Benefits of a Frontal Offset Regulation

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Abstract

Australia currently has a dynamic full frontal crash standard ADR 69, similar to the US FMVSS 208 with provisions for restraining the test dummies. The European road safety community have outlined a proposed EEVC frontal offset requirement, due to be introduced in Europe during 1998. The question is whether this additional standard is warranted in Australia and would it be cost-effective. A study was undertaken for the Federal Office of Road Safety to address this question. An analysis was performed initially of 215 hospitalised drivers who sustained a lower limb injury in a frontal crash, comparing full frontal with offset frontal outcomes. This finding supported the need for further countermeasures for frontal offset crashes, especially those which addressed lower limb injuries. A one-day workshop of international specialists was then held to determine the likely injury reductions of the proposed EEVC offset standard. Using these findings, a Harm Reduction analysis was undertaken to arrive at the benefits of Australia mandating the proposed EEVC offset regulation in addition to ADR 69. The findings revealed considerable additional benefits of between A$297 million and A$460 million each year, depending on the level of airbag usage in 1998. This equates to a unit Harm benefit per car of between A$296 and A$576. On this basis, it would seem highly desirable for Australia to mandate for the standard as outlined by Lowne (1994). Any attempt to remove the lower limb injury criteria from this proposal would severely compromise these benefits and make it difficult to support.

Keywords

SAFETY, ACCIDENT, VEHICLE OCCUPANT, INJURY, COUNTER-MEASURE, COST-BENEFIT, ECONOMIC, HARM, EVALUATION

Notes

(1) FORS reports are disseminated in the interest of information exchange.
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(a) reports generated as a result of research done within FORS are published in the OR series;
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(c) reports based on analysis of FORS statistical data bases are published in the SR series;
(d) minor reports of research conducted by other organisations on behalf of FORS are published in the MR series.

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EXECUTIVE SUMMARY

INTRODUCTION

Australian vehicles are currently required to meet Australian Design Rule ADR 69 which specifies head, chest and femur dummy criteria in a dynamic full frontal crash test at 48km/h. This is based on the US regulation FMVSS 208 with the added allowance for the test dummies to be restrained by seat belts.

The European road safety community has been working towards developing a dynamic frontal offset standard to be mandated for all European vehicles towards the end of 1998. The Federal Office of Road Safety is participating in this work with a view to adopting this new regulation if warranted. The question arises whether there would be sufficient additional benefits to Australian motorists in addition to ADR 69 and whether they would be cost-effective.

This study was commissioned by FORS to address this question. The tasks included an examination of the pattern of injuries sustained in offset compared with full frontals as well as a Harm analysis to calculate the likely benefits of the proposed EEVC offset requirement.

PROPOSED EUROPEAN OFFSET STANDARD

The proposed EEVC offset requirement specifies a range of head, neck, chest, femur and lower leg criteria for two Hybrid III test dummies situated in the front seat of a passenger car impacting a deformable face fixed barrier offset 40% on the driver's side.

The injury criteria specified for the dummies are more comprehensive than those currently applying in ADR 69 or FMVSS 208 and importantly includes lower leg injury criteria. This is really a first and an important break through for occupant protection. A number of studies have reported lower leg injuries are frequent in frontal crashes and while not necessarily life threatening, nevertheless, are often disabling and extremely painful requiring considerable rehabilitation and very costly to the community in general.

In addition to lower limb criteria, the proposed EEVC offset requirement also includes neck injury criteria and more comprehensive head and chest requirements. Moreover, the standard is likely to lead to structural improvements in cabin integrity which will benefit car occupants.

INJURIES IN OFFSET CRASHES

The first task undertaken was an analysis of the Crashed Vehicle File at MUARC, a database containing details of over 500 crashes and 600 hospitalised passenger car occupants. Of these, 215 were frontal crashes where the driver sustained a lower leg injury, roughly equally divided between full frontal and offset configurations.

The analysis revealed that the outcome for drivers involved in near-side offset collisions was considerably worse than for equivalent full frontal drivers. They sustained more severe injuries, especially to the lower torso and the legs than their counterparts in full frontal crashes and, on average, at lower impact speeds. This was not a function of differences in seat belt wearing,rates but did appear to be influenced slightly by the type of car they were travelling in.

Lower limb injuries and severe injuries to the upper limbs seem to be areas requiring particular attention in near-side offset collisions (that is, when the offset crash was on the same side of the vehicle as the driver). Reduced intrusion inside the passenger compartment by the steering column, instrument panel, A-pillar and floor and toepan need greater emphasis in near-side offset frontal crashes for drivers.

ESTIMATING INJURY REDUCTIONS

As there were no injury data available and very few test results, an expert panel was formed comprising international specialists from vehicle manufacturing, research organisations, and government agencies responsible for vehicle safety.

From a one-day workshop held in Washington DC in December 1995, a number of assumptions were developed on which to calculate the likely injury reductions of the offset standard by body region. The expert panel were unanimous in their view that the benefits would be derived from three sources, namely from a general improvement in structural integrity (the so-called universal benefit), from a greater use of driver side airbags, and from specific countermeasures to address particular injuries such as those to the lower legs.

It was especially noteworthy that there was a high degree of consensus among the expert panel of the need for such a standard and likely injury reductions that would accrue. There was also a strong call from many of these organisations for a single worldwide offset standard to ensure the best possible outcome for vehicle occupants.

THE HARM REDUCTION METHOD

A Harm analysis was then performed using these assumptions as a basis for calculating the likely Harm saved by the EEVC proposed offset standard. The Harm Reduction method developed by the Monash University Accident Research Centre in conjunction with Dr. Kennerly Digges for previous benefit studies was again used here.

The national Harm database developed previously (eg; Monash University Accident Research Centre, 1992; Fildes, Digges, Carr, Dyte & Vulcan 1995) was the basis for calculating the benefits of the proposed EEVC offset standard. Allowances were made for subsequent vehicle safety improvements such as ADR 69 in arriving at these benefits.

Analysis by body region was undertaken using a 3-step cascading model. Harm saved from the universal benefit was first deducted, followed by increase in airbag usage (up to 100%) and finally specific countermeasure benefits. Given that the likely usage rate of driver airbags in 1998 was unknown, these benefits were calculated for a range of possible usage rates from 70% to 100%.

OFFSET BENEFITS

The benefits of adopting the proposed EEVC offset standard were expressed as both the annual Harm saved assuming all vehicles in the fleet were compliant as well as the unit Harm benefits per car across its lifetime. In computing unit Harm benefits, 5% and 7% discount rates were employed for 15 year and 25 year life of the vehicle periods.

Annual Harm Benefits

The annual Harm reduction that would accrue from the offset standard in addition to that achieved from ADR 69 was estimated to be at least A$297 million (a 15% reduction in frontal Harm) and at best, A$460 million (a 23% reduction in frontal Harm). The full benefits would apply when all vehicles in the fleet complied with both standards.

Unit Harm Benefits

Unit Harm benefits (the average savings per car across its lifetime) were then calculated using 5% and 7% discount rates and life of the vehicle periods of 15 and 25 years. These calculations showed that unit Harm savings from adopting the EEVC offset requirement would be somewhere between A$296 and A$576 per car. In other words, the break-even cost for having to meet this new requirement is likely to be somewhere in this range.

It should be noted that the most conservative estimate was for a 15% reduction in frontal Harm attributed directly to this standard assuming no benefit from increased airbag use. This would seem to be a worthwhile improvement in occupant protection alone. The minimum break-even cost to achieve this benefit would be A$296 per vehicle which seems feasible in light of industry estimates which suggest a A$100 additional cost for achieving the side impact standard improvements outlined in Fildes et al, (1995).

RECOMMENDATION

On the basis of the evidence presented here, it would seem desirable for Australia to consider introducing an offset frontal crash standard similar to that being proposed in Europe. The benefits likely to accrue would be somewhere between A$297 million and A$460 million annually with 100% fleet compliance. The break-even cost per car across its lifetime would be on average from A$296 to A$576. This finding is conditional on all aspects of the EEVC proposal outlined here and is likely to be severely compromised if any of the injury criteria were to be removed or downgraded over that currently proposed.

Chapter 1 Introduction

1.1 BACKGROUND

ADR 69 has just come into force in Australia which specifies a minimum level of protection that vehicle manufacturers and importers of passenger cars are expected to meet in a dynamic full frontal crash. This standard, based on the US standard FMVSS 208, is expected to lead to an increase in occupant protection within the range of 10 to 25 percent, depending on what new safety features manufacturers choose to fit as a result of ADR 69. However, it has always be recognised that while full frontal crash tests the efficacy of the restraint system in a high deceleration crash, offset frontal crashes lead to a marked increase in vehicle deformation which is more than likely associated with an increase in intrusion injuries.

Since 1993, the Federal Office of Road Safety (FORS) have been participating in the European Experimental Vehicle Committee (EEVC) Working Group 11 research to develop a dynamic offset frontal test procedure. FORS has advised the manufacturing industry that the final EEVC test procedure would form the basis of an ADR for offset frontal impact protection, providing it can be shown to be cost effective. Under the arrangements for introducing new or amended ADRs, FORS is required to include a Regulatory Impact Statement for public comment.

Given the Monash University Accident Research Centre's unique Australian database and expertise in these studies, the Federal Office of Road Safety commissioned MUARC to undertake a study aimed at assessing the benefits of Australia adopting this European offset frontal crash standard. For the purpose of this study, it was assumed that this new offset standard would be in addition to ADR69, rather than to replace it.

1.1.1 Project Objectives

It is understood that the major study objective was:

> *"to estimate the benefits likely to accrue from adoption of an additional offset frontal impact ADR similar to that currently under consideration in Europe."*

It would be helpful to compare the types and severity of injury sustained in offset compared to full frontal to show the desirability of having different frontal standards. Moreover, as some concerns have been expressed about what the most desirable crash speed should be for the test, it would be worthwhile estimating these benefits at two different speeds, namely 56km/h and 60km/h to gauge the likely differential benefits.

In short, the study was expected to demonstrate the benefit of a new offset standard over that likely to accrue from the recently introduced ADR69 regulation.

1.2 THE PROPOSED EUROPEAN STANDARD

The proposed European offset standard was outlined by Lowne (1994). While there might be some additional minor changes to the proposal since then, recent information confirms that the proposed standard is still much the same as outlined in this publication (Richard Lowne is the Chairman of the EEVC working group 11 responsible for development of the standard).

1.2.1 Specifications

The proposal calls for an offset frontal impact test with a 40% overlap and a deformable barrier. The deformable material is specified as 50psi aluminium honeycomb similar to that used in the FMVSS 214 MDB face. The lower edge of the deformable face is to be set 200mm above the ground level. The speed of impact is set at 56km/h to harmonise with 35mph used in the NHTSA (and Australian) NCAP test procedure. Two Hybrid III 50th percentile dummies are placed in the two outboard front seating positions. Injury criteria are not 100% clear at this time but the following have been suggested as possible candidates:

1. **Head.** While Head Injury Criteria (HIC) has a number of deficiencies, it is still considered to be the best parameter for measuring risk of head injury and likely to be recommended. A peak resultant head acceleration of 80g might also be included subject to further testing.
2. **Neck.** Criteria likely to be recommended include axial tension, shear force, and extension moment, based on figures proposed by Mertz (1991). This is still currently being finalised.
3. **Chest.** Chest deflection should not exceed 50mm other than when forces are widely distributed (by an airbag for instance) and V*C should be less than 1.0m/sec.
4. **Abdomen.** It is acknowledged that compression of the abdomen needs to be limited but more details were being sought at the time before this can be specified. More recent information suggests that this criterion is not included in the final standard.
5. **Femur.** Femur loads should not exceed the force-time performance figures provided by Mertz (1991).
6. **Tibia.** Criteria are proposed for axial compression (maximum 8kN) with a Tibia index less than 1.3. The movement of the sliding knee joints should not exceed 15 mm. These criteria are currently still subject to debate and others are also under consideration.
7. **Intrusion.** Steering wheel displacement at the centre of the hub should not exceed 100mm in the rearward horizontal direction and 80mm vertically. Upward rotation of the steering column and wheel is to be less than 25deg. The dummies must be capable of being removed intact without adjusting the seating position after the test and must be able to be used in further testing.

