IMPROVED SIDE IMPACT PROTECTION (ISIP) IN AUSTRALIA: OVERVIEW OF A COLLABORATIVE APPROACH

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ABSTRACT

This paper includes an overview of a collaborative research project of Improved Side Impact Protection (ISIP) that commenced in 1997. The research program was sponsored by the Australian Research Council and involved a partnership of industry, government and research agencies, both in Australia and overseas. The overall aim was to develop a new approach to optimising vehicle design using Harm as the main outcome criteria. The program involved a number of research activities including mass data analysis, in-depth real-world crash investigations, simulation modelling and the development of a family of Injury Assessment Functions. The paper outlines the structure and progress of these activities, summarises the results and provides an overview of the optimiser model emanating from this research.

INTRODUCTION

Side impacts are frequent and extremely harmful crashes in Australia today. Twenty five percent of vehicle casualties (28 percent of fatalities) occur from these crashes, accounting for roughly one-third of occupant Harm on our roads [1]. The likelihood of being killed or seriously injured is very high in side impact crashes.

Current side impact regulations in Europe and the USA specify acceptable performance levels for a single crash configuration and impact speed. While the desirability of both these standards was shown to be financially beneficial [2], it is unlikely that designing for a single crash type will provide optimal benefits across all side impact crash types and impact speeds. It is argued [3] that optimum side impact protection can only be achieved, taking into account the frequency of side impact crash configurations, likely injuries and the resultant Harm to society.

The Optimising Approach

Design optimisation for minimal societal Harm provides significant benefits over design for a specific crash condition. Traditionally, the crash performance of a particular vehicle design is 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. Modelling for an optimum outcome attempts to capture the fleet wide 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 types is computed in units of fatalities, injuries, and social cost, weighted by its probability of occurrence, and summed. The result is an optimum vehicle design outcome in terms of minimising Harm with associated reductions in the number of fatalities and serious injuries for accident-involved occupants of this car.

The Concept of Harm

As noted earlier, this study used "Harm" [4] as the main design criterion. Harm comprises both frequency and cost of injury components and thus takes into account injury outcomes that are both frequent and costly to the community. Costs included not only treatment and rehabilitation costs but also a range of other costs to society from injury such as loss of wages, 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 was 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 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 accidents at the expense of potentially more common crash types, 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, weights trauma across all severity levels, and avoids the bias inherent in traditional metrics such as number of fatalities.

THE IMPROVED SIDE IMPACT PROTECTION STUDY

In 1997, the Monash University Accident Research Centre was funded by the Australian Research Council through the SPIRT research program to undertake collaborative research into optimising for side impact protection using minimal Harm as the main outcome criterion. The collaboration included Holden Limited, The Commonwealth Department of Transport and Regional Services, the Australian Automobile Association, Autoliv Australia, Human Impact Engineering and Civil Engineering at Monash University. The Road Accident Research Unit at the University of Adelaide, and Roadwatch at the University of Western Australia also contributed to the study, as did a number of local and international specialists in side impact safety and vehicle design.

