DETERMINING SIDE IMPACT PRIORITIES USING REAL-WORLD CRASH DATA AND HARM

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ABSTRACT

This paper describes a new approach to prioritising occupant protection interventions, based on the amount of real-world Harm they address. It was conducted to highlight priorities associated with systems modelling optimisation. However, it is also suitable for a wider application generally in targeting interventions aimed at maximising occupant protection improvements. It is especially useful for optimising vehicle design strategies but can also be used more strategically to help justify the need for new regulations, aimed at occupant protection improvement.

KEYWORDS: Side Impacts, Harm, Models, Crashworthiness, Accident Data

INTRODUCTION

Optimising occupant protection in vehicle design requires decisions about priorities during the design process. Choosing interventions that will address relatively frequent injuries is critical for the process of maximising benefits to the occupants of vehicles in particular crash types, typically experienced by passenger cars in real-world crashes. The question is, on what basis should a manufacturer prioritise critical design features or interventions during this process?

The Monash University Accident Research Centre is currently involved in research, aimed at optimising vehicle design for enhanced side impact protection. The process involves the development of a systems model for optimising protection based on identifying a minimum Harm outcome. A schematic view of the process is provided in Figure 1 below.

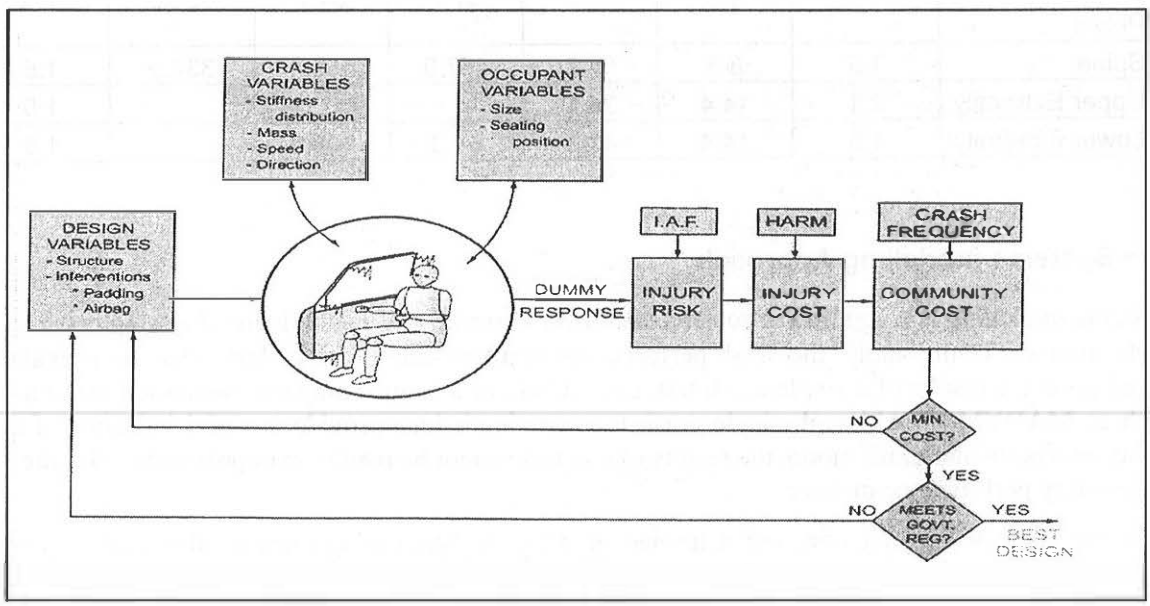

Figure 1 *Optimisation process for vehicle design (Fildes et al, 1998b)*

The currency of the model is societal Harm, which includes both frequency and cost components of injury. It has a number of advantages over other criteria, such as fatalities or injuries alone in that it has the potential to take into account not only life-threatening aspects of injury but also their long-term consequences. This requires accurate costs of injury, which includes not only their 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 charges, family and associated losses and allowances for pain and suffering. Vehicle damage and traffic delay costs can be included or excluded, depending upon whether they are seen as costs associated with the crash or the injuries sustained.

The Harm values used in this study were developed from analysis of Australian injury frequencies and injury costs (Fildes and Cameron, 1998). The Harm costs were computed based upon a matrix of average injury costs in the USA developed by Miller, Pindus, Leon and Douglass (1990). It was then necessary to convert these figures to equivalent Australian body region and severity level costs (in 1991 $A). This was accomplished by (1) calculating the two-way frequency distribution of all Australian injuries by body region and AIS level based upon Australian accident data, (2) weighting each injury by its US average cost (Miller et al, 1990), (3) adjusting the total injury cost of all road users (excluding vehicle damage costs) in 1985, given as $3166.5 million (1985 $A) by Steadman and Bryan (1988), and finally (4) converting the resulting costs to 1991 $A. The final Harm values are presented in Table 1 below.