Several supplementary tests are also under consideration including steering wheel impacts, seat and seat attachments, seat belts and anchorages and fuel leaks, but these are not considered in this report.

1.2.2 Test Crash Speed

As noted above, the proposed standard calls for a test impact speed of 56km/h. A number of researchers have questioned the suitability of this speed based on test results conducted at varying speeds.

Transport Canada conducted a series of offset tests using the European format and showed that at 56km/h, the 3 vehicles tested essentially met the requirements, whereas at 60km/h, the vehicles failed in several areas, predominantly in regard to lower limb injury criteria. A summary of the results of these 3 tests are shown in Appendix C. In addition, EEVC test results conducted during the development of the proposed procedure show similar trends (these results are about to be published by the EEVC group in a technical report and should be available later in 1996).

The Insurance Institute for Highway Safety in the US have also conducted offset crash tests using the European test set-up but with speeds of 40mph (64km/h). They argued that like the New Car Assessment Program, their tests should be higher than the planned regulatory speeds to test the crashworthiness of cars at faster speeds than that required for compliance. Their results, also shown in Appendix C, reveal considerable variations in deformation but very few instances where the European test criteria were exceeded. These were for current model US vehicles, some of which had already been designed assuming an offset requirement.

The current US Government view about impact speed is that even these speeds are too low to lead to significant reductions in injuries. They are currently working on developing an alternative offset crash procedure involving a moving barrier at speeds around 70mph with a 15deg crabbed configuration into the driver's side front corner of the vehicle. As this development work is still very much in its infancy, it will be interesting to watch future developments from the National Highway Traffic Safety Administration in this area.

In summary, there is a suggestion that a 56km/h crash test speed may be too low to induce much in the way of additional injury reduction benefits to a full frontal crash test requirement such as FMVSS208 or ADR69. It would seem appropriate, therefore, to consider the differential benefits of a higher test speed such as 60km/h.

1.2.3 Full Frontal Versus Offset Compatibility

As the European community does not currently have a full frontal regulation, the offset requirement is likely to provide greater benefits than in countries such as the US and Australia which already have a full frontal standard. The question arises then whether an offset standard will provide added benefits to the existing full frontal regulation.

The Insurance Institute for Highway Safety, in a recent Crashworthiness publication on mid-size 4-door cars, claimed that the two tests are in fact complementary. Full width tests, they argued, lead to designs in which the car's front-end structure absorbs the crash energy like an accordion. Offset procedures lead to design improvements in structural integrity of the occupant passenger compartment, essential to protect the occupants in these types of collisions. Having both standards, therefore, will force manufacturers to address both of these design parameters. Moreover, they note that "*The bottom line is that full-width tests are especially demanding of restraints but no so much so of frontal structures, while the reverse is true in offset tests.*"

Thus, there is *a priori* support for the notion of having both a full-frontal and an offset-frontal crash standard. Ultimately, the additional benefits that are likely to accrue will be an important consideration for any country choosing to have both standards.

1.3 OVERVIEW OF THE APPROACH

The study utilised the Harm reduction method to compute the potential benefits of the proposed dynamic offset frontal impact requirement. Harm refers to the cost of trauma and is the product of the frequency of injury and cost to the community.

Initial research using the Harm Reduction method was by Malliaris in the US during the 1980s. MUARC subsequently adopted and developed this method for use in Australia during the 1990s (refer FORS report CR100 for a full outline of this development and its application in describing the potential benefits of a range of frontal crash countermeasures). Since then, it has also be used for assessing the relative merits of Australia adopting either the US or European side impact regulations (CR154). Originally, the method was used to specify the total injury savings by the introduction of a particular safety measure. However, in conjunction with Professor Kennerly Digges of University of Washington, MUARC subsequently expanded the method to permit a more detailed and systematic assessment of injury reduction by body region and seating position which could then be summed to total Harm reduction and unit Harm benefits.

1.3.1 Injury Reductions

The approach enabled test and crash data findings published in the road safety literature to be incorporated in the calculations, thereby reducing the amount of guess-work normally required in calculations such as these. Where no published figures were available, however, it is necessary to use the consensus view of a panel of experts in arriving at these likely body region and restraint condition savings.

The amount of published data is normally a function of the attention a particular measure has received by the research community as well as its newness. Very little information has been published on the likely injury reductions from an offset frontal crash test. Most of the data to date has reported differences in test dummy outcomes in these and comparative crash tests. In making these judgements, therefore, heavy reliance needed to be made on expert panel assessments for computing the likely injury reduction effects.

On behalf of FORS, MUARC organised a one-day workshop in conjunction with NHTSA's Pelvic and Lower Extremity Injury (PLEI) conference held in Washington DC on the 4-6 December 1995 and involved a number of international vehicle design, research and government agency specialists. The workshop provided an up-to-date account of offset regulation developments and involved a lengthy discussion of the likely injury benefits if Australia adopted the European Offset standard procedure. The minutes of this meeting are attached in Appendix B.

The meeting led to consensus on a number of assumptions necessary to enable the benefits to be computed using a body region by contact source spreadsheet analysis approach similar to that previously described in CR100 and CR154. The procedure and the assumptions used in this study are fully described in Chapter 3 of this report.

Chapter 2 Offset Injury Analysis

The first step in the study was to examine the pattern of injuries sustained by occupants in representative real-world frontal offset crashes and compare these with those sustained in full frontals. This was to highlight injury differences in these two crash types to provide initial knowledge of the injurious nature of offset crashes.

The injury analysis was conducted on the Crashed Vehicle File held at MUARC containing a sample of 500 random crashes within one hour's drive of Melbourne where at least one occupant was either hospitalised or killed. These data have been a valuable source of information in a number of studies carried out for the Federal Office of Road Safety. An overview of the Crashed Vehicle File is included below.

2.1.1 The Vehicle & Occupant Population

The population of crashed vehicles comprised post-1981 passenger cars and their derivatives (station wagons, panel vans, etc) that were involved in a road crash in Victoria where at least one occupant was injured severely enough to require admission to (or treatment in) hospital. The breakdown of the sample revealed 3% of the patients required medical treatment only, 82% were admitted for at least one night, while 15% died either at the scene or later in hospital (details of cases where occupants died at-the-scene were kindly provided by the Coroner's office). Previous reports had demonstrated that the cases collected in this study were roughly representative of all serious injury cases in Victoria (Monash University Accident Research Centre, 1992).

2.1.2 Procedure

The process was triggered by the admission of a suitable road crash victim at one of a number of Melbourne and Metropolitan hospitals which had agreed to participate in the study. Patients were screened by a research assistant (nurse) at each hospital for the type of crash and suitability of the vehicle. These patients were then asked whether they were willing to participate in the study and signed an agreement form. Crash and patient injury details were obtained from the patient's medical record and from details obtained from the patient during an interview. In addition, permission was also sought to inspect the vehicle involved in the crash. For cases where the patient was severely injured, permission was sought from a member of the patient's family. The crashed vehicle was subsequently located and an inspection crew was dispatched to make the necessary measurements and photographs of the extent of damage. Where a second vehicle was involved, it was also tracked down and briefly examined to complete the details required to explain the damage and to calculate the impact velocity. Each case was fully documented and coded into a computer database for subsequent analysis.

2.1.3 Calculation of Impact Velocity

Impact speed in this study was defined as the change in velocity from the moment of impact until the study vehicle separated from its impacting source (delta-V). This value was calculated in this research using the CRASH 3 program made available by the National Highway Traffic Safety Administration. It should be noted that the delta-V values computed are best estimates of impact velocity and are subject to some error from the assumptions and vehicle stiffness values used in making these calculations. In this study, American stiffness values had to be used in the calculations of delta-V for vehicles of the same sizes as the Australian vehicles as local figures were not readily available. These errors could be reduced to some degree if appropriate stiffness values for Australian vehicles were to be provided by the local manufacturers.

2.1.4 Selection Criteria

The inclusion/exclusion criteria used in the study for determining the suitability of a crash are described below. Using these inclusion/exclusion criteria, roughly, one in twenty-five road trauma attendances were suitable for inclusion in the study.

VEHICLE SUITABILITY: Vehicle suitability was any car or derivative with a Victorian registration number that commenced with either a "B, C or D" or a personalized plate (this effectively included all vehicles first registered during 1982 or later). Any vehicle subsequently found to be re-registered or unsuitable was excluded from the study by the project team at a later date. Four-wheel-drive vehicles of a standard car design (eg, Subaru models or Toyota Tercel) were included as suitable vehicles. However, the usual high clearance four-wheel drive vehicle configuration was not considered to be a passenger car derivative and they were excluded from this study.

CRASH SUITABILITY: Because of the difficulty in interpreting injuries and causes in multiple collisions, only single collisions were included. The impacted object could have been either another car, a truck, or a movable or immovable object, including roll-overs. Where there was clear evidence that a vehicle occupant had been fully ejected from a vehicle during the collision (such as being thrown from a vehicle during a rollover), they were excluded from the study. This was because of the impossibility of interpreting vehicle injury source information for these cases. However, where a belted occupant suffered damage as a result of either a full or partial ejection from the vehicle, an assessment of vehicle contribution to their injuries was attempted.

PATIENT SUITABILITY: Patient suitability consisted of any vehicle occupant who was admitted to one of the participating hospitals from a suitable vehicle or collision. The patient had to be defined as a recent road accident victim (TAC, MCA or other hospital coding) rather than a re-admission from a previous crash. Patients could be conscious or unconscious and fatalities and patients that subsequently died in hospital were also included. As noted earlier, details of fatalities where the patient died at the scene were provided directly by the Coroner's Office in Melbourne.

In most cases it was not possible to obtain details of all occupants involved in the collision. However, where the condition and circumstances of other injured occupants could be obtained, these details were also collected. This included both adults and children. While occupants are required by law to be belted in all vehicles, a number of them nevertheless do not wear seat belts in cars. Hence, it was felt legitimate to include patients in the crashed vehicle sample who were both belted and unbelted so as not to bias the study and overlook another set of problems for a subgroup of vehicle occupants most at risk.

2.1.5 Hospital Participation Rates

Approval to approach and interview patients was obtained from the ethics committees of ***five*** major trauma hospitals in Victoria and included the Alfred Hospital (and Trauma Centre), Box Hill Hospital, Dandenong and District Hospital, Monash Medical Centre, and the Austin Hospital (Spinal Unit). In addition, another ***three*** private hospitals to whom road trauma patients from Dandenong were transferred, namely Knox Private, Dandenong Valley Private, and South Eastern District Hospitals, also kindly agreed to participate. This approval was subject to obtaining the patient's agreement to participate, as well as ensuring confidentiality of this information.