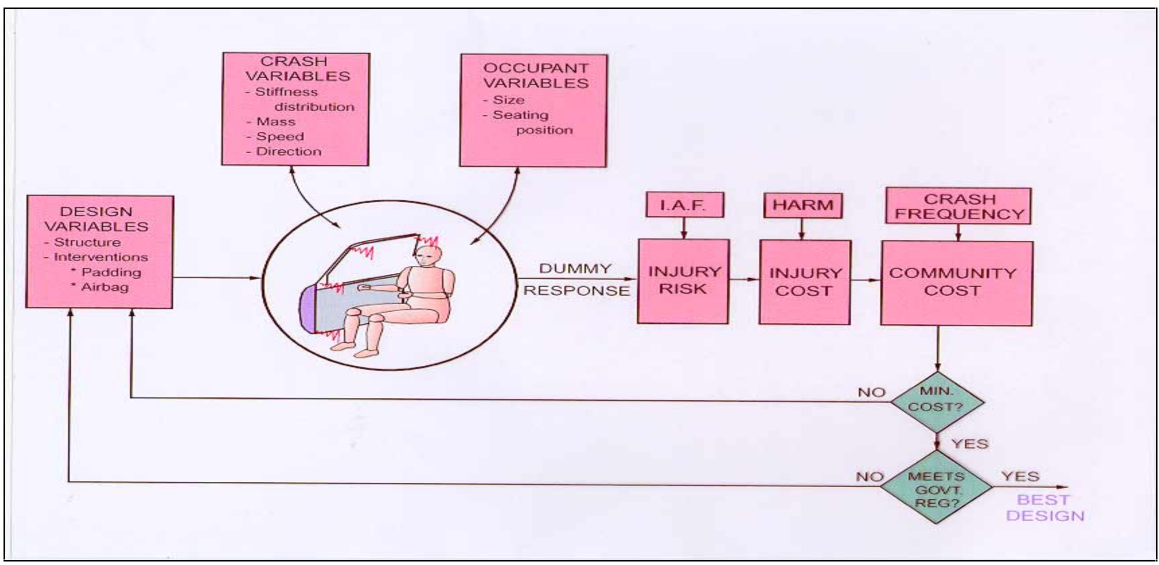

Figure 1 Optimisation process for vehicle design

Outline of the Optimisation Approach

An outline of the optimisation process is shown in Figure 1. Central to the process is the vehicle and human body model (illustrated in the oval) into which a number of exposure variables (crashes and occupants) are feed such as mass, speed and direction of input of the striking vehicle or object and the size and seating position of the occupant. The model is run for a particular set of design parameters and the dummy response is converted into injury risk by body region using Injury Assessment Functions (IAFs) for each region. These are then costed and converted into societal Harm across the various crash frequencies expected for the vehicle under design.

The model is then run again for another set of design parameters or variables until a minimal Harm outcome is achieved. The design parameters include both structural options and available interventions such as airbags, padding and seat belt systems. Various constraints need to be fed into the model such as maximum HIC and chest loads to ensure that the final design meets government regulations. Ultimately, though, the final design is expected to achieve a superior level of protection over that specified by existing side impact safety standards.

Research Tasks

The ISIP research program was structured into four key activities to produce the optimising technique. Members of the research team were assigned to four Working Groups formed to provide the necessary inputs to the optimiser as detailed below.

Working Group 1 – to collect and analyse field crash data as required by other Working Groups.

Working Group 2 – to review existing injury costs and injury patterns to produce more up-to-date Harm matrices for Australian crashes.

Working Group 3 – to produce a family of Injury Assessment Functions (IAFs) for each body region, injury severity level and occupant age and sex.

Working Group 4 – to develop the technique and software necessary to undertake the optimising process.

An outline of the project structure aimed at developing the side impact protection optimiser is shown graphically in Figure 2 below. The remainder of this paper will focus on the activities and outputs from each of these four working groups towards the development of the improved side impact protection optimising technique.