Table 1. Average Cost per Injury (1991 $A, '000)

	INJURY SEVERITY						
BODY REGION	Minor (AIS = 1)	Moderate (AIS = 2)	Serious (AIS =3)	Severe (AIS = 4)	Critical (AIS = 5)	Maximum (AIS = 6)	Unknown
External	1.5	8.3	23.2	37.7	54.7	332.3	1.5
Head	2.1	9.8	40.3	92.9	328.2	332.3	1.5
Face	2.1	9.8	40.3	53.2	108.9	332.3	1.5
Neck	2.1	9.8	40.3	53.2	108.9	332.3	1.5
Chest	1.5	8.3	23.2	37.7	54.7	332.3	1.5
Abdomen-Pelvis	1.5	8.3	23.2	37.7	54.7	332.3	1.5
Spine	1.5	8.3	54.2	467.0	558.4	332.3	1.5
Upper Extremity	2.1	14.4	34.1				1.5
Lower Extremity	1.5	14.4	43.3	64.0	108.9		1.5

The Systems-modelling Approach

Systems-modelling is a significant enhancement over conventional methods for assessing crash safety performance. Traditionally, the crash performance of a particular vehicle design has been evaluated based upon the results of a single crash test, e.g. NCAP, or a single computer simulation using a code such as MADYMO. Although single crash tests or simulations provide a useful indicator of crash safety in a particular crash mode, the results of one test cannot be readily extrapolated to infer the fleet wide safety performance of a car.

Cars are subjected to not one, but a myriad of different types of crashes on the road. Systems-modelling attempts to capture this fleetwide crash safety performance by evaluating car design across the full range of potential impact speeds, angles, collision partners, occupant seating locations, and occupant restraints. The outcome of each of these collision modes is computed in units of fatalities, injuries, or social cost, weighted by its probability of occurrence, and summed. The result is a system-

wide measure of safety performance of the car design in terms such as the annual number of fatalities or the Harm incurred by accident-involved occupants of this car.

Tradeoff between Model Accuracy and Development Costs

The drawback of the system modelling approach is its cost. Systems-modelling requires the execution of large numbers of computational models in order to develop a system-wide measure of safety performance. There are two primary components of systems-modelling cost. The first is the large amount of time required to develop models for a crash simulation codes such as Madymo. The second component is the enormous computational time required to execute these Madymo models over all permutations and combinations of possible crash configurations.

Each crash configuration, which is simulated in the System Model, requires its own Madymo model. For example, the car-to-car crash mode requires a different Madymo model than the pole-to-car crash mode. Although developing more Madymo models improves the accuracy of the estimates of total Harm, this strategy also escalates the engineering and computational costs. To make the systems-modelling approach feasible, it is not practical to model all crash modes but those which are rare or of little social consequence can be safely neglected in order to minimize analysis costs while having little outcome on the final result. The challenge then is to determine the minimum number of crash configurations, which must be modeled in order to capture the systems wide essence of side impact societal cost.

PRIORITISING METHOD

A study was undertaken recently at the Monash University Accident Research Centre to identify those crash modes that should be modeled as part of a systems approach to improving side impact protection in real-world crashes.

This study is based upon the analysis of the MUARC Crashed Vehicle File (CVF) that contains detailed records of real world crashes, which occurred in Victoria, Australia from 1989 to 1992. To be included in the CVF, the crash had to involve at least one occupant who was either hospitalized or killed. The CVF is comprised of 501 crashes involving 606 injured occupants. Of these cases, the CVF contains 198 side impacts involving 234 occupants. The CVF contains only injured occupants. Uninjured occupants were not included in the file.

Each accident record included crash type, principal direction of force, crash profile, vehicle deformations, occupant description, a description of the injuries sustained, and the source of these injuries. Change of velocity during impact was calculated using the CRASH3 accident reconstruction program. Occupant injuries were scored using the Abbreviated Injury Scale (AIS85) procedure and vehicle damage was evaluated using the procedure specified in the U.S. National Automotive Sampling System (NASS).

In interpreting the study that follows, it should be emphasized that CVF is a sample of car crashes, which occurred in Victoria in 1989-1992. The CVF is several years old, and reflects the fleet composition and accident environment of the period 1989-92. Likewise, the sample of crashes in the CVF reflects the traffic accident environment of Victoria, Australia. The CVF is not a national database of crash records, and in particular, is biased toward the ratio of urban-to-rural crashes, unique to the State of Victoria.

In this study, Harm and the cost of injury as defined in MUARC (1994) was used as a measure of social cost. As noted above, these included not only their 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 charges, family and associated losses and allowances for pain and suffering. The approach was to rank order all side impact crashes in terms of both Harm and relative frequency of occurrence. This rank ordering can then be used as a means of assigning priorities for model development based upon the "societal importance" of each crash configuration.