On average, 100 patients were admitted each week across the five study hospitals requiring treatment from vehicle crashes. After applying selection criteria, approximately four patients per week were judged suitable for inclusion in the study (non-acceptable patients included pedestrians, motorcyclists, bicyclists, and non-eligible vehicles). Refusal rates in the study were extremely low (7 out of every 100 patients expressed a desire not to participate). A reducing road toll over this period meant that more cases were available at the start, than at the end, of the study.

2.1.6 Patient & Vehicle Assessment

The assessment and classification of injuries sustained by road trauma patients (including injury severity judgements) requires specialised medical training and skills. Four State Registered Nurses (SRN's) were employed by MUARC during the course of this study as research assistants to undertake these duties and were extensively trained in the collection of injury data for research purposes and in making Abbreviated Injury Score (AIS) assessments of injury severity. A hospital proforma was developed to provide a standardised format for the collection of the patient's medical, vehicle, and crash information which was trialled and modified prior to commencement of its use in the project.

A detailed assessment of the crashed vehicle was critical in accurately specifying vehicle involvement in patient injuries and has been previously undertaken in several other centres in Australia and overseas. Information and discussion of inspection procedures was undertaken by the authors during overseas visits (Fildes and Vulcan 1989) and when local or international specialists visited MUARC (eg, Professor Murray Mackay, Dr. Bob Campbell, Professor Kenerely Digges, and Mr. Tom Gibson). The National Highway Traffic & Safety Administration (NHTSA) in Washington D.C. kindly provided the National Accident Sampling System's (NASS) crash inspection proforma (including training and coding manuals) as well as the computer software CRASH3 for computing Delta-V. Figure 2.1 shows the NASS vehicle proforma for coding impact direction and vehicle region. A mechanical engineer was employed to undertake this task and given the necessary training in undertaking these inspections.

When these site data were complete, Delta-V impact velocity calculations were undertaken and the injury and vehicle damage information was coded into a computer database for subsequent analysis. The reliability of the engineer's judgements at assessing injury and vehicle component interactions was compared with judgements made by the project's consultant epidemiologist, Dr. J.C. Lane, and Mr. Tom Gibson of the N.S.W. Road and Traffic Authority. The inter-rater reliability assessment was 70% for these judges.

Figure 2.1 *National Accident Sampling System proforma for coding vehicle impact location and direction.*

2.1.7 Coding Injuries & Contacts

INJURIES: The National Accident Sampling System occupant injury classification system includes 20 separate body region injury codes. To simplify presentation of the results (especially given the small patient numbers) these were subsequently grouped into a number of discrete body regions to simplify the analysis and yet still permit meaningful comparisons to be made. For this offset analysis, ***twelve*** body region injury categories were assigned, namely the head, face, neck, chest, abdomen, pelvis, spine, upper limb, knee, thigh, leg and ankle/foot.

INJURY CONTACT SOURCES: The NASS injury source classification further allows for the scoring of 82 specific vehicle components as points of contact. Again, to simplify presentation of the results for this limited number of cases, these were grouped into a limited number of meaningful categories.

In this analysis, ***twelve*** vehicle regions were assigned comprising the front windscreen and header, steering assembly, instrument panel, door panel, A-pillar, seat belts, roof, floor and toe pan, exterior & striking object, rear surface, non-contacts, and others/unknown. Steering assembly included the steering wheel and column, floor and toe pan included the pedals in the front, while the instrument panel comprised both upper and lower sections.

2.2 VARIABLES & ANALYSES OF THESE DATA

A number of independent variables were of particular interest in the crashed vehicle study. These included patient characteristics, injuries sustained (including AIS severity), vehicle damage and extent of deformation, direction of principal force, severity of impact (delta-V), component and equipment failures, cabin distortion and intrusions, use of restraints, and an assessment of the source of all injuries. The use of the restraint was especially relevant in this study as the inspection method used has been shown to be the only objective and accurate means of making these assessments (Cromark, Schneider and Blaisdell, 1990).

The dependent variables comprised crash and injury involvement rates per 100 vehicles or patients relative to the population of crashes investigated in the follow-up study of crashed vehicles. Interactions between injury and vehicle source were of particular importantance in this study. Presentation of the results was confined to reporting percentage differences in involvement and rank ordering of involvement rates for injuries per body region and vehicle components.

2.2.1 Overall Results

The final data base comprised details on 501 vehicles involving 606 patients from crashes that occurred in Victoria between the 1st April 1989 and the 31st July 1992, comprising 69% metropolitan and 31% rural crashes. The crashed vehicle database contains information on 572 variables for each crash investigated. Analysis of the crash configurations on the data base showed that frontal crashes accounted for 56% of all crashed vehicles inspected, side impact 41%, roll-overs 3%, and there were no rear-end collisions included in the sample. While the proportion of frontal collisions was slightly less to that reported among TAC claims for the same period (56% cf 65%, Fildes et al 1991), there were differences in the proportions of side impact (41% cf 14%), rear end (0% cf. 11%), and roll-overs (3% cf. 10%).

Given the focus of this report, the analysis to follow will concentrate entirely on results of frontal crashes comparing full frontals with offsets (the definition of frontals from the NASS diagram in Figure 2.1 was a C or D for full frontals and L, R, Y or Z for offsets. Given that the offset standard calls for a 40% overlap on the driver side, only outcomes to drivers were included in the analysis.

2.3 FRONTAL CRASH ANALYSIS

Full details were available on 215 frontal crashes involving an injured driver. The population characteristics of the side impact sample is shown in Table 2.1 below.

Table 2.1
Population Characteristics of Frontal Crash Sample (n=215)

Feature	Full Frontal (n=102)	Offset (Near) (n=76)	Offset (Far) (n=37)
1. IMPACT VELOCITY			
Mean Delta-V (km/h)	55.8	52.7	48.6
Standard deviation (km/h)	19.9	20.2	25.6
Range (km/h)	21-115	17-125	10-144
2. VEHICLE TYPES			
Mini (<750kg)	4%	3%	3%
Small (751-1000kg)	25%	30%	17%
Compact (1001-1250kg)	41%	42%	50%
Intermediate (1251-1500kg)	28%	24%	28%
Large (>1500kg)	2%	1%	2%
Mean Vehicle Weight	*1124kg*	*1096kg*	*1125kg*
3. DRIVER'S SEX			
Males	59%	55%	54%
Females	41%	45%	46%
4. DRIVER'S AGE			
<17 years	0%	0%	0%
18-25 years	32%	33%	30%
26-55 years	51%	51%	46%
56-75 years	17%	13%	22%
>75 years	0%	3%	2%

NB: Offset near refers to offset collisions on the driver's side of the vehicle (the standard configuration) whereas offset (far) refers to offset crashes on the front passenger side.

Of particular note are the roughly equal numbers of offset and full frontal crashes in this sample, although full frontals were slightly more severe crashes than either near or far offsets (the higher variance for far-side offsets is probably a function of the small numbers). There were also slightly more small cars among those injured in near-side offsets over full frontals. There were very few driver differences across the 3 crash types.

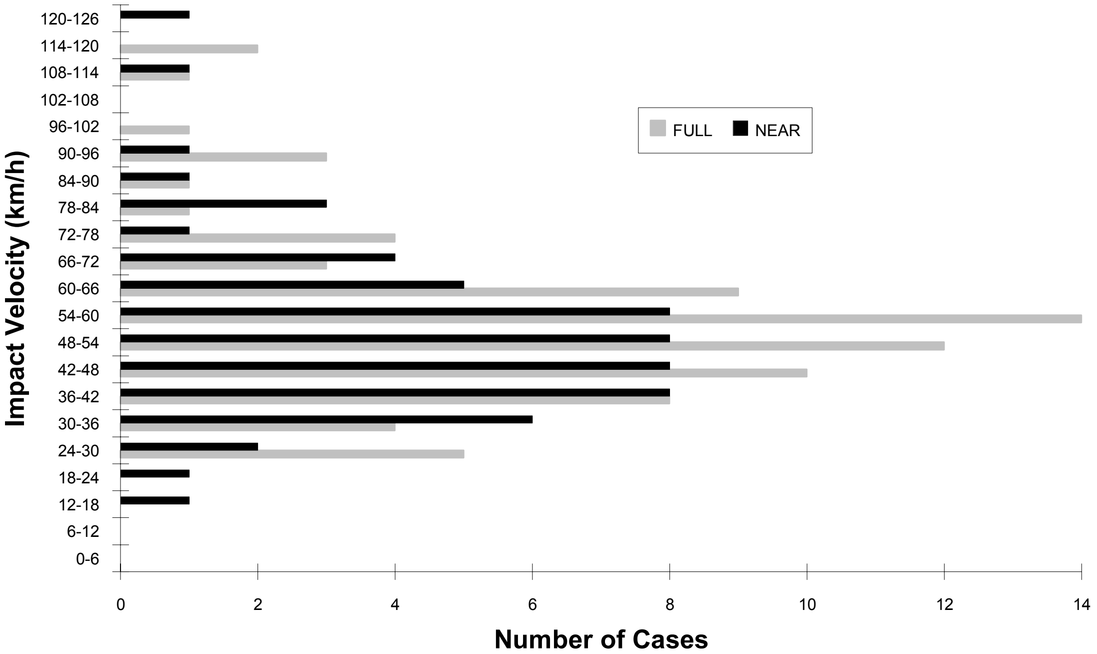

Figure 2.2 Frequency histogram of delta-V distributions for full frontal and near-side offset crashes observed in the Crashed Vehicle File.

2.3.1 Change of Velocity on Impact

As noted earlier, change of velocity on impact (delta-V) was computed using the CRASH3 computer program supplied by NHTSA from deformation details measured from the crashed vehicles. The histogram distributions of delta-V for the full and near-side offset crashes is shown in Figure 2.2. While there were slight differences in the means, the distributions are nevertheless quite similar for both crash types.

2.3.2 Intrusions & Deformations

Table 2.2 lists the intrusions and/or deformations observed in the front seat occupant areas for full and near-side offset frontals. Floor, toepan and the instrument panel were the most frequent intruding component in both frontal crash types. Not surprisingly, the A-pillar, side panel and the door more commonly intruded in offset crashes than full frontals, illustrating the higher likelihood of lower limb injuries to drivers in these crashes. There was also a much higher incidence of lateral and vertical steering column movements in offset crashes, confirming the greater need to include intrusion criteria for these movements in any offset crash regulation.

2.3.3 Ejection & Entrapment

Table 2.3 shows the entrapment and ejection analysis for full frontals and near-side offsets. While the patterns are not all that consistent given the small number of cases, there was a slightly greater proportion of entrapments observed among offset than full frontals (31% c.f. 22%). However, while there was a suggestion of more ejections among unbelted occupants, (8% c.f. 1%), there were no apparent differences between offset and full frontals.