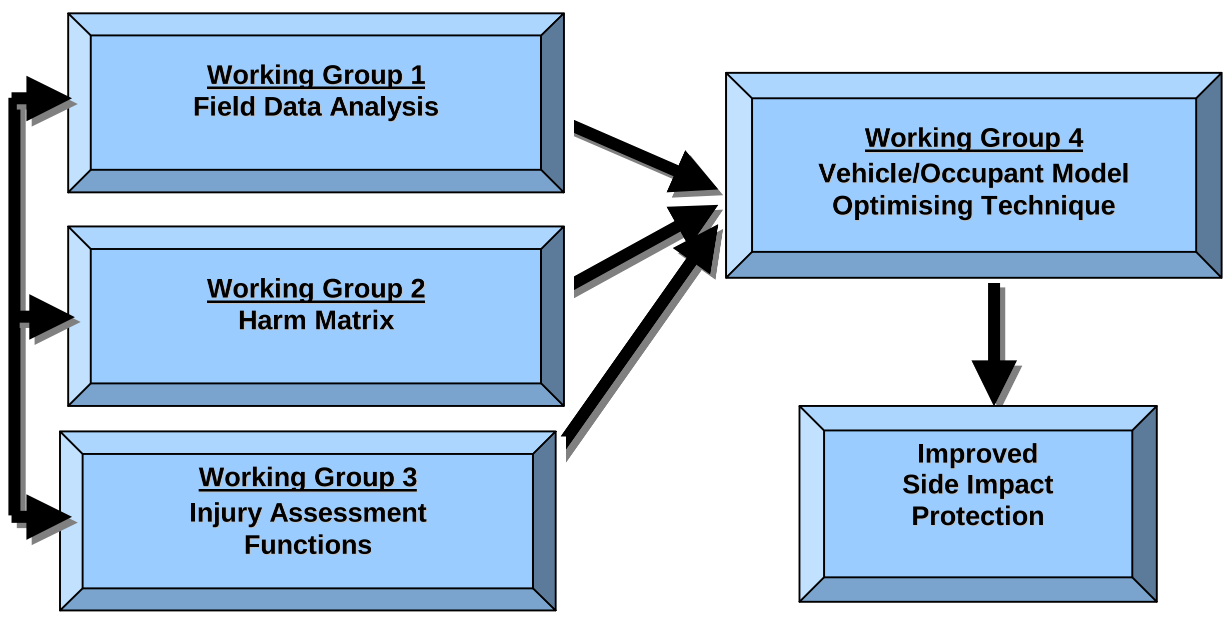

Figure 2 ISIP research program structure

WORKING GROUP 1 ACTIVITIES

When designing for improved side impact protection, it is important to understand the various crash and injury patterns that occur on our roads. The Monash University Accident Research Centre has been examining real-world side impact crashes for the last 10 years. Data were collected in and around Melbourne during the 1990s for more than 200, side impact crashes, where at least one occupant was either hospitalised or killed. The results from this research are published in a project report [5] and an overview of a selection of these is outlined below.

Types of Side Impact Crashes

Figure 3 shows that another vehicle was involved in almost three-quarters of these crashes, and a pole or tree in roughly one-quarter of them. Another car was the predominant striking vehicle in car-car crashes.

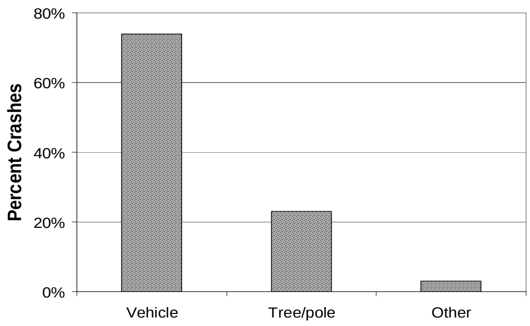

Figure 3 Type of Impacting Object

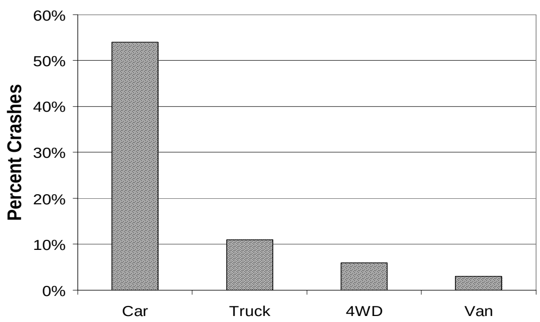

Figure 4 Breakdown of the Striking Vehicle

Impact severity was measured using Delta-V, the change of velocity that occurred during the crash. As shown in Figure 5, the median value of Delta-V was between 25 and 30km/h for both vehicle and pole crashes. Interestingly, three-quarters of side impacts involving another vehicle and two-thirds of pole impacts had a crash severity less than 40km/h, which roughly equates with an impacting speed of less than 80km/h. The higher Delta-V values would likely represent the more severe occupant outcomes.

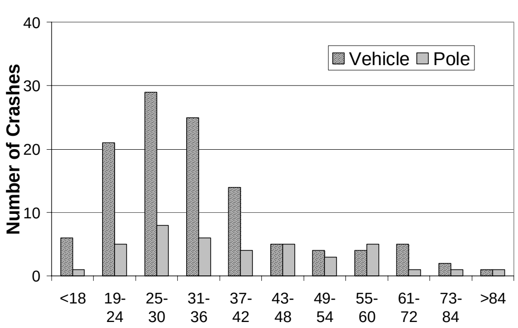

Figure 5 Crash Severity Distribution

Occupant Harm

Harm is a metric that incorporates both the frequency and cost of injury. It is especially useful in examining injury patterns as it weights in favour of those injuries that are both common and extremely costly for society. This means that injuries that may not be life threatening but do have long-term consequences for those sustaining them are not overlooked.