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. Harm, by its nature, provides the cost of total crash injuries, includes all severity levels, and avoids the bias inherent in traditional metrics such as number of fatalities.

RESULTS

The discussion below presents the ranking of crash modes by striking vehicle and object, occupant seating location, impact angle, and near-side vs. far-side impacts. Emphasis was on ranking crash modes that required the development of new computational models. Because the systems model will exercise the computational models across the range of impact speeds, certain specialised distributions such as Harm vs. delta-v were not required and were not investigated in this study. Analysis of the database was undertaken using SPSS analytical techniques. Both percent Harm and percent Injured Occupants are reported in the findings which follow. The reader will note that frequently the two measures will differ – indicating crash configurations where injured occupant counts are a less than accurate measure of social cost.

Side Impacts by Striking Vehicle / Object

Figure 2 illustrates the distribution of Harm by bullet vehicle or object. As might be expected, passenger vehicles (cars, four wheel drive vehicles, and passenger vans) were the most frequent striking object (63%) and accounted for the greatest amount of Harm (57%). Heavy vehicles, e.g., delivery trucks, articulated trucks, and trams, accounted for less than 10% of the Harm. Note that pole and tree impacts resulted in a disproportionate amount of Harm. In the CVF, pole and tree impacts accounted for 23% of the injured persons, but over 28% of the Harm.

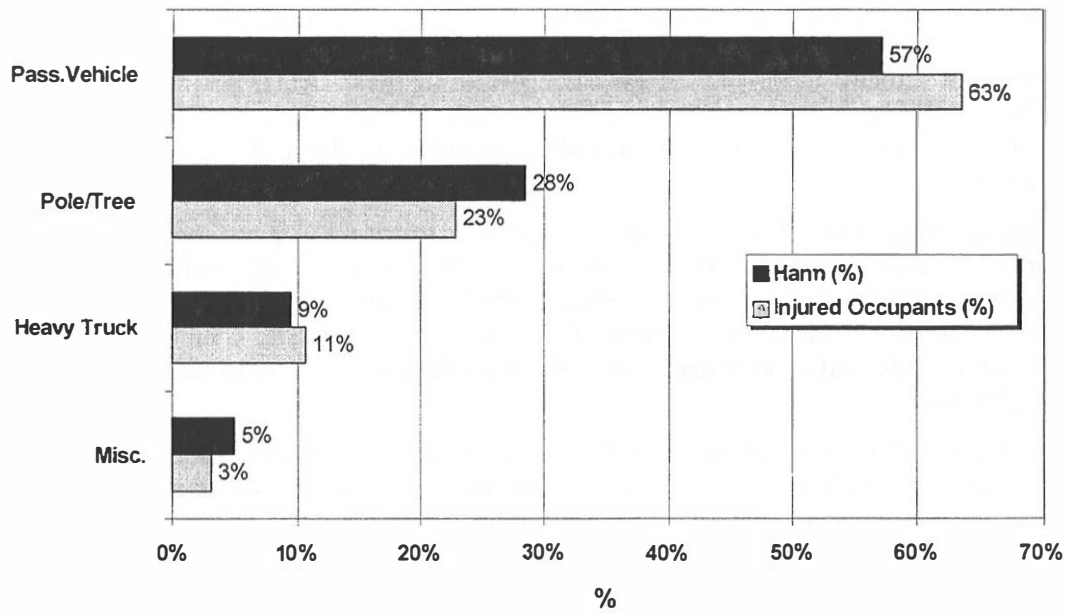

Figure 2 *Distribution of Side Impacts by Striking Vehicle/Object (CVF 1989-92)*

Figure 3 examines the distribution of Harm for side impacts in cases where a passenger vehicle (car, four wheel drive, or van) was the bullet vehicle. As a class, striking cars accounted for the largest contribution of Harm (45%) while passenger vans accounted for the least Harm (2%). Note that a disproportionate amount of the Harm can be attributed to four wheel drive-to-car collisions. Although striking four-wheel drive vehicles accounted for only 6% of the side impact injured occupants, these crashes led to 10% of the Harm, suggesting an incompatibility between cars and Four-Wheel-Drive vehicles in side impact. This confirms similar findings observed in the United States (Gabler & Hollowell, 1998).