Table 2.2
Rank Ordering of Vehicle Intrusions and/or Deformations for Full and Near-side Offset Frontal Crashes in the Crashed Vehicle File (n=178 crashes)

Full Frontals			Near-Side Offsets		
Item	Freq.	%	Item	Freq.	%
Floor & toepan	52	51%	Floor & toepan	58	76%
Instrument panel	36	35%	Instrument panel	43	57%
Steering assy	6	6%	A-pillar	19	25%
Console	4	4%	Side panel	18	24%
W'screen & header	3	3%	Steering assy	16	21%
Roof	2	2%	Door panel	6	8%
Side panel	1	1%	Console	6	8%
			B-pillar	4	5%
			Roof	3	4%
			Side rail	2	3%
			W'screen & header	1	2%
			Other	3	1%
TOTALS	***104***	***102%***		***179***	***234%***

Steering Assembly Movement by Direction of Displacement

Full Frontal			Near-side Offsets		
Lateral movement	29	30%	Lateral movement	41	55%
Longitudinal	40	41%	Longitudinal	44	55%
Vertical movement	30	31%	Vertical movement	35	47%

Table 2.3
Entrapment and Ejection Analysis for Full and Near-side Offset Frontals

Condition	Full Frontals				Near-Side Offsets			
	Restrained		Unrestrained		Restrained		Unrestrained	
	Freq.	%	Freq.	%	Freq.	%	Freq.	%
1. ENTRAPMENTS								
None	43	84%	8	57%	24	67%	6	86%
Partial entrapment	2	4%	1	7%	8	22%	1	14%
Full entrapment	6	12%	5	36%	4	11%	0	0%
TOTALS	***51***	***100%***	***14***	***100%***	***36***	***100%***	***7***	***100%***
2. EJECTIONS								
None	79	99%	16	94%	59	100%	9	90%
Ejected	1	1%	1	6%	0	0%	1	10%
TOTALS	***80***	***100%***	***17***	***100%***	***59***	***100%***	***10***	***100%***

NB: It was not possible to code partial ejections using this retrospective examination method.

2.3.4 Seat Belt Wearing

The seat belt wearing behaviour of the drivers involved in full and offset frontals is shown in Table 2.4 below. While there were some minor differences between wearing rates for near-side and far-side offset drivers, these differences were not statistically significant because of the small numbers involved. There were no differences observed for drivers between full and offset frontal crashes (79% and 78% respectively). The over-representation of unrestrained drivers in this injured population compared with the population at large (approximately 4 times over-represented) has been previously explained as possibly reflecting both an increase in the risk of injury as well as an increase risk in crash involvement (Fildes et al, 1991; 1994).

Table 2.4
Seat Belt Usage Among Frontal Crash Occupants

Wearing Status	Full Frontal		Offset -Near		Offset-Far		Total Offset	
	Freq.	%	Freq.	%	Freq.	%	Freq.	%
Restrained	84	83%	62	85%	26	70%	88	80%
Unrestrained	17	17%	11	15%	11	30%	22	20%
TOTAL KNOWN	***101***	***100%***	***73***	***100%***	***37***	***100%***	***110***	***100%***

2.4 INJURIES IN FULL & OFFSET CRASHES

The study was particularly interested in the types of injuries sustained by these occupants and the sources of these injuries inside the vehicle. In addition, analysing the injury and contact source combinations provides a means of identifying particular vehicle components that are a major sources of trauma to occupants in these crashes and therefore require attention.

Table 2.5
Body Regions Injured for Drivers in Frontal Crashes

Body Region	Full Frontal		Near-Side Offset		Far-side Offset	
Injured	ALL	AIS>2	ALL	AIS>2	ALL	AIS>2
Head	54%	14%	63%	14%	41%	8%
Face	72%	3%	78%	-	65%	-
Neck	16%	4%	21%	1%	13%	-
Chest	76%	15%	68%	11%	68%	14%
Abdomen	35%	1%	34%	7%	49%	3%
Pelvis	27%	-	24%	5%	5%	-
Spine	5%	-	1%	1%	11%	3%
Upper Limb	62%	1%	74%	16%	68%	8%

Knee	60%	3%	43%	5%	43%	-
Thigh	19%	12%	37%	20%	16%	5%
Leg	29%	7%	39%	5%	24%	5%
Ankle/Foot	30%	4%	41%	7%	30%	-

2.4.1 Body Regions Injured

Table 2.5 shows the body regions injured for drivers in frontal crashes, for all and severe injuries (AIS>2). Of special interest, there was a higher rate of severe (AIS>2) face, neck and chest injuries for those injured in full frontal over offset crashes but noticeably fewer upper and lower limb severe injuries. Table 2.6 further shows that occupants injured in near-side offsets on average sustained more severe injuries (the ISS was around 8% higher and there was a higher probability of a severe injury) than those injured in full frontals. However, far-side offset injuries were markedly less severe injuries than either near-side offset or full frontal casualties, probably because far-side occupants were further away from the main crash forces.

Table 2.6
Severity of Injury by Frontal Crash Type

Crash Type	Number Occupants	Average ISS*	Probability of Serious Injury AIS>2	ISS>15	ISS>25
Full frontal	102	21.6	0.52	0.50	0.29
Near-side Offset	76	23.4	0.71	0.59	0.34
Far-side Offset	37	7.1	0.41	0.11	0.03

** Injury Severity Score (ISS) is a generally accepted measure of overall severity of injury from road trauma (Baker et al 1974). It is calculated by summing the squares of the 3 highest Abbreviated Injury Scores (AIS) recorded for each of 3 body regions injured.*

Table 2.7
Points of Contact for Drivers Injured in Frontal Crashes

Points of Contact	Full Frontal ALL	Full Frontal AIS>2	Near-Side Offset ALL	Near-Side Offset AIS>2	Far-side Offset ALL	Far-side Offset AIS>2
W'screen & header	19%	-	13%	-	22%	3%
Steering assy	77%	15%	83%	18%	73%	5%
Instrument panel	73%	6%	66%	17%	54%	11%
Door panel	2%	1%	11%	3%	3%	-
A-pillar	6%	1%	16%	7%	-	-
Seat belts	63%	3%	51%	-	59%	3%

Roof	2%	1%	3%	-	-	-
Floor & toepan	33%	6%	47%	9%	35%	5%
Exterior & striking obj.	1%	1%	8%	1%	-	-
Rear surface	2%	1%	-	-	-	-
Non-contact sources	9%	-	9%	-	11%	3%
Other/unknown	22%	1%	17%	1%	24%	-

2.4.2 Injury Source

The sources of these injuries are listed in Table 2.7 where the most common source of severe injury (AIS>2) in near-side offset crashes seem to have resulted from contact with the steering assembly, instrument panel, floor & toepan, A-pillar and door panel (the higher incidence of these contacts generally over those in full frontal casualties is a reflection of the higher likelihood of severe injury among occupants injured in near-side offset crashes). The patterns of injuries and contact sources were examined in detail to highlight areas where improvements are necessary.

2.4.3 Injury and Contact Source Analysis

FULL FRONTALS: For those injured in full frontals the results in Table 2.8 show that the ***six*** most frequent injury-source combinations for all injuries were:

- chest with the seat belt (55%);
- knee with the instrument panel (52%);
- face with the steering assembly (51%);
- upper limb with the instrument panel (33%);
- head with the steering assembly (30%); and
- ankle/foot with the floor and toepan (30%).

For **severe injuries** only (AIS>2), the ***four*** most frequent injury-source combinations were:

- chest with the steering assembly (12%);
- head with the steering assembly (9%);
- thigh with the instrument panel (7%); and
- thigh with the steering assembly (6%).

NEAR-SIDE OFFSETS: The pattern of injury-source combinations was quite similar for near-side offset driver injuries (all severities) to that for the full frontals, although their relative order changed slightly, as shown below:

- face with the steering assembly (53%);
- ankle/foot with the floor and toepan (42%);
- upper limb with the instrument panel (41%);
- knee with the instrument panel (38%);

- chest with the seat belt (37%); and
- chest with the steering assembly (36%).

For **severe injuries** only (AIS>2), there was a higher rate of injuries reflected in the following list of the most frequent injury-source combinations:

- chest with the steering assembly (13%);
- head with the steering assembly (9%);
- thigh with the instrument panel (17%);
- upper limb with the instrument panel (7%); and
- ankle/foot with the floor and toepan (7%).

Table 2.8
Injury and contact source analysis for all injuries and AIS>2 for the 102 drivers injured in full frontal collisions in the Crashed Vehicle File.

Contact source		***Head***	***Face***	***Neck***	***Chest***	***Abdomen***	***Pelvis***	***Spine***	***Upper limb***	***Knee***	***Thigh***	***Leg***	***Ankle/Foot***	***TOTAL***
Windshield & header	ALL	5	15						5					**25**
	AIS>2													**0**
Steering assembly	ALL	30	51	8	27	13			11	17	8	2		**167**
	AIS>2	9	2	3	12	1			1	2	6	1		**37**
Instrument panel	ALL	8	10				2		33	52	11	20		**136**
	AIS>2	3							2	1	7	2		**15**
Door panel	ALL				1				1					**2**
	AIS>2				1									**1**
Side glazing	ALL								2					**2**
	AIS>2													**0**
A-pillar	ALL	4	4						1					**9**
	AIS>2	1												**1**
Floor & toepan	ALL										1	7	30	**38**
	AIS>2											4	4	**8**
Roof	ALL	2	1	1										**4**
	AIS>2	1												**1**
Rear surface	ALL	2	2	1										**5**
	AIS>2	1		1										**2**
Seat belt	ALL			2	55	23	25		19					**124**
	AIS>2				4									**4**
Striking object	ALL	1	1											**2**
	AIS>2	1	1											**2**
Ground	ALL	1	1	1										**3**
	AIS>2													**0**
Non-contact	ALL	4		3				4						**11**
	AIS>2													**0**
Other/unknown	ALL	1	7		3			1	14					**26**
	AIS>2								1					**1**
TOTAL	***ALL***	***58***	***92***	***16***	***86***	***36***	***27***	***5***	***86***	***69***	***20***	***29***	***30***	***554***
	AIS>2	***16***	***3***	***4***	***17***	***1***	***0***	***0***	***4***	***3***	***13***	***7***	***4***	***72***

Top row figures are the injury/source contact rates per 100 occupants for ALL levels of injury. The lower line figures are the contact rates for severe injuries only (AIS>2). Multiple injuries are included where separate injury/sources are involved.

Table 2.9
Injury and contact source analysis for all injuries and AIS>2 for the 76 drivers injured in near-side offset frontal collisions in the Crashed Vehicle File.

Contact source		***Head***	***Face***	***Neck***	***Chest***	***Abdomen***	***Pelvis***	***Spine***	***Upper limb***	***Knee***	***Thigh***	***Leg***	***Ankle/Foot***	***TOTAL***
Windshield & header	ALL	5	12	1					8					**26**
	AIS>2	1												**1**
Steering assembly	ALL	33	53	8	36	16	3		25	8	5	1		**188**
	AIS>2	9			13	4			4	1	1			**32**
Instrument panel	ALL	5	7		3	1	7	1	41	38	24	29		**156**
	AIS>2	3			1	1	5	1	7	4	17	1		**40**
Door panel	ALL	1			8	4	1		4		4			**22**
	AIS>2	1			3	1			3					**8**
Side glazing	ALL	1	4						5					**10**
	AIS>2													**0**
A-pillar	ALL	5	7		1		1		4		4			**22**
	AIS>2	1					1		3		3			**8**
Floor & toepan	ALL										1	9	42	**52**
	AIS>2											4	7	**11**
Roof	ALL	3	3											**6**
	AIS>2	1												**1**
Rear surface	ALL													**0**
	AIS>2													**0**
Seat belt	ALL			5	37	12	14		13					**81**
	AIS>2				1									**1**
Striking object	ALL	7	7	1					4					**19**
	AIS>2	1							1					**2**
Ground	ALL	3	1		1	1			3	1	1	1	1	**13**
	AIS>2	1												**1**
Non-contact	ALL	5		7										**12**
	AIS>2			1										**1**
Other/unknown	ALL		1		1	3	1		8					**14**
	AIS>2								1					**1**
TOTAL	***ALL***	***68***	***95***	***22***	***87***	***37***	***27***	***1***	***115***	***47***	***39***	***40***	***43***	***621***
	AIS>2	***18***	***0***	***1***	***18***	***6***	***6***	***1***	***19***	***5***	***21***	***5***	***7***	***107***

Top row figures are the injury/source contact rates per 100 occupants for ALL levels of injury. The lower line figures are the contact rates for severe injuries only (AIS>2). Multiple injuries are included where separate injury/sources are involved.