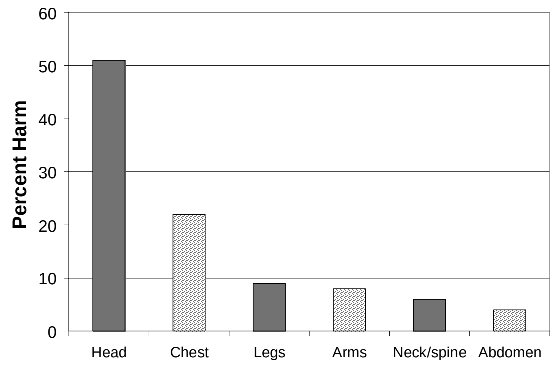

Figure 6 Side Impact Harm by Body Region

Figure 6 shows that the majority of Harm sustained in a side impact crash involve injury to the occupant's head and chest. The main causes of these injuries involve contact with the door, the impacting object (exterior) and to a lessor amount, other occupants in the vehicle and the dashboard .

Near-side and Far-side Harm

Harm can occur to occupants in side crashes from impacts to the adjacent side of the car (the near-side) or the opposite side of the car (the far-side). Drivers can be involved in far-side collisions without a front passenger but the converse is not possible under normal driving.

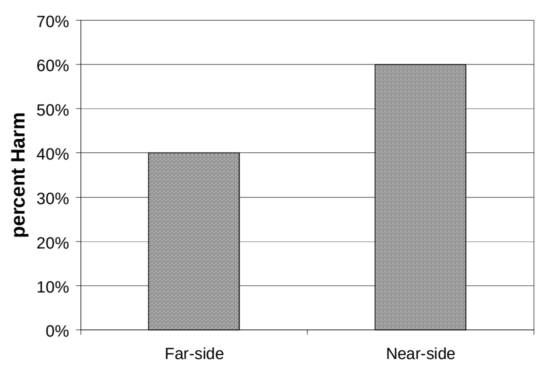

Figure 7 Proportion of side Harm

Figure 7 shows the distribution of Harm from contacts on both sides of the car. While nearside collisions account for the largest amount of side impact Harm, collisions to the far side still represent a sizeable 40% of this Harm. Moreover, the injury patterns and contact sources are quite different for these different crash configurations as shown in Figures 8 and 9.

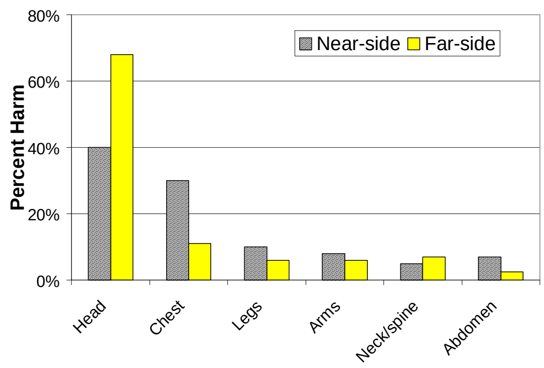

Figure 8 Body Harm by Impacted Side

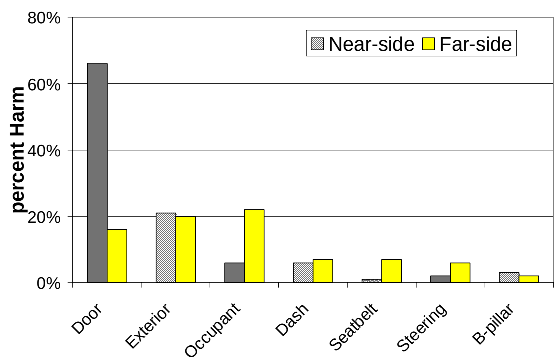

Figure 9 Contact Region by Impacted Side

Notably, Harm to the Head is more predominant in far side and chest Harm in nearside crashes. In addition, while Harm from exterior contacts is roughly equal in both crash types, contact with the door is more common in nearside crashes and contact with other occupants is almost exclusively associated with far-side collisions. This is not too surprising given the crash dynamics and exposure patterns.

WORKING GROUP 2 ACTIVITIES

Working Group 2 objectives were two-fold. First, to undertake a detailed analysis of Harm patterns in side impact crashes by various crash configurations to highlight modelling priorities. This involved a very detailed analysis of the Harm associated by type of striking vehicle, impact angle, and seating position. Second, to re-examine current injury frequencies and costs in Australia and update with more current estimates of the cost of injury using Human Capital methods. This second task was necessary as injury costs in Australia were based on figures derived during the late 1980s. Thus, current Harm analyses are now almost 10 years old and likely to be out-dated, given the expected benefits of technology introduced in Australia during recent years.