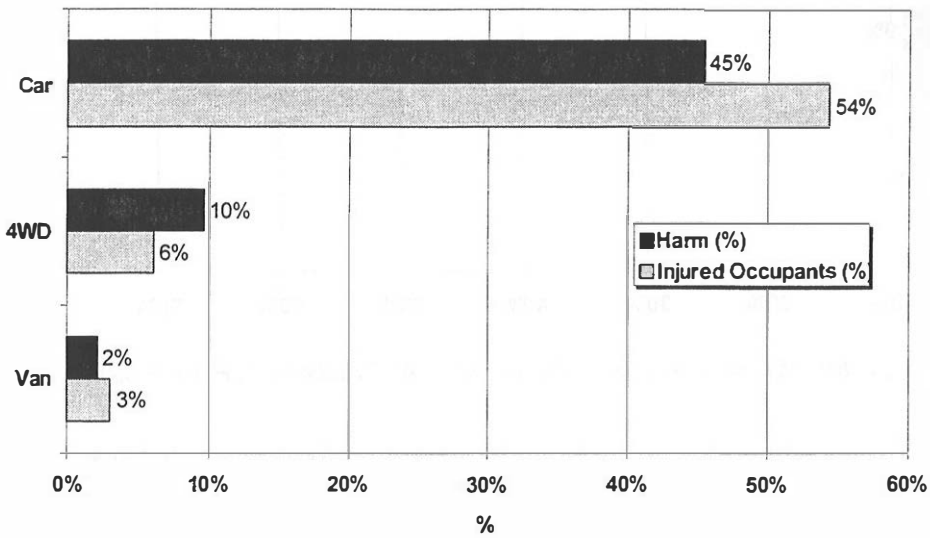

Figure 3 *Distribution of Side Impacts by Striking Vehicle/Object (CVF 1989-92)*

As these data are approximately ten years old, we would expect current data to show a change in the relative proportion of Harm from striking cars and 4 wheel drives. Currently, Four-Wheel-Drive vehicles account for approximately 20% of passenger vehicle sales in Australia. We can expect that Four-Wheel-Drive vehicles would lead to at least this fraction of passenger vehicle Harm, and possibly higher due to the crash incompatibility of cars and Four-wheel drives. This finding suggests that the system model should contain cars, Four-Wheel-Drive vehicles, and poles as bullet vehicles. The ranking further suggests that modelling of heavy trucks and passenger vans would be of only limited value. Collisions with passenger vans are relatively rare (only 2% of all injured persons). Collisions with heavy vehicles are not common (under 10% of Harm), and, in any case, it is unclear what injury countermeasures, if any, are available to alleviate the Harm from these frequently catastrophic encounters.

Distribution of Side Struck Occupants by Seating Location

Figure 4 shows the distribution of side impact Harm by occupant seating location for all side impacts in the CVF. Because every car carries a driver but does not necessarily carry any passengers, we would expect drivers to incur the majority of injuries in side impact. As confirmed in Figure 3, drivers were the most frequently injured occupant (61%) in side impact and accounted for the greatest amount of Harm (62%). Left front seat passengers were the next most frequently involved occupant (27%) and accounted for 23% of the Harm. Rear seat passengers were the least frequently involved occupant (12%) and incurred only 15% of the Harm.

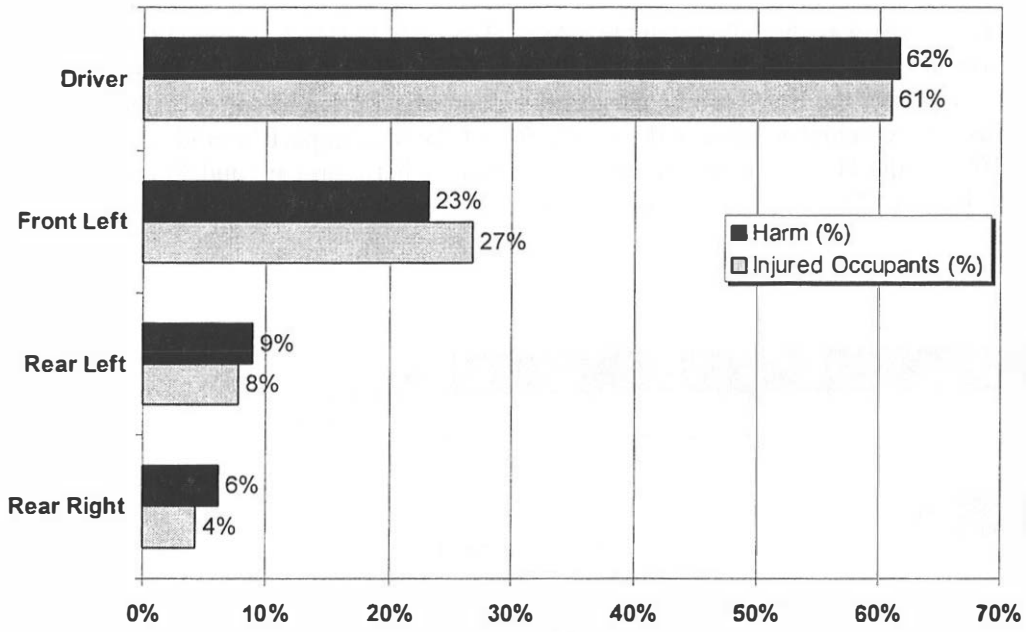

Figure 4 *Distribution of Side Struck Occupants - All Crashes (CVF 1989-92)*

As the systems model can capture 85% of the Harm by modelling front seat occupants only, there appears to be little computational benefit from including rear seat occupants. Note that this recommendation addresses only which occupants should be modeled, not which occupants should be protected. As rear seat occupants are frequently children, it is imperative that occupant protection be made available to rear seat occupants as well as front seat occupants. It is expected that design features developed under this research program, e.g. improved padding, which improve side impact protection for front seat occupants will provide guidance for designing occupant protection for rear seat occupants as well.