Table 2.10
Injury and contact source analysis for all injuries and AIS>2 for the 37 drivers injured in far-side offset frontal collisions in the Crashed Vehicle File.

Contact source		*Head*	*Face*	*Neck*	*Chest*	*Abdomen*	*Pelvis*	*Spine*	*Upper limb*	*Knee*	*Thigh*	*Leg*	*Ankle/Foot*	*TOTAL*
Windshield & header	ALL	11	16	3					3					**33**
	AIS>2	3												**3**
Steering assembly	ALL	19	35	3	24	16		3	19	11	5			**135**
	AIS>2	3			5	3			3					**14**
Instrument panel	ALL	8	11	3	8	5			27	35	8	16		**121**
	AIS>2	3			5				5		5			**18**
Door panel	ALL								3					**3**
	AIS>2													**0**
Side glazing	ALL													**0**
	AIS>2													**0**
A-pillar	ALL													**0**
	AIS>2													**0**
Floor & toepan	ALL										8	8	30	**46**
	AIS>2											5		**5**
Roof	ALL													**0**
	AIS>2													**0**
Rear surface	ALL													**0**
	AIS>2													**0**
Seat belt	ALL				46	35	5		19					**105**
	AIS>2				3									**3**
Striking object	ALL													**0**
	AIS>2													**0**
Ground	ALL	3												**3**
	AIS>2													**0**
Non-contact	ALL	3		5				8						**16**
	AIS>2							3						**3**
Other/unknown	ALL		5						16			3		**24**
	AIS>2													**0**
TOTAL	***ALL***	***44***	***67***	***14***	***78***	***56***	***5***	***11***	***87***	***46***	***21***	***27***	***30***	***486***
	AIS>2	***9***	***0***	***0***	***13***	***3***	***0***	***3***	***8***	***0***	***5***	***5***	***0***	***46***

Top row figures are the injury/source contact rates per 100 occupants for ALL levels of injury. The lower line figures are the contact rates for severe injuries only (AIS>2). Multiple injuries are included where separate injury/sources are involved.

2.5 OFFSET INJURY ANALYSIS SUMMARY

The offset injury analysis revealed a number of interesting and important findings, especially when comparing the different patterns observed between full frontal and near-side offset frontal crashes, as summarised below:

- Drivers were more likely to be hospitalised or killed at lower impact speeds in near-side frontals than full frontal crashes. Moreover, they were slightly over-represented in smaller cars (less than 1000kg);
- There were many more vehicle intrusions and deformations observed in the passenger compartment of the vehicles involved in near-side offsets compared to full frontals;
- Deformation of the steering column was much more common in near-side offsets with a higher likelihood of lateral, longitudinal and vertical movement over full frontals;
- Seat belt wearing behaviour was similar among drivers injured in near-side frontal and full frontal crashes;
- Drivers in offset crashes sustained more severe (AIS>2) abdomen, pelvic, spine, upper limb, knee, thigh and ankle-foot injuries than full frontal crash occupants, but fewer face, neck, chest and leg injuries. The severe head injury rate was equal in both frontal crash types;
- The average Injury Severity Score (ISS) was higher for drivers injured in near-side offsets than in full frontal crashes and they had a higher probability of sustaining a severe injury;
- Near-side offset drivers were more likely to have been severely injured from contact with the steering assembly, instrument panel, A-pillar, door, and the floor and toepan than those in full frontal crashes (this finding was somewhat accentuated by the higher rate of severe injury among offset crash drivers);
- The FIVE most severe injury-source combinations for drivers injured in near-side offset collisions comprised chest contacts with the steering assembly, head with the steering assembly, thigh with the instrument panel, upper limb with the instrument panel, and the ankle-foot with the floor and toepan. Apart from differences in the rates, the severe injury-source patterns were similar for full frontals and near-side offsets.

Chapter 3 Benefits of an Offset Frontal Crash Standard

The results of the offset injury analysis in the previous Chapter clearly shows that greater attention to vehicle crashworthiness in near-side offset collisions is likely to lead to significant improvement in occupant protection in Australia. The final EEVC offset frontal test procedure is being considered by the European Parliament for introduction as an EC directive for all new model passenger cars manufactured in Europe late in 1998. Passenger cars sold in Australia are already required to meet a dynamic full frontal crash standard ADR 69 which is similar to the US regulation FMVSS 208 except for a seat belt wearing requirement. FORS plans to introduce an offset frontal ADR in addition to ADR 69 if it is shown to be cost effective.

This Chapter presents an analysis undertaken on the likely community savings in reduced trauma if Australia was to adopt the European offset regulation in addition to ADR 69. The analysis used the ***Harm Reduction*** method developed by the Monash University Accident Research Centre in conjunction with Kennerly Digges and previously reported in Monash University Accident Research Centre (1992) and Fildes Digges, Carr, Dyte & Vulcan (1995).

3.1 ONE-DAY WORKSHOP

As noted in the introduction, a one-day workshop was held in conjunction with the Pelvic and Lower Extremity Injury (PLEI) conference in Washington DC to help determine the injury reduction potential of the European offset standard. The workshop involved a number of international vehicle design, research and agency specialists and was necessary because of the gulf of previously published data on injury reductions associated with this procedure. Minutes from the workshop are included in Appendix A of this report.

Participants at the meeting provided a broad overview of recent developments in offset crash protection and alternatives to the European standard. In addition, they were specifically asked to help define a number of assumptions of the likely outcome and injuries mitigated as a direct result of the European procedure. The authors of this report are most grateful to the people who contributed at this meeting and subsequently in formulating the assumptions described in detail further on in this Chapter.

3.2 HARM REDUCTION METHOD

The Harm Reduction method has been described in detail previously in earlier reports. An overview of the method is provided here for those not familiar with the approach, including some slight recent changes to the discounting procedure. The concept of "Harm" was first developed in the US and applied to National Accident Sampling System (NASS) database by the National Highway Traffic Safety Administration as a means of determining countermeasure benefits for road safety programs (Malliaris, Hitchcock & Hedlund 1982; Malliaris, Hitchcock & Hansen 1985; Malliaris & Digges 1987). In its original form, it was not suitable for immediate application to these data as it lacked an Australian cost basis.

Moreover, it had never quite been used previously for itemising injury reductions by body regions as was envisaged here. Thus, the development and use of Harm in the previous study (Monash University Accident Research Centre 1992) and this study represented a significant international advancement in the ability to assess injury mitigation effects of vehicle countermeasures.

3.2.1 Harm & Injury Mitigation

Harm is a metric for quantifying injury costs from road trauma. It is a function of the number of injuries sustained, expressed in terms of community costs. The Harm method adopted here comprised the systematic approach outlined in detail in Monash University Accident Research Centre (1992). This approach is more suited for use in computing likely benefits of countermeasures where there are no global estimates of the likely improvements but where there are results reported on the expected specific body region injury reductions (many publications on the likely effectiveness of new regulations, for instance, show specific test results for particular body region and contact source benefits). The method allows a picture of the expected overall benefit to be pieced together from a series of individual body region and seating position estimates. A computer spreadsheet was developed for making the detailed Harm calculations by body region, similar to that used previously in CR100.

3.2.2 National Statistics & Harm Estimates

The first step in the process was to develop National Harm patterns for Australia. These estimates form the basis of the potential savings of injury costs from new occupant protection countermeasures aimed at reducing or preventing injury. This process was described fully in CR 100 (Monash University Accident Research Centre 1992) and will not be repeated here. However, a summary is provided to outline how this was achieved (those requiring more detail are referred to the original publication). It draws heavily on the excellent work undertaken by Max Cameron and his co-workers at MUARC in the original study.

3.2.3 Occupant casualties and injuries

Unfortunately, no comprehensive Australia-wide database of injuries and their causes was available for this analysis, thus it was necessary to construct one. This involved a complex process of merging several data sources of fatalities, hospitalised occupants and those needing medical treatment, with the necessary checks and balances to ensure that the numbers, use of restraints, seating position, impact direction and speed zone were representative of Australia, generally.

Three data sources were available for constructing the Australia-wide casualty database. First, details of those killed in Australia are collected by the Federal Office of Road Safety's "*Fatal File*" of which the 1988 database was most relevant. Second, MUARC's "*Crashed Vehicle File*" described in the previous Chapter contained a random sample of 500 crashes where at least one occupant was either hospitalised or killed in Victoria between 1989 and 1992, containing comprehensive details on crash characteristics, injuries and cause of injury. Third, the Transport Accident Commission in Victoria maintain a detailed injury and crash database on all casualties in Victoria which involve injury costs of A$317 (1987) or more.

Annual Australia-wide estimates were produced by merging these three databases and adjusting the numbers to suit national averages between 1988 and 1990. In total, the database comprised 1,612 killed, 17,134 hospitalised and 58,448 medically treated (not admitted to hospital) occupants or 77,194 total casualties involving an estimated 284,540 injuries at a rate of 3.7 injuries per occupant casualty. This was taken to represent a single year of occupant casualties in Australia.

Source of injury was not available in either FORS Fatal File or the TAC database, but was in the Crashed Vehicle File (CVF). To correct for this deficiency, the most severe hospitalised and killed cases in the CVF were taken to represent all fatalities and the minor CVF cases (hospitalised for 3 or less days) were taken to represent non-hospitalised injury sources. Thus, injuries within the Fatal File and TAC database were assumed to have been caused by the same sources as their relevant proxies in the CVF. Following this adjustment, the Australia-wide all injury database was then complete.

Subsequently, these data were broken down by the key factors likely to be relevant for this offset crash analysis (eg. seating position, restraint use, and type of frontal impact) and the frequencies of injuries to these occupants, categorised by the body region and Abbreviated Injury Scale (AIS) severity level disaggregated by the same factors as above as well as by the contact source of the injury. These tables formed the basic pattern of injuries and injury sources used in this analysis.

3.2.4 Casualty costs

The next step was to derive comprehensive cost data, categorised and disaggregated by the same factors as for the injury frequency estimates noted above. This was necessary so that individual units of Harm (eg; restrained Head injuries of AIS severity 2) could be established to permit detailed cost savings to be arrived at for incremental changes in trauma patterns. Estimates of the cost of injury by AIS in Australia were published by the Bureau of Transport Economics for 1985 $A (Steadman & Bryan, 1988). However, these figures do not breakdown injury costs by body region which is essential for estimating the Harm reductions associated with side impact improvements. To estimate this, it was necessary to use the average cost of each specific injury based on a matrix of average injury costs in the USA developed by Miller et al (1991) and explained in detail in Monash University Accident Research Centre (1992).

These figures were then converted into Australian average injury costs in A$(1991). The estimated total injury cost to car occupants during 1988-90 was calculated to be $3142.6 million per annum in 1991 prices. The re-scaled average injury costs per level of injury severity are given in Table 3.1.