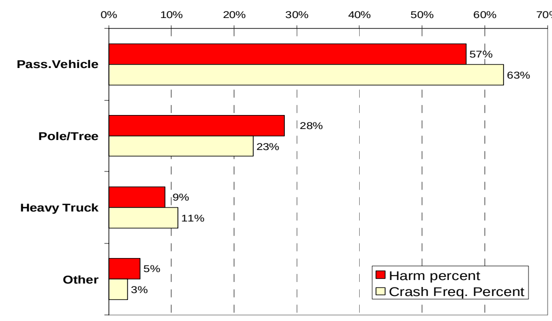

Figure 10 Distribution of Side Impacts by Striking Vehicle/Object (CVF 1989-92)

Figure 10 shows the distribution of the striking vehicle or object that collided with the side impacted passenger car. 63% of the Harm was from another passenger vehicle, 28% from a pole or a tree and 9% from a heavy truck. In this case, there was little difference in the distributions between Harm and crash frequency.

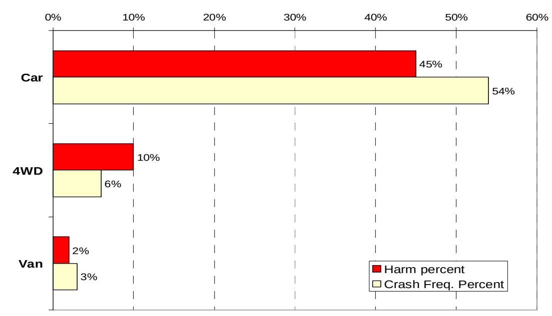

Figure 11 Distribution of Side Impacts by Striking Vehicle/Object (CVF 1989-92)

The distribution for the striking vehicle only is further broken down in Figure 11. Of the 57% of passenger vehicle strikes, the majority (45%) was from another car, 10% from a Four-Wheel-Drive vehicle and 2% from a passenger van. These figures will vary depending on their mix in the vehicle fleet.

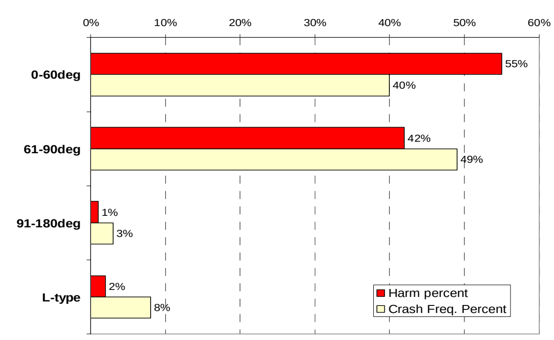

Figure 12 Distribution of vehicle-to-car side impacts by impact location and angle (CVF 1989-92)

Figure 12 shows the angle of impact of the striking vehicle in car-to-vehicle side impact crashes. Most

Harm (55%) was derived from impacts between 0-60deg, and 61-90deg (42%). Interestingly, the frequency priorities were reversed (40% and 49% respectively). This is a clear example where harmful events are not necessarily captured precisely from examining crash frequency figures alone.

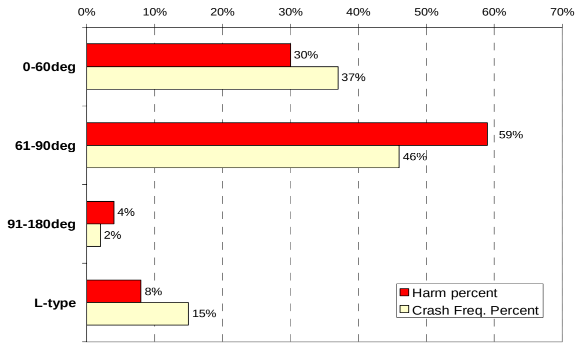

Figure 13 Distribution of pole-to-car side impacts by impact location and angle (CVF 1989-92)

Figure 13 shows the same plot of Harm and crash frequency by impact direction when the striking object was a pole or a tree. For this crash type, most of the Harm was from crash configuration of 61-90deg (59%) and 0-60deg (30%). Again, crash frequency did not capture these harmful crash types very well, although much better than when the striking object was another vehicle.

Injury Costing

Estimates of injury costs are in the final stages of completion at the time this paper was completed and will be reported in more detail later this year. Preliminary findings show that earlier estimates of Harm by body region and injury severity were rather conservative based on current prices and values. Moreover, early allowances for pain and suffering were quite inadequate and did not accurately reflect true estimates of the full indirect costs associated with road trauma recuperation.