Side Crashes by Impact Location and Angle

In the CVF, each side impact is coded not only by impact angle, but also by impact region. Figure 5 shows the definition of impact region and angle used in this analysis as defined in NASS. The analysis, which follows, aggregates all side impacts into two categories: impacts with passenger compartment involvement and impacts without passenger compartment involvement. The first grouping includes all impacts having NASS coding P, Y, Z, and D. The second grouping, referred to here as L-type collisions, include NASS coding F and B. Zero degrees represent the front of the struck car, 180° is the rear of the struck car and 90° represents the side of the struck car.

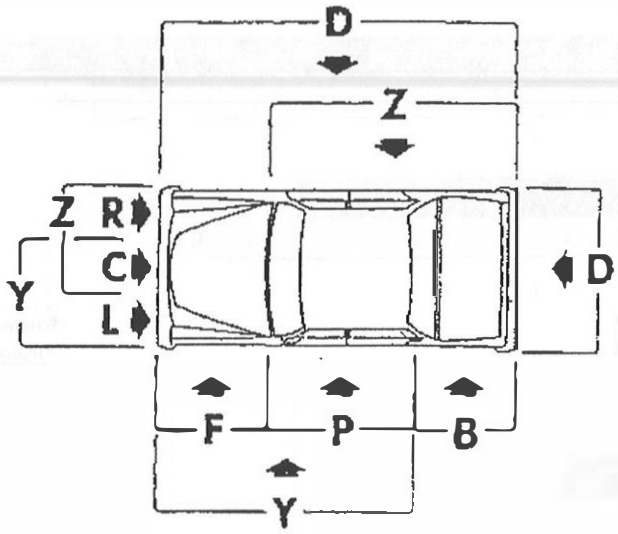

Figure 5. *NASS proforma for coding impact location (from NHTSA, 1989)*

Figures 6 and 7 show the distribution of side impact crashes by impact location and angle for vehicle-to-car and pole-to-car impacts.

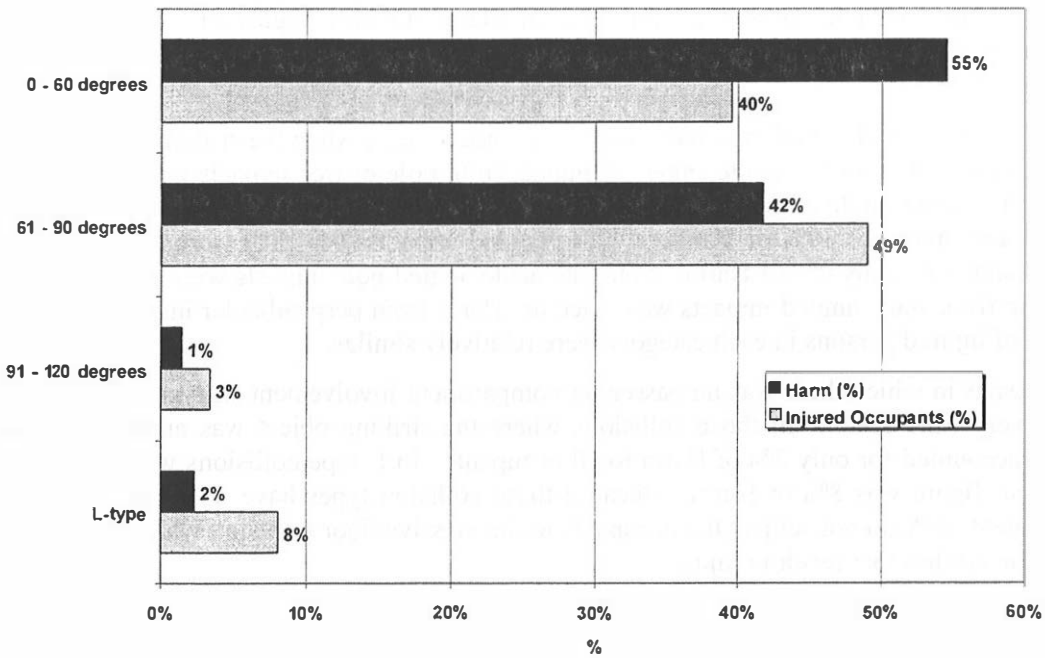

Figure 6. *Distribution of vehicle-to-car side impacts by impact location and angle (CVF 1989-92)*