3.2.5 Relevance of 1991 Figures

It would have been preferable if recent injury patterns and costs were available for this analysis, given the sizeable reductions that have occurred in the road toll between 1991 and 1994 and recent inflationary effects. However, it was not possible to re-do these estimates within the time frame and budgetary constraints of the project. It should be noted, though, that these two influences would tend to offset each other (the effects of a reducing road toll would be somewhat ameliorated by the increase in cost of injury through inflation). Thus, it was felt that the total Harm figures were still appropriate for this analysis.

Table 3.1
Total injury cost ("Harm") to occupants of cars and car derivatives in all types of impact (1991 $A millions, average per annum during 1988-90).

	INJURY SEVERITY							
BODY REGION	Minor (AIS = 1)	Moderate (AIS = 2)	Serious (AIS =3)	Severe (AIS = 4)	Critical (AIS = 5)	Maximum (AIS = 6)	Unknown	**TOTAL**
External	0.0	4.3	0.2	0.0	0.5	6.2	0.0	11.2
Head	12.8	116.6	217.2	290.4	524.9	49.4	0.0	1211.2
Face	99.4	80.3	29.9	2.8	0.0	0.0	0.7	213.1
Neck	20.1	14.1	25.7	0.6	16.3	2.6	0.0	79.5
Chest	33.6	63.7	139.3	99.4	47.5	68.0	0.0	451.4
Abdomen-Pelvis	36.4	64.8	89.7	21.2	23.3	2.0	0.0	237.4
Spine	3.8	23.4	30.9	3.5	42.8	18.3	0.0	122.7
Upper Extremity	64.4	147.4	85.0	0.0	0.0	0.0	0.0	296.7
Lower Extremity	64.4	188.6	265.4	0.6	0.2	0.0	0.0	519.3
TOTAL	334.9	703.2	883.3	418.4	655.6	146.4	0.7	3142.6
No. Occupants Sustaining Injury								77194

From MUARC 1992

3.2.6 Baseline Harm Matrices

The total harm in Table 3.1 was then broken down by seating position, restraint use and impact direction by using the same procedures for subsets of the injury and occupant casualty data. These figures provided the baseline injury-cost data for establishing the potential cost savings of an offset impact regulation to reduce occupant injuries in near-side offset frontal crashes. Each injury in the CVF was associated with a contact source of the injury. For the hospitalised occupants included in this file it was possible to disaggregate the injury frequencies and total harm by the contact source. However, neither the Fatal File nor the TAC claims records contained injury contact sources to allow similar categorisation of the injuries of the killed and medically treated occupants.

To achieve this, data were selected from the CVF to act as proxies for the killed (the proxy was those hospitalised for more than 20 days, plus the 23 actual fatalities) and the medically treated but not admitted to hospital (the proxies were those hospitalised for less than 3 days). The injury frequencies from these proxies were adjusted within each AIS severity level by body region category to match the principal estimates. Where the proxy occupants did not sustain any injuries in an injury category for which Harm was estimated by the principal method, the distribution of harm by contact source was estimated from the contact source distribution of the next lowest injury severity level within the same body region.

The total Harm within each body region of the front seat occupants involved in offset frontal impacts, broken down by contact source of the injury, for both restrained and unrestrained occupants respectively, was ultimately produced and used as the baseline Harm figures to calculate the potential savings if an offset impact regulation was to be introduced. This process is explained further in the next section.

3.3 INJURY REDUCTION ASSUMPTIONS

The proposed frontal offset standard represents a bold approach to improve occupant protection further in frontal crashes. The method attempts to use the best information available to estimate the benefits likely to accrue from this standard. As a result of the one-day workshop and subsequent review, several assumptions were derived of the likely impact the European standard would have in Australia in addition to ADR 69. The order in which these assumptions would apply to existing Australian Harm patterns was also considered important in determining the overall size of effect. These assumptions incorporate the existing body of test data, injury data, biomechanics criteria and expert opinion. As new information becomes available, these assumptions can be modified and the benefit estimates re-assessed.

3.3.1 Universal Benefit

The consensus view of the expert panel was that the European offset test procedure will require manufacturers to devote additional attention to the crashworthiness design of the front of the car. In an offset test, the crash energy must be absorbed by engaging only part of the front structure, thus the structural deformation is more complex and intrusion into the passenger compartment is more difficult to control, compared with a full frontal test. The presence of a deformable element on the barrier encourages structural designs which distribute crash energy, rather than concentrate it in the deformation of stiff longitudinal members. The test requirements for minimum levels of Tibia Index (TI), chest deflection (and V*C), steering wheel displacement and peak head acceleration are also likely to provide a strong incentive for manufacturers to control occupant compartment intrusion. Consequently, the offset test procedure would be expected to lead to designs better able to distribute energy more evenly across the vehicle's front structure.

The anticipated result is best illustrated by test results recently conducted and published in the USA by the Insurance Institute for Highway Safety (IIHS 1995). The group tested 16 mid-size 1995-96 US passenger cars in a frontal offset test similar to the one proposed in the European standard but at a higher impact speed (64km/h). Figures 3.1 to 3.3 show the comparative results from two of these cars, one which performed very well (Taurus) and the other (Contour) not so well. The test results are shown in Table 3.2 below.

Table 3.2
Test Data for 2- Offset tests involving 1995-96 US cars (courtesy of IIHS)

Test Vehicle	Footrest Intrusion	Chest Acceleration	Chest Deflection	Tibia Index (TI) Left	Tibia Index (TI) Right
Taurus	8cm	31g	36mm	0.4	0.5
Contour	18cm	34g	35mm	1.7	1.6

For the examples discussed above, the Tibia Index is the principal criterion likely to induce control of the stiffness and compatability of the front structure. The expert panel however agreed that other test criteria, such as the 2-D steering wheel intrusion criterion would also require careful control of the vehicle's frontal deformation. In addition, the chest deflection requirement would likely lead to more careful control of the dummy and any potential intruding components which could affect the chest loads.

Figures 3.1 to 3.3

The effect of the structural improvements induced by the standard would be to increase the safety and integrity of the occupant compartment through designing more compatable front structures. Because the impact loads would be more evenly distributed throughout the front structure, the loading on the occupant compartment would be reduced. This is assumed to provide a universal benefit in all frontal crashes involving significant deformation of the front structure. This benefit would reduce the crash severity experienced by the occupants in cars which meet the standard, compared to today's cars. Table 3.2 showed that the peak chest load in the Taurus was 10% lower than the Contour. It was also more than 20% lower than the rest of the fleet tested by IIHS (on average, 40g). This is illustrative of the reduction in crash severity provided by the Taurus (the expert panel felt that the 1995-96 Taurus was representative of the vehicle improvements that could be expected once the offset standard was in place - see the workshop minutes in Appendix A).

BENEFIT: Thus, the universal benefit would be equivalent to a reduction in crash severity of 10% over the range of crash severities to which it is applicable, that is, all frontal crashes in the severity range from 20 to 60km/h. This represents 55% of all frontal crashes in Australia where someone is injured. For the more severe test (60km/h impact speed), this benefit was assumed to be larger at 15%.

3.3.2 Increased Airbag Usage

Table 3.3 below shows that approximately 43% of new passenger cars sold during 1995 in Australia were fitted with at least a driver's side airbag as standard equipment. While it's to be expected that the frequency of airbags will increase as standard equipment in the years ahead, the expert group were in complete agreement that the new offset standard will ensure 100% fitment of airbags. This was essentially due to the additional head injury criteria of 80g (in addition to HIC in the current standard). Accurate predictions of airbag fitment rates for cars sold in Australia after 1998 was not available, although it was possible to estimate current airbag fitment rates on the basis of limited information available as shown in Table 3.3 below. It would be expected that fitment rates in 1998 would be greater than today's rates although whether it ever reaches a 100% fitment rate without the offset standard is not clear.

Table 3.3
Proportion of Airbag Sales in 1995 popular passenger cars from information provided by Paxus & FORS (Seyer, 1996)

MAKE	1995 Car Sales	Airbag Sales	Airbag Rates
Honda	14,000	14,000	100%
Ford	119,200	93,300	78%
Holden	107,300	38,440	36%
Mazda	20,600	6,800	33%
Nissan	18,100	5,800	32%
Toyota	68,300	19,500	29%
Hyundai	34,700	5,680	17%
Mitsubishi	53,200	3,000	6%
TOTAL	**435,400**	**186,520**	**43%**

NB: Annual sales from Paxus based on the most popular makes and models .

BENEFITS: Adjust the CR100 benefits for full size driver airbags for head, chest, abdomen and facial Harm for the estimated non-airbag car sales in 1998. The resultant Harm is then the additional benefit that can be attributed to the offset standard. As no definitative figure is available on what the likely airbag sales will be in 1998, sensitivity analysis involving a range of possible figures would be appropriate from todays figure of around 40% up to 100%.

3.3.3 Additional Chest Benefits

The proposed offset procedure specifies a 50mm maximum deflection, a V*C<1.0m/sec and reduced steering column movements vertically to 80mm max and rearward to 100mm max. The consensus of the workshop group was that this would reduce chest injuries essentially from contacts with the steering column and belt. Moreover, these benefits would be expected to acrue predominantly from small to medium cars. To meet these criteria, the group stressed that a 30% additional margin would be required when crash testing during vehicle design. Therefore, the resulting vehicle performance was assumed to be 35mm chest deflection, and V*C less than 0.7m/sec. For steering wheel displacement, the design was assumed at 70mm rearward, and 56mm upward.

BENEFIT: A review of test results from the Canadian Department of Transport (CDOT) shows that both small and midsize cars equipped with air bags failed to meet the chest criteria target. In Australia, these two classes of cars constitute 83% of passener car Harm (CR100). It is assumed that reducing the chest loading would reduce belt induced chest and abdominal injuries at all crash severities below 56km/hr, a range which accounted for 70% of this Harm. The relevance is 0.83*0.7 = 0.58 for all injury severities; the AIS reduction from belt contacts is AIS 2. For a 60 km/hr standard, 80% of the harm is contained in the range 0 to 60 km/h. The relevance is 0.83*0.8 = 0.66 for all injury severities with a similar AIS 2 shift .

For chest Harm from steering wheel contacts, it was assumed that the steering wheel intrusion occurred for 40-56km/h crashes which accounted for 40% of this Harm (CR100). In EEVC and Canadian tests 80% of cars failed the test (see Appendix C). Assume a relevance of 0.8*0.4=0.32 and a AIS 2 shift for the 56km/hr standard (for chest and abdominal injuries from steering wheel contact). At 60km/h, 90% of the cars failed to meet steering wheel intrusion design requirements. For the 60km/h standard, we assume that intrusion is reduced for 90% of the cars over the range of crash severities of 40 to 60 km/h. This range contains 50% of the Harm. The relevance here is 0.5*0.9=0.45 and the AIS shift is 2.

3.3.4. Pelvic & Thigh Injuries

The allowable femur load in the offset standard has reduced from a blanket 10kN requirement in ADR 69 to a 9kN peak load with 7.9kN for 10msec and above. Further, the manufacturers agree that they would need to design for 5.4kN to meet this new requirement. EEVC and CDOT tests revealed that 50% of cars tested failed to meet 5.4kN at 56km/h and 60% at 70km/h (see Appendix C). The amount of femur Harm relevant for mitigation at 56km/h is 70% and at 60km/h, 80% based on CR100 Harm distribution figures.