The consequences of this are rather important for the optimisation process. The real benefit of using Harm as the outcome measure is its ability to focus attention on addressing the most harmful events as a matter of priority rather than simply addressing the more severe crash types. While Harm obviously gives credence to severe injuries also through their sizable costs to the community, it is also capable of taking into account more frequent less life-threatening injuries that incur long-term consequences. In short, it is capable of bringing together both severity and disability aspects of injury. This assumes, however, that the costs reflect true and accurate accounts of the real impact of these injuries. If not, then the optimisation procedure is likely to produce less than optimum design solutions. It is intended to repeat the detailed Harm analysis reported briefly here once the present Harm values are upgraded to ensure that the priorities implicit in these findings still hold

WORKING GROUP 3 ACTIVITIES

The third working group set out to compile a set of injury assessment functions by different age and sex distributions for injuries sustained in a side impact crash of different crash severities. These functions were necessary for converting dummy measures obtained from the MADYMO human dummy model incorporated in the optimiser routine into probabilities of injuries.

A number of Injury Assessment Functions have been published and are available for frontal impact analysis from various biomechanical agencies. However, Injury Assessment Functions for side impact were less well formulated and additional work was needed to generate the functions required for this project. To date, a comprehensive set of IAFs for side impact collisions have not been published, although there have been some isolated figures of potential use here.

Two workshops were held involving a number of leading international specialists in side impact biomechanics and crashes (Appendix 1 lists the international advisory panel who generously provided their time and assistance with this task). From these discussions, it was decided to identify priority Injury Assessment Functions, based on Harm measures and these are shown in Table 1.

Table 1 Side impact Injury Assessment Function priorities based on associated Harm

Priority	Body Region	Percent SI Harm	AIS	IAFs available
1	Head	47%	3,4,5	none
2	Thorax	22%	3,4,5	4+
3	Lower limb	9%	1,2,3	2+
4	Upper limb	6%	1,2,3	none
5	Spine	4%	2,5,6	none
6	Face	3.6%	1,2	none
7	Pelvis	3.1%	2,3	2,3
8	Shoulder	1.9%	2	none
9	Abdomen	1.8%	1,4	4+
10	Neck	1.7%	1,3,5	2+

Table 1 shows that head and chest injury predominate side impact Harm in Australia, hence, there was a need to focus on relationships between head and chest injury by crash severity warranted higher priority. A search then commenced to see what IAFs were available within the existing literature that could be used within this project. Figure 14 is one example of an injury tolerance curve for the chest based on three studies that had been published.

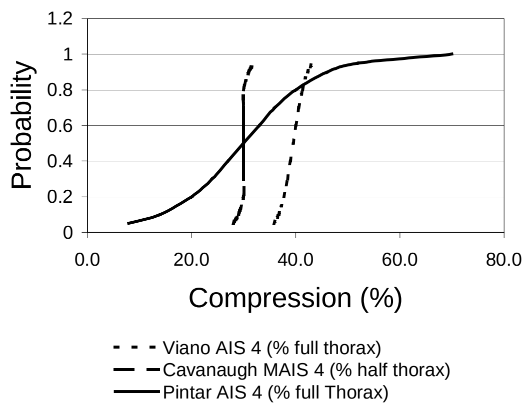

Figure 14 Injury tolerance for the chest based on percent chest compression [6]

These three curves were generated from cadaver data using different test methods and are clearly fundamentally different. While it would be possible to select one curve for use in this project, it is only for the more severe chest injuries (AIS4+) and does not cover all priority injury severities required.

There was a need, therefore, to investigate alternative methods of generating IAF curves and this more recent research is to be reported in a separate companion paper at this conference [6].

WORKING GROUP 4 ACTIVITIES

The fourth and final task was to develop the optimiser software incorporating the required routines to arrive at a minimum Harm outcome. This optimising process took the information generated by the first three Working Groups and selected the best vehicle design. This final step in the research project represented both the core element, and the greatest challenge, of the project.

The foundations for the simulation model were based upon the in-depth analysis of real-world side impact crashes described earlier. Analysis of these crashes identified the crash direction and crash severity by comparing the static deformation measured on the vehicles examined in the field data collection with deformation measured from laboratory tests. Crash severity was then calculated from these measurements. These investigations also identified the injuries resulting from the crash, but no information could be gained about the impact loading to the occupants.

