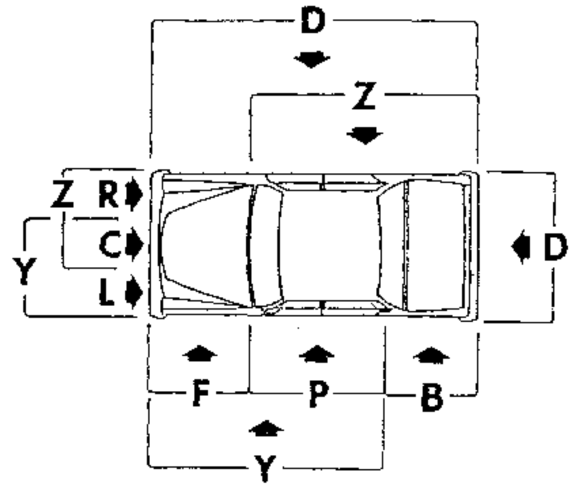

Figure 14. Side Crash Impact Locations

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.

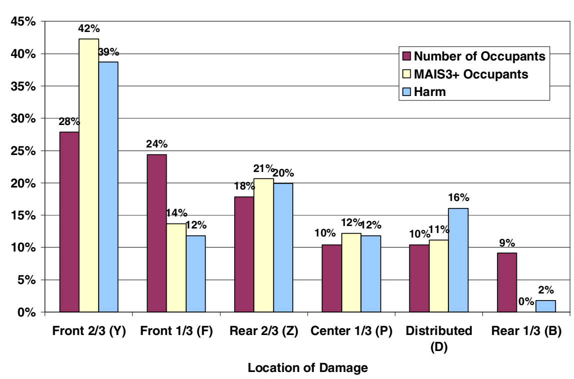

Figure 15. Distribution of Far Side Impact Injuries by Location of Impact

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.

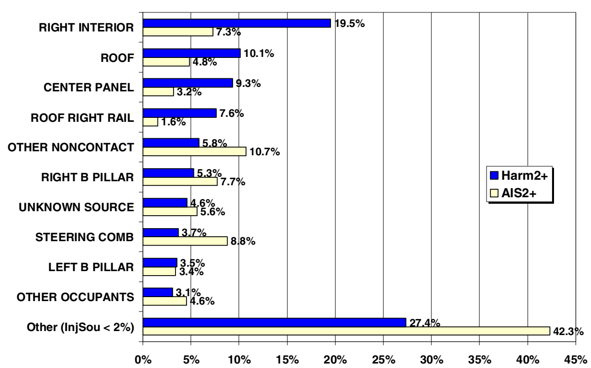

Figure 16. Distribution of Head Injuries by Injury Source

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.

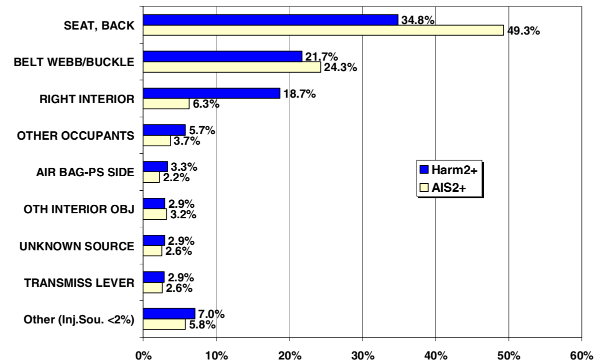

Figure 17. Distribution of Chest Injuries by Injury Source

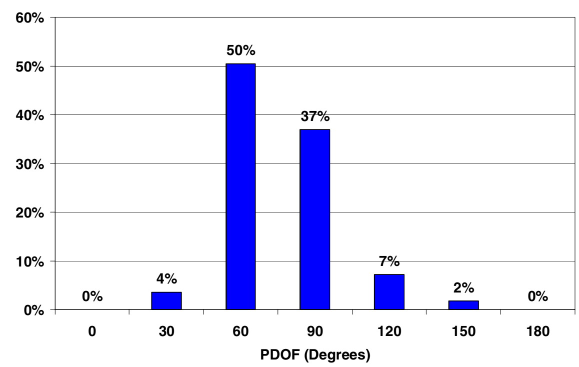

Figure 18. Distribution of Serious Chest Injuries (AIS 3+) by PDOF

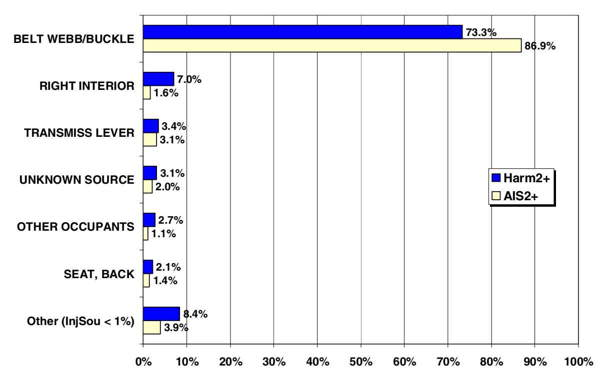

Figure 19. Distribution of Abdominal Injuries by Injury Source

As shown 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. These data suggest that current safety belt designs appear to interact very poorly with the abdomen of far side struck occupants. Analysis of high speed video of side impact crashes suggests that some of these abdominal injuries could also be the result of contact with the center console. Because the center console is so much stiffer than the abdomen, it is possible that impacts with the center console are not always apparent to accident investigators.