BENEFITS: Relevance at 56km/h is 0.35 at all AIS levels with an AIS 2 injury shift. For 60km/h, assumed a relevance of 0.56 at all AIS 2 injury shift. These benefits will apply equally to both pelvic and thigh Harm.

3.3.5. Knee Injuries

No prior injury criteria has been allowed for knee benefits in ADR 69, therefore this is a new benefit entirely. The offset standard calls for an A-P maximum tibia displacement of 15mm (assume a design criteria of 10mm for manufacturers). EEVC and CDOT tests revealed that all small cars failed to meet this criteria at 56km/h, while 33% of all cars failed at 60km/h. It was assumed that this criteria would provide a benefit for all knee Harm below these two impact test speeds (at 56km/h, 70% of 33% for small cars, and at 60km/h, 80% of 56% for all cars, based on CR100 Harm distributions).

BENEFITS: Relevance at 56km/h is 0.23 (0.7x0.33) at all AIS levels with an AIS 2 injury shift and 0.45 at 60km/h.

3.3.6. Lower Leg

New injury criteria has been developed based on the Tibia Index (TI) which specifies maximum TI = 1.3. EEVC and CDOT data showed that 20% of vehicles failed at 56km/h which increased to 75% failure rate at 60km/h (see Appendix C). An assumption was made about the resultant tibia moment in the Transport Canada tests (M_{res}=1.4142M_y). It would seem feasible that with full measurement, none of the 56km/h cars tested would have exceeded TI=1.3. Obviously, TI in its present form is very sensitive to crash severity. It should be noted that these measurements were based on current version of Hybrid III. The basis of TI=1.3 criteria has changed since these tests were conducted and, in addition, current plans are to incorporate a foot-ankle-leg system with biofidelity and meaningful ankle joint criteria. These changes seem critical to realizing substantial benefits against footwell injuries if tests are to be conducted at 56km/h.

In the light of this, it is reasonable to assume that there will be substantial lower limb benefits from this standard, given these dummy developments and the fact that manufacturers are likely to design for a criteria of around 70% that specified by the standard. It is expected that the revised leg will mainly influence the very high values of TI, thus no additional benefit would be obtained beyond that evident by the current version. (In the event that the validation test data shows considerable variation to those apparent in the EEVC and Transport Canada data, these figures might need to be revised). Harm mitigated is for all injuries below the test speed (70% at 56km/h and 80% for 60km/h).

BENEFIT: At 56km/h, the relevance figure would be 0.14 for AIS 2+ levels with an AIS injury shift of 2. At 60km/h, the relevance would be 0.6 for AIS 2+ injuries with a AIS 2 shift.

3.3.7. Ankle & Foot Benefits

The offset standard calls for an 8kN compressive force requirement as part of its lower leg injury criteria (6kN design requirement). EEVC and Transport Canada tests data showed that no vehicle exceeded this figure, although some improvement would be expected in the compressive force as a result of TI improvements. Moment forces of 50-150Nm were recommended by the working group as those levels least likely to result in injury.

On the basis that some manufacturers would respond to these figures by providing additional reductions in moment (M_y) below these figures (58% EEVC and Transport Canada vehicles failed these values at 56km/h and 75% failed at 60km/h), some benefit should be allowed for ankle and foot improvements such as improved floor and toepan structure and provision of floor padding as experienced in the 1996 Ford Taurus. Kallina (1995) claimed that Mercedes-Benz gained a 27% reduction in ankle and foot injuries as a result of structural and padding improvements. However, structural benefits have already been allowed for in the universal benefit. On the basis that half of the savings were from structural improvements, floor padding is expected to reduce foot and ankle injury Harm by 15% in 58% of cases at 56km/h and by the same proportion in 75% of cases at 60km/h.

BENEFIT: A relevance figure of 0.10 for all AIS levels with an AIS 1 shift at 56km/h and a relevance of 0.15 for all AIS levels with an AIS 1 shift at 60km/h.

3.3.8. Neck Injury Benefits

The offset standard specifies 3 new neck injury criteria for tension, shear and extension movement, based on figures reported by Mertz (1991). These are shown in Figures 3.4 to 3.7. The EEVC and Transport Canada test figures show that 22% of the vehicles failed these criteria at 56km/h and 30% at 60km/h. Harm distributions for the head and neck from CR100 showed that 75% of the Harm occurred at speeds up to 56km/h and 85% up to 60km/h.

BENEFIT: At 56km/h, a relevance of 0.17 is assumed for all AIS levels with an AIS 1 injury shift, while for 60km/h, the relevance is 0.26 all else being the same.

3.3.9. Front Left Passenger Benefits

The offset workshop group agreed that while the standard was primarily aimed at improving occupant protection for drivers (it is a 40% offset on the driver's side only), there would nevertheless be some additional benefit to be gained to front left passengers from the universal benefit from improved structural integrity and compatibility. In addition, some additional benefit would be expected to the chest and abdomen (from seatbelt and dashboard) and lower limbs assuming that counter-measures would apply equally to all front seat occupants.

BENEFIT: Assume that the benefits outlined above for the body regions stipulated apply to front occupant Harm, rather than just drivers.

Figure 3.4 *Neck axial tension performance limit (Mertz 1991)*

Figure 3.5 *Neck shear performance (Mertz 1991)*

Figure 3.6 *Neck axial compression limit (Mertz 1991)*

Figure 3.7 *Femur axial compressive force (Mertz 1991)*

3.3.10 Baseline Fleet Performance

To date, the experience in testing vehicles in this mode is not nearly as extensive as testing in the rigid full frontal barrier mode. The EEVC and the Canadian Department of Transport have conducted an initial evaluation of cars of different sizes when crashed into an offset deformable barrier at 56 and 60km/h. Ten different makes and models were tested at 56km/h. Seven of these cars were also tested at 60km/h. Three cars in each group were equipped with air bags. This group of 17 cars was assumed to be representative of the fleet in Australia. Tables of the test results are included in Appendix C of this report.

Members from the industry agreed at the workshop that the inclusion of test criteria which required additional control of occupant compartment intrusion would offer new challenges. In the event intrusion is controlled rather than prevented, large uncertainties exist on test to test variability. In addition, the new dummy criteria, particularly the new Lower Extremity and Chest criteria, are very sensitive to the position of the dummy relative to interior components. In order to meet a standard involving these new requirements, manufacturers would need to introduce additional margins in their design goals. The consensus of the group was that the design would be at least 30% below the requirements for the standard. Based on this information, it was assumed that all existing cars which did not have a 30% margin in the newly required criteria would have to be modified to meet the standard.

Chapter 4 Harm Benefits

The previous chapter described the Harm reduction method used for calculating the benefits of the European frontal offset regulation for Australia and the various data sources and assumptions necessary for making these computations. This chapter shows the resultant benefits summed from individual body regions and seating positions, assuming that cars sold in this country have met this standard at the end of 1998.

Benefits have been expressed two ways. First, as an annual savings in Harm assuming that all vehicles in the total vehicle fleet were to meet this standard (this can be expressed as both a savings in A$ for the population each year as well as a proportional reduction in Harm). Second, as a unit Harm figure for each vehicle over its life, based on 5% and 7% discount factors, assuming vehicle life and write-off rates similar to those of the immediate past.

4.1 DETAILED HARM CALCULATIONS

The assumptions were subsequently converted into relevance figures and applied to the existing Harm distributions in arriving at the likely body region and contact source benefits for the standard. The computation process was undertaken in ***THREE*** separate stages:

1. The Universal benefit was first deducted from the original Harm distribution leaving a modified (lesser) Harm distribution.
2. The airbag benefit (from zero to a 30% increase in the usage of airbags in 1998 due to the offset test procedure) was then subtracted from the modified Harm distribution.
3. The individual countermeasure benefits were then subtracted from the remaining Harm.

This procedure was necessary to minimise the chance of double counting these benefits. The order was deemed to reflect the manner in which the benefits would accrue to the population from the introduction of the standard. Because of its cascading nature, the size of each of the three benefit components is dependent upon its position in the process. Thus, its size of effect will be somewhat dependent on its position in the computation process.

Spreadsheets were developed around a series of body regions and contact sources for front seat occupants in frontal crashes. While it was assumed that most of the benefits from the offset standard would be to the lower limb regions, nevertheless, given the range of test criteria, there would be some benefits for all body regions. Injury and contact source relevance was judged on the basis of the likelihood of a particular countermeasure being introduced as a consequence of the regulation. This was assessed from comments made by vehicle manufacturers as well as the discussion that emanated from the earlier one day meeting of international research specialists in Washington DC (see Appendix A).

One-page summaries of the spreadsheets are shown in Appendix B which detail the benefits by body region and contact source for the various countermeasures and airbag sales. These body region benefits are summed in Table 4.3 and 4.4 to show the total amount of Harm saved by the offset standard each year (in A$ millions) as well as the discounted unit value per car over its life. The discounting procedure is explained in the next section and in Appendix D.

4.2 CALCULATING INDIVIDUAL VEHICLE SAVINGS

The annual Harm saved by the requirement for manufacturers to meet the European offset test procedure assumes that all vehicles on the road instantaneously meet this standard. In fact, of course, it can take many years for this situation to arise as 15% of cars involved in crashes are more than 15 years old and there are many vehicles aged 25 years or more still operating in this country. In establishing benefit-cost relationships, it is necessary to convert annual Harm saved (a community benefit) into a saving spread across the life of an individual vehicle to compare this with the cost of having to meet this new requirement.

This is achieved by estimating the average risk of a vehicle being involved in a crash for each year of its life and multiplying that risk by the annual Harm saved per crash for that time period. The average Harm savings can then be summed across the life of the vehicle. There are alternative methods for making these estimates, each with their particular strengths and weaknesses.

4.2.1 Immediate Past History

In these calculations, it was assumed that the immediate past history of crashworthiness, new car sales and crash patterns would continue and therefore be the best predictor of future crash risk, vehicle population size and salvage rates. This eliminates the need for tenuous subjective predictions and has credibility in that the past is often the best predictor of the future in dealing with human behaviour. It does assume of course that the crashworthiness history of the vehicle fleet will not alter dramatically; an assumption that has some credibility based on recent evidence (Cameron, Newstead and others, 1994) if attention is confined to the last 15 years.

The method, fully detailed in Appendix D, assumes that the risk of a new car being involved in a casualty crash during, say the 3rd year of its life, is the same as the risk of a car which was first registered 3 years ago having a crash this year. To calculate this yearly risk, the frequency of crashes for 3 year old cars is divided by the total number of cars sold 3 years ago. The risk of a crash across the lifetime of a car then is the sum of each year's crash experience over the number of new cars sold. The process of focussing on each crash year and the number of vehicle sales each year takes account of vehicles that exit from the vehicle fleet through wreckage, wear and tear, etc. as well as the lower distances travelled by older cars and the different characteristics of those who driver older cars.

The next step is to assume that the proportion of total Harm saved for all cars of a certain age group is equal to the percent of total relevant casualty crashes involving that age group. The formula used helps explain this:

$$\frac{H_3}{H} = \frac{F_3}{F} \quad \text{or} \quad H_3 = \frac{F_3}{F} \times H$$

where H_3 = Harm reduction for all cars in their third year

H = total annual Harm reduction for all cars

F_3 = number of cars involved in casualty crashes in third year

F = total number of cars involved in casualty crashes in one year

The average Harm reduction for any one car in its third year is calculated by dividing H_3 by the number of new cars registered three years ago. The total benefit for a single car from the new offset standard is then obtained by adding up the Harm reductions for each year of its life and discounting these benefits back to the first year. This is explained in more detail in Appendix D to this report.