As a first step in developing the optimiser, a very large and accurate computer model was developed, consisting of a detailed model of a Holden Commodore with a test dummy in the driver's seat, plus an impacting vehicle represented by a mobile barrier with a deformable front structure. This model utilised about 300,000 finite elements. The model of the Commodore and occupant is shown in Figure 15.

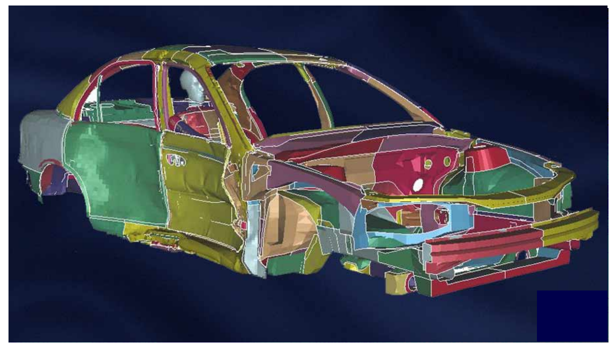

Figure 15 Full-sized Side Impact Computer Model for Design Validation

The Development of a Simplified SI Model

The optimisation process required an efficient side impact simulation method, in order to reduce computer-processing time to within practical limits. The order of magnitude reduction in computational time was achieved by a partial de-coupling of the simulation of the side impact event. After running the full-sized side impact model of Commodore, occupant and impacting vehicle or pole, the calculated vehicle structural response was used as input to this smaller model. The simplified side impact model incorporated only those parts of the structure that influenced the vehicle components interacting with the occupant (Figure 16).

The simplified side impact model used about 5000 elements to represent the occupant and the critical characteristics of the vehicle structure, padding and airbag characteristics. The dummy was modelled to provide the same data as that generated by the physical crash-test dummy. This simplified side impact model required 70 minutes run-time on a HP J-class workstation, an acceptable time for use in an optimising process. This represents a significant reduction from the full-sized model size of 300,000 elements requiring 2-3 days run time on a HP N-class server.

This hybrid sub-system model was constrained by dynamic boundary conditions specified from the full size model. The use of this type of model is a new approach to a complex problem that has been explored by some simulation experts around the world, but as far as is known, this is maybe the most extensive successful application of the technique.

The simplified MADYMO model was then run with the chosen restraint parameters. During development and validation of the optimisation model, EuroSID dummies were used for both the DYNA full-sized side impact computer model run and the MADYMO ssimplified side impact model run. As mentioned earlier, the dummy interaction with the vehicle side structure influences the vehicle structural deformation, hence it is necessary to utilise the same dummy type in both runs in order to ensure comparable results. The MADYMO EuroSID used in the simplified side impact model was taken from the TNO dummy database and incorporates a combination of flexible bodies, rigid bodies and facet surfaces. It is computationally simpler than the finite element EuroSID used in the DYNA full-sized side impact computer model. Work is continuing to validate the performance of BioSID and SID IIs dummies in the simplified model.

The components represented in the simplified model are shown in the following illustration of a side impact crash (Figure 16.

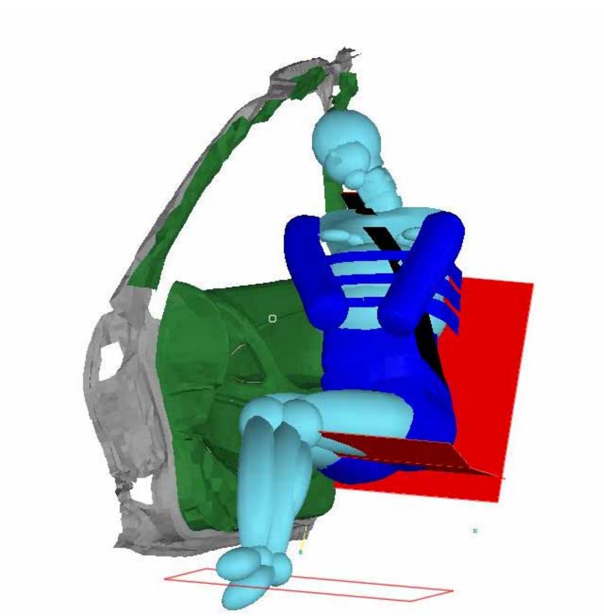

Figure 16 Simplified SI Model for Optimisation

DISCUSSION

Within the relatively short 3-year timeframe, the project has achieved much of its objectives. There is still some fine-tuning and validation testing to be done before the optimizer model is complete. Nevertheless, a number of milestones have been achieved so far regarding improved knowledge of side impact crashes in the real world. These are outlined below.