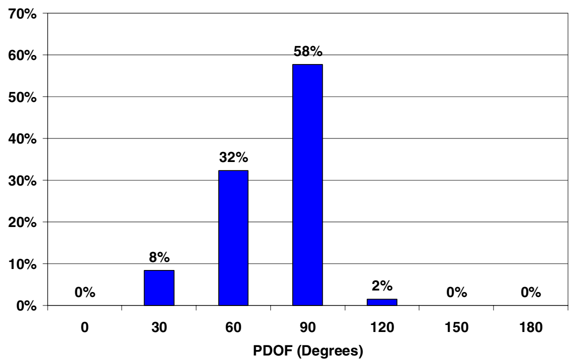

Figure 20. Distribution of Serious Abdominal Injuries (AIS 3+) by PDOF

CONCLUSIONS

This paper has evaluated the risk of injury from far side impact crashes in Australia and the United States. Our analysis was based upon an examination of injury outcomes of 107 occupants drawn from the Australian MIDS database, and over 4500 occupants extracted from the U.S. NASS/CDS 1993-2002 crash investigations database. All cases were three-point belt restrained occupants of passenger cars, light trucks and vans who were exposed to a far side impact.

The goal of this study was to establish priorities for injury countermeasure development. Specific conclusions are as follows:

- Far side struck occupants have a significant risk of injury in both Australia and the United States. As a fraction of all occupants who experienced a side impact, far side struck occupants accounted for approximately 20% of the seriously injured persons and 25-29% of the Harm.

- Protection of the head, chest, and spine are priorities for countermeasure development in both Australia and the United States. These three body regions accounted for approximately half of all the Harm attributed to far side impact.

- Injuries to the upper and lower extremities combined for approximately 40% of the far side impact Harm in both countries – a surprisingly large fraction.

- Nearly half of all AIS 2+ injuries to the chest were the result of contact with the seat back. 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.

- The accident data suggest that improvement of safety belt loading should be a priority for both abdominal and chest injury reduction. Injuries induced by the safety belt or buckle accounted for approximately one-fourth of AIS 2+ chest injuries. 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. Future studies will investigate whether some of these abdominal injuries may be the result of undetected contact with the center console.

As a first step toward the development of a far side impact test procedure, the analysis used U.S. data to investigate 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^{o} was most likely to be associated with serious injury. A PDOF of 60^{o} +/- 15^{o} was experienced by 60% of the seriously injured persons and resulted in 45% of the Harm.

- A vehicle or fixed object striking the occupant compartment of a subject vehicle 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.

ACKNOWLEDGEMENTS

The funding for this research has been provided by private parties. Dr. Kennerly Digges and the FHWA/NHTSA National Crash Analysis Center at the George Washington University has been selected to be an independent solicitor of and funder for research in motor vehicle safety, and to be one of the peer reviewers for the research projects and reports. The Australian Research Council awarded Grant No. LP0454122 to Professor Brian Fildes at the Monash University Accident Research Centre. Neither of the private parties have determined the allocation of

funds or had any influence on the content of this report.

REFERENCES

1. AAAM. Abbreviated Injury Scale – 1990 Revision, Association for the Advancement of Automotive Medicine, Des Plains, Illinois (1990)

2. Digges, K., and Dalmotas, D., "Injuries to Restrained Occupants in Far-Side Crashes," Proceedings of the Seventeenth International Conference on Enhanced Safety of Vehicles, Amsterdam, Netherlands (2001)

3. Fildes, B.N., Lane, J.C., Lenard, J., and Vulcan, A.P., Passenger cars and occupant injury: Side impact crashes. Report CR 134, Federal Office of Road Safety, Canberra, Australia (1994)

4. Fildes, B., Linder, A., Douglas, C., Digges, K., Morgan, R., Pintar, F., Yogandan, N., Gabler, H.C., Duma, S., Stitzel, J., Bostrom, O., Sparke, L., Smith, S., and Newland, C., "Occupant Protection in Far Side Crashes", Proceedings of the Nineteenth International Conference on Enhanced Safety of Vehicles, Washington, DC, USA (2005)

5. Gabler, H.C. and Hollowell, W.T.,"The Aggressivity of Light Trucks and Vans in Traffic Crashes", SAE Transactions, Journal of Passenger Cars, Section 6, v.107, Paper No. 980908 (1998)

6. Insurance Institute for Highway Safety (IIHS) "Crash Compatibility: How Vehicle Type, Weight Affect Outcomes", Status Report, 33(1). (1998)

7. Malliaris, A.C., Hitchcock, R., and Hedlund, J., "A Search for Priorities in Crash Protection", Crash Protection, SAE SP-513, pp. 1-33, Society of Automotive Engineers (1982)

8. SAE Standard J224, Collision Deformation Classification (1980).

9. Summers, S., Prasad, A., Hollowell, W.T., "NHTSA's research program for vehicle aggressively and fleet compatibility", Proceedings of the Seventeenth International Conference on Enhanced Safety of Vehicles, Paper no. 249 (2001)