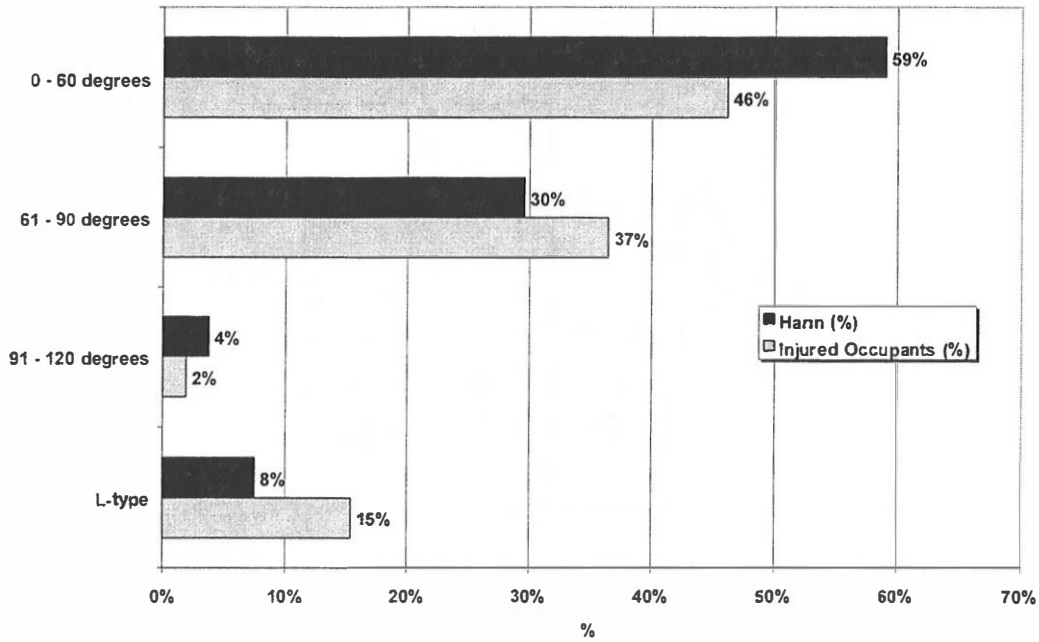

Figure 7. *Distribution of pole-to-car side impacts by impact location and angle (CVF 1989-92)*

Figure 6 shows the distribution of side impacts by impact angle when the striking object was a passenger vehicle. Although the most frequent angle of impact was 61-90° (relatively perpendicular), acute angles of impact (0-60°) inflicted the most harm upon occupants. Fifty-five percent of all Harm resulted from acute angles of impact from passenger vehicles while perpendicular impacts (61-90°) from passenger vehicles accounted for 42% of Harm. Obtuse angles of impact (91-150°) were relatively rare (3% of all injured occupants), and resulted in only 1% of Harm from striking passenger vehicles.

Figure 7 shows the distribution of side crashes by impact angle when the striking object was a pole or tree. Like vehicle impacts, acute angles of impact from pole or tree impacts inflicted the majority of the Harm. Acute angled impacts (0-60°) accounted for 59% of the Harm, while perpendicular pole impacts accounted for 30% of Harm. Obtuse angled impacts (91-150°) were relatively uncommon, and accounted for only 4% of Harm. Note that acute angled pole impacts were particularly injurious: the Harm from acute angled impacts was twice the Harm from perpendicular impacts even though the number of injured persons in each category were relatively similar.

Side impacts in which there was no passenger compartment involvement (L-type collisions) generally caused very little Harm. In those collisions where the striking object was another vehicle, L-type crashes accounted for only 2% of Harm to all occupants. In L-type collisions with a pole or tree, the equivalent figure was 8% of Harm. Because these collision types have no passenger compartment involvement, they do not subject the occupants to the massive door intrusion which is characteristic of many side crashes that result in injury.

These findings suggest that when struck by a passenger vehicle or pole or tree, the model needs to include both perpendicular and angled side impact modes. However, there appears to be limited benefit for modelling L-type collisions. When the striking object is either a passenger vehicle or a pole/tree, the angled model should simulate a 30° impact. There appears to be little computational benefit to modelling obtuse angled impacts.

Side Impacts: Near-side vs. Far-side Impacts

Of the 231 occupants subjected to side impact in the CVF, 165 were seated on the struck, or near-side of car while 66 were seated on the far-side of the car. Figure 8 shows that 71% of all occupants were on the near-side of the impact resulting in 67% of the Harm. This proportion of near-side to far-side

injured occupants was relatively constant regardless of whether the bullet object was a passenger vehicle or a pole/tree.