The detailed in-depth analysis of side impact crashes and their associated Harm is something of a first in this area. Such a detailed analysis of the extent, severity and types of real-world side impacts provided unique insights into the causes and extent of side impact trauma in Australia. Type of impact by crash severity was useful for identifying design priorities and the resulting occupant kinematics modelled during this process enabled design solutions to be identified, based on minimizing societal Harm.

The research into injury costs in Australia will provide updated estimates of the likely cost to society of body region injuries by severity. Using the Human Capital method, allowances are made for both direct costs to the various agencies involved in trauma management and rehabilitation. In addition, more attention to accurate long-term injury costs (including loss of quality of life) to the individuals and their families beyond the initial treatment will further enhance these figures. Indeed, it was argued that using the Harm method including injury costs is a suitable means of weighting for both injury severity and disability associated with the long-term consequences of injury.

Assembling all available information on Injury Assessment Functions in side impacts provides additional information in this field. While the number of existing side impact IAFs was scant, additional research undertaken by the research team will provide additional knowledge and relationships of injury functions in side impact crashes beyond that currently available. Finally, the work in developing a Harm optimising model for manufacturers to use in designing for improved side impact protection is unique to the authors' knowledge. The development of a simplified vehicle and human model for this process is expected to result in a practical and useable tool that can be run on current workstations.

The final product from this research project is the design optimisation procedure, which will be generally available to the automotive industry and government organisations with an interest in improved vehicle safety. Those with an interest in adopting the software will need to undertake some initial additional research to fine-tune the optimising model to suit their vehicles. After that, the side impact optimiser will then be suitable for determining design strategies and countermeasures to provide optimum solutions and strategies for reducing Harm to their vehicle occupants involved in a side impact crash.

Of special note was the extensive international collaboration research effort associated with this project, which helped ensure its success. This involved the combined efforts of specialist researchers, industry partners, government agencies involved in vehicle safety and consumers organisations representing groups such as ANCAP and EuroNCAP. It is hoped that this work will ultimately provide additional insights and improvements into improved occupant protection in one of the more severe type of crash experienced on our roadways.

Future Research

This side impact study was predominantly focused on injuries and Harm to nearside occupants. This was judged to be appropriate given the overwhelming amount of Harm associated with these crashes (60% of all side impact Harm in Australia). However, as was highlighted during the study, injuries to far-side occupants still accounts for a sizeable 40% of occupant Harm in side impact crashes. Moreover, the design solutions are likely to be quite different, given the unique patterns of injuries and contact sources from this trauma. Further research is warranted to address optimization of vehicle design for far-side occupant Harm, both for single and multiple front seat occupants.

Acknowledgements

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REFERENCES

1. Fildes BN, Vulcan AP, Lane KC & Lenard J. Side impact crashes in Australia, paper 94-S6-O-01, Enhanced Safety of vehicles conference, Munich Germany, National Highway Traffic Safety Authority, Washington DC. 1994.
2. Fildes BN, Digges KH, Carr D, Dyte D. & Vulcan AP. Side impact regulation benefits, Report CR154, Australian Transport Safety Bureau, Canberra, Australia, 1995.
3. Fildes BN, Vulcan AP, Grzebieta R, Sparke L, Seyer K, et al. Optimal side impact protection, Proceedings of the Road Safety and Enforcement Conference, Wellington New Zealand, 1998.
4. Fildes BN & Digges KH. Harm reduction for estimating countermeasure benefits, Proceedings of the Burden of Injury Conference, Road Accident Prevention Research Unit, Department of Public Health, University of WA. 1996
5. Gibson T, Fildes B, Deery H, Benetatos E. McvLean J et al. Improved side impact protection: a review of injury patterns, injury tolerance and dummy measurement capabilities, MUARC Report No. 147, Monash University, Clayton, Australia, 2001.
6. Gibson T, Benetatos E., Newstead S. & Fildes B. Improved side impact protection: the development of injury assessment functions, ESV paper 264, National Highway Traffic Safety Administration, Washington DC.

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