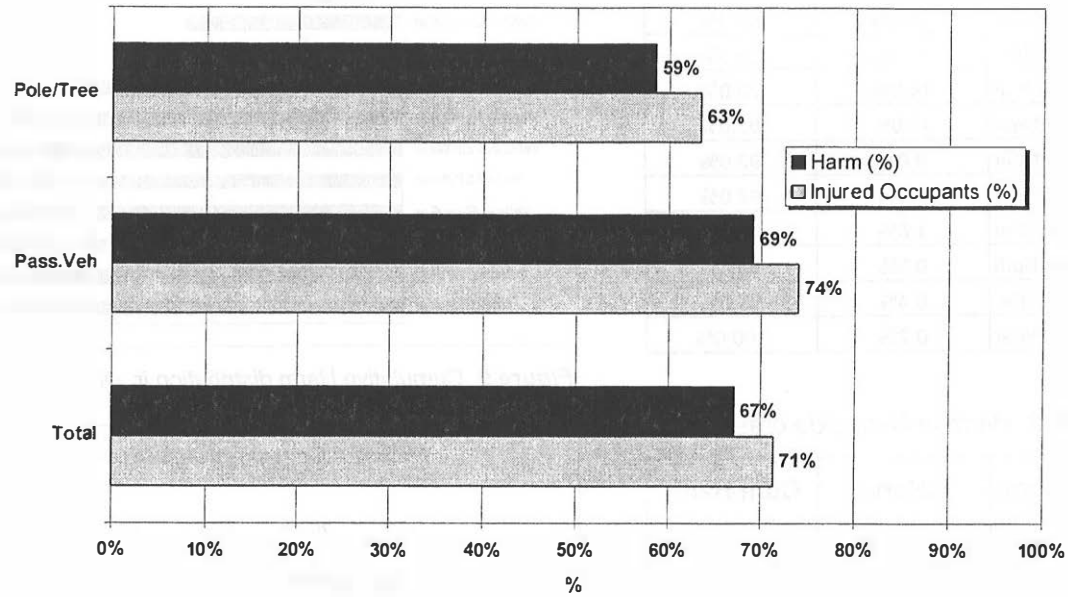

Figure 8. *Near- versus Far-side Impacts (CVF 1989-92)*

Although near-side impacts account for the majority of injured persons and Harm, far-side impacted occupants did account for nearly 1/3 of all Harm and injured persons. Other research has shown that the two types of collisions are characterized by substantially different injury patterns (Fildes et al, 1994). These two types of collisions require different types of countermeasures for occupant protection. The systems model can be tailored for either developing near-side and far-side impact countermeasures singularly or together, depending on the modelling requirements.

Priority Ranking

This study set out to provide a priority ranking of crash types and configurations for optimising side impact protection using a systems-modelling approach. From the finding presented, it is now possible to show these collectively in order of the amount of total Harm that each configuration contributes to total side impact Harm. For ease of understanding, these are presented separately for near-side and far-side Harm, as well as for total Harm. Tables 1 to 3 and Figures 9 to 11 show these results.

Table 1 *Harm in side impact crashes*

Configuration	%Harm	Cum Harm
Vehicle/Driver/Near	27.0%	27.0%
Vehicle/Driver/Far	18.0%	45.0%
Pole/Driver/Near	14.0%	59.0%
Pole/Driver/Far	14.0%	73.0%
Vehicle/FLP/Near	10.0%	83.0%
Vehicle/Rear/Near	9.0%	92.0%
Pole/FLP/Near	5.0%	97.0%
Vehicle/Rear/Far	1.8%	98.8%
Pole/Rear/Both	0.6%	99.4%
Vehicle/FLP/Far	0.4%	99.8%
Pole/FLP/Far	0.2%	100.0%

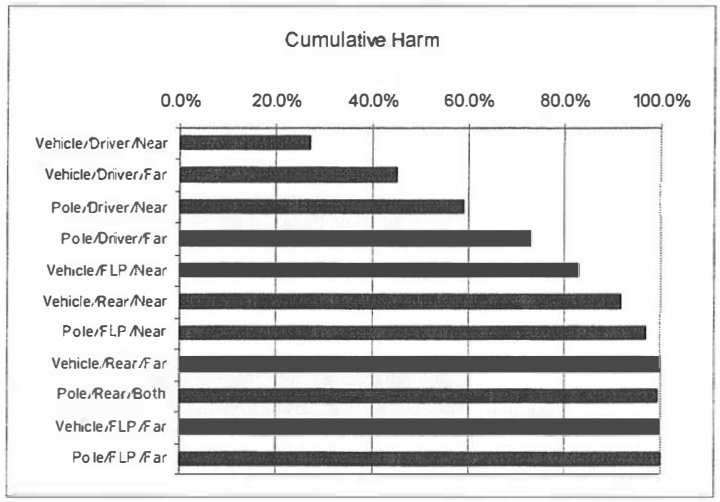

Figure 9 *Cumulative Harm distribution in all side impact crashes*

Table 2 *Harm in Near-side crashes*

Configuration	%Harm	Cum Harm
Vehicle/Driver	29.0%	29.0%
Vehicle/FLP	28.0%	57.0%
Pole/Driver	19.0%	76.0%
Vehicle/Rear	13.5%	89.5%
Pole/FLP	10.0%	99.5%
Pole/Rear	0.5%	100.0%

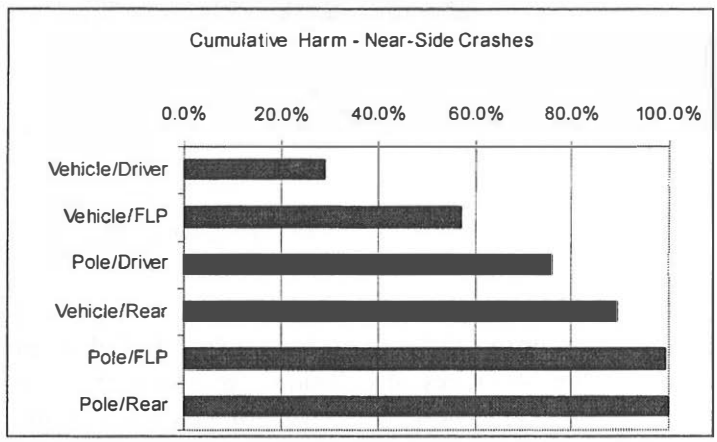

Figure 10 *Cumulative Harm distribution in near-side crashes*

Table 3 *Harm in Far-side crashes*

Configuration	%Harm	Cum Harm
Vehicle/Driver	51.8%	51.8%
Pole/Driver	40.3%	92.1%
Vehicle/Rear	5.2%	97.3%
Vehicle/FLP	1.2%	98.5%
Pole/Rear	0.9%	99.4%
Pole/FLP	0.6%	100.0%

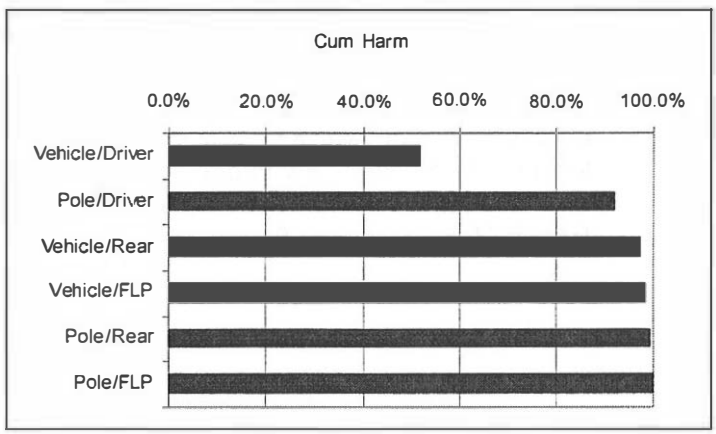

Figure 11 *Cumulative Ham distribution in far-side crashes*

These results are very interesting and provide guidance for optimising occupant protection in vehicle design. For instance, Table 1 and Figure 9 shows that in all side impact crashes, focussing countermeasures on the vehicle impacts for the driver and front-left passenger only will cover more than 55% of the Harm associated with these crashes. Including design improvements aimed at pole crashes will increase the coverage to 88% of the Harm associated with side impact crashes.

Of this 88%, near-side crashes will account for two-thirds, and far-side crashes one-third, of the side impact Harm. In short, a design strategy simply focussed on improving the outcome of drivers only in

near-side vehicle crashes (the current side impact regulation strategy) at worst addresses 27% and best 37% of the side impact Harm, assuming that manufacturers apply similar countermeasures to both front seating positions. Including a pole crash test should increase the intervention coverage to around 56% of the Harm suffered in side impacts. These findings show that including measures also aimed at improving far-side occupant protection will increase the coverage by approximately half again.

This is not to say that the countermeasures will necessary save this amount of Harm, as this is dependent upon the effectiveness of the treatments applied. What it does say, though, is that there is an urgent need to consider other treatments aimed specifically at far-side occupant protection, as this has the potential to lead to a sizeable improvement in occupant protection in side impact trauma, based on data collected in real-world crashes.

It should also be acknowledged that measures aimed at improving driver protection in near-side crashes might also have some benefits in pole impacts and for far-side occupants, although these benefits, if they exist at all, will be purely coincidental.

CONCLUSION

This paper has presented a new approach to prioritising vehicle design interventions, based on the amount of real-world Harm they potentially address. While the focus of this analysis was side impact crashes, it has the potential to be applied to other crash configurations as well. The analysis was undertaken to highlight priorities associated with systems modelling optimisation. However, it is also suitable for a wider application generally in targeting interventions aimed at maximising occupant protection improvements. It is especially useful for optimising vehicle design strategies but can also be used more strategically to help justify the need for new regulations, aimed at occupant protection improvement.

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