4.2.2 Discounting Procedure & Rate

When predicting the likely benefits of a new countermeasure, it is normal to discount future benefits back to the present so that they can be compared with present day costs of the measure. The discounting procedure used in these calculations first takes the annual Harm saved for the offset standard and attributes this (discounted) to for one car over its expected lifetime. The selection of an appropriate discount rate is really a matter of opinion (there is no magic number). Traditionally, the Commonwealth Government has used 7% as an appropriate rate, while other state governments, however, have used a range of different values (the Victorian Government, for instance, has used 4%). A smaller discount rate gives greater weight to future benefits and is thus less conservative.

Department of Finance (1991) recommend that where possible, sensitivity analysis be undertaken involving a range of different discount rates. Current practice is to compare the benefits at 5% and 7% to gauge the likely usefulness of any new countermeasure. It is acknowledged that the choice of the discount rate has a marked effect on the calculation. Not only does it influence the BCR, but also the cost of death or serious injury [Steadman & Bryan 1988 used a 7% discount rate in determining the cost of injury for each injury severity level and noted that a 4% rate would increase the cost of injury overall by 17%]. For these calculations, injury costs have been taken at the BTCE 7% discount rate but the Harm benefits have been calculated for both 5% and 7% discount rates.

4.2.3 Life Period of Vehicle Fleet

Another issue involves deciding what constitutes the life period of the vehicle fleet over which the benefits are to be claimed. Tables D.1 and D.2 in Appendix D show that approximately 99% of casualty crashes involve vehicles 25 years old or less which seems to be a reasonable vehicle fleet age. On the other hand, it has been argued that it is more reasonable to use a shorter period of say 15 years (which accounts for around 85% of casualty crashes) particularly as repairs and replacement costs for the safety features have been ignored in determining their benefits. A recent study by Cameron et al (1994) which examined the role of vehicle age and crashworthiness showed that the risk of severe injury has not changed all that markedly over the last 15 years or so. Accordingly, benefits for the frontal offset standard have been calculated over both a 15 and 25 year life period. Based on the results in Appendix D, the multipliers used for assessing the unit Harm benefits of the frontal offset standard were:

	15 year Fleet Life	25 year Fleet Life

5% discount rate	1.1274	1.2532
7% discount rate	0.9984	1.0873

Multiplier figures by 10^{-6} to convert from A$ millions to A$.

4.3 HARM BENEFITS

The study objectives called for the Harm benefits to be calculated separately for both the 56km/h and a 60km/h crash test speed. This was for reasons of sensitivity analysis as well as to show the efficacy of these requirements. The expert group agreed that the offset standard was expected to ensure that all new cars would have at least a driver airbag in Australia to ensure that the injury criteria specified in the offset standard was met.

Approximately 43% of new car sales in Australia currently had a driver airbag fitted and this proportion is growing. On this basis, it was judged that for the year 1998 (the proposed introductory period for the frontal offset standard) at least 70% of new cars would have driver airbags fitted regardless of the offset standard. Thus, the difference between the expected rate in 1998 and 100% could be attributed to the benefits of the offset standard procedure.

A summary of the benefits due specifically to the offset standard for a range of different test speeds, life of the vehicle fleet and discount rates are shown in Tables 4.1 and 4.2. The individual Tables showing the summed benefit by type of benefit and body region for each test speed and airbag sales proportion is shown in Appendix B.

Table 4.1
Summary of Harm reductions for the various outcomes dependent upon driver airbag fitment rates achieved in 1998.

PERCENT DRIVER AIRBAGS IN NEW CARS	56km/h TEST SPEED		60km/h TEST SPEED	
	ANNUAL HARM	% FRONT TRAUMA	ANNUAL HARM	% FRONT TRAUMA
70%	$418m	21%	$460m	23%
80%	$377m	19%	$420m	21%
90%	$337m	17%	$381m	19%
100%	$297m	15%	$342m	17%

Table 4.2
Summary of Unit Harm reductions for the various outcomes dependent upon discount rate, fleet life and driver airbag fitment rates achieved in 1998.

PERCENT AIRBAGS IN NEW CARS	56km/h TEST SPEED				60km/h TEST SPEED			
	15yr FLEET		25yr FLEET		15yr FLEET		25yr FLEET	
	5%	7%	5%	7%	5%	7%	5%	7%

70%	$471	$417	$523	$454	$518	$459	$576	$500
80%	$425	$376	$472	$410	$474	$420	$527	$457
90%	$380	$336	$422	$366	$430	$381	$478	$415
100%	$334	$296	$372	$322	$385	$341	$428	$372

4.4 OVERVIEW OF THE RESULTS

The results of the Harm analysis undertaken in this study illustrate what the benefits would be if Australia were to adopt the proposed European frontal offset requirement in addition to ADR 69 for both a 56km/h or a 60km/h crash test speed.

4.4.1 Benefits at 56km/h

Tables 4.1 shows the resulting Harm benefits for the European offset standard applied to the Australian passenger car fleet for a 56km/h test speed with airbag sales from 70% to 100%. The total Harm saved varies from A$297 million annually (a 15% reduction in total frontal crash Harm) up to A$418 million annually or a 21% reduction in Harm, depending on the level of driver airbag sales.

UNIT HARM: Table 4.2 shows that the unit Harm benefit at the lower crash test speed varies somewhere between $296 and $523 depending upon which figures are selected for the life of the vehicle fleet and for discount rate. The break-even cost for manufacturers to meet this standard is, therefore, equivalent to this unit Harm benefit figure.

4.4.2 Benefits at 60km/h

At the higher test speed of 60km/h, the equivalent total frontal Harm benefit varies from A$342 to A$460 million annually (from 17% to 23% of total frontal Harm) depending on the level of airbag fitment in 1998 (see Table 4.1). Most of the specific countermeasure benefits were either for the torso or lower limb injury reductions.

UNIT HARM: The unit Harm reduction per car at the higher crash test speed is again depending on fleet life period and discount rate chosen. Table 4.2 shows that this figures varies from $341 to $576 which again is equivalent to the break-even cost for meeting the EEVC offset frontal crash standard.

Chapter 5 General Discussion and Recommendation

The study set out to examine the injury pattern to occupants of passenger cars involved in full and offset frontal crashes and to estimate the injury reduction benefits likely to accrue if Australia was to mandate the proposed EEVC offset standard currently under consideration in Europe. Annual benefits to the community were to be calculated for crash tests at both 56km/h and 60km/h assuming different levels of airbag sales in 1998. Unit Benefits (Harm savings per car) were estimated for 5% and 7% discount rates, assuming both a 15 year and 25 year life of the vehicle.

5.1 OVERVIEW OF THE STANDARD

The proposed EEVC offset standard differs from current full frontal standards such as the US FMVSS 208 and Australian ADR 69 in a number of ways.

First, the test impact configuration calls for a 40% overlap using a deformable barrier face along with an increase in impact speed to either 56km/h or 60km/h. This is a more severe structural test for current models manufactured to meet either FMVSS 208 or ADR 69 and is likely to lead to new designs which will emphasise greater structural integrity of the passenger compartment.

Second, the inclusion of lower leg injury criteria is an attempt to control for these injuries. While they are not necessarily life threatening, are very frequent injuries in frontal crashes, are disabling and painful for those who sustain them, and extremely costly for society in general. The proposed EEVC standard includes a Tibia Index (TI) which specifies criteria for axial compression and knee movement. Although TI has been criticised as not being a totally adequate measure of leg injury, nevertheless it is an important criteria as a first step in raising awareness and focussing attention on the need to protect this region of the body. It would be a poor outcome for occupant protection worldwide if this criteria was to be abandoned.

The standard also specifies neck injury criteria which are unique. Measures of tension, shear and extension have been included which will lead to greater consideration of neck injuries in road crashes and are likely to promote increased use of driver (and possibly passenger) airbags. The proposed EEVC offset standard also stipulates more comprehensive head and chest injury criteria. While maintaining HIC as the principal measure of head injury, it also incorporates a peak head acceleration criteria of 80g, albeit averaged across a 3 msec clip which has been criticised as an unnecessary and unproductive constraint. Chest deflection has been decreased from 75 to 50mm and chest viscous criterion (V*C) of 1.0m/sec added. This is also likely to be a more stringent measure of chest injury than current criteria.

Finally, the inclusion of a more stringent longitudinal steering column movement (from 125mm to 100mm) and the first time inclusion of a vertical steering column movement

criterion of a maximum of 80mm should also help to reduce cabin intrusions in these relatively common severe types of frontal crashes experienced worldwide.
In short, the proposed EEVC offset standard appears likely to produce additional occupant protection benefits beyond those of the present ADR 69 requirement that presently applies to Australian cars.

5.2 INJURIES IN OFFSET CRASHES

A number of overseas reports have pointed to more severe outcomes for occupants involved in offset frontal crashes and it was deemed necessary to examine if this was also the case in Australia. This was to show the need for further consideration of frontal crash protection beyond ADR 69.

The analysis in Chapter 2 showed that the outcome for drivers involved in near-side offset collisions was considerably worse than for equivalent full frontal drivers. They sustained many more severe injuries, especially to the lower torso and the legs than their counterparts in full frontal crashes and, on average, at lower impact speeds. This was not a function of differences in seat belt wearing but did appear to be influenced slightly by the type of car they were travelling in.

Lower limb injuries and severe injuries to the upper limbs seem to be areas requiring particular attention in near-side offset collisions (that is, when the offset crash was on the same side of the vehicle as the occupant). Reduced intrusion inside the passenger compartment by the steering column, instrument panel, A-pillar and floor and toepan need greater emphasis in near-side offset frontal crashes for drivers as well as passengers. It is unlikely, therefore, that the full frontal dynamic crash standard ADR 69 will provide sufficient benefit for front seat occupants involved in offset crashes. The need for both full frontal and offset frontal crash requirements seems warranted from these findings.

5.3 BENEFITS OF THE STANDARD

The likely benefits for Australia were then assessed using the Harm Reduction method previously developed for these purposes by the Monash University Accident Research Centre in conjunction with Kennerly Digges and Associates of Charlottesville, Virginia.

As there were no published data on the injury savings from the proposed EEVC standard, it was necessary to bring together a group of international researchers, vehicle manufacturers, and government safety agency experts to arrive at a consensus view of these savings. A one-day workshop was held in Washington, DC in conjunction with the Pelvic and Lower Extremity Injury (PLEI) conference during December 1995. From this meeting, a number of assumptions were developed on which to calculate the likely injury reductions by body region. Benefits were to be derived from ***three*** sources of vehicle design improvement, namely:

1. a universal benefit from general structural improvement (this would to apply to all frontal crash injuries),
2. an increase in airbag usage (it was agreed that the EEVC offset standard would ensure that all cars would provide at least a driver side airbag), and

3. specific vehicle design countermeasures aimed at achieving the test criteria specified by the standard, most notably lower limb and chest injury criteria.

Test data were available from a series of EEVC crash tests and the Canadian Department of Transport that specifically tested to the proposed EEVC standard at 56km/h and 60km/h. In addition, the Insurance Institute of Highway Safety (IIHS) and the Australian NCAP program also had offset test results which were very useful in translating the assumptions agreed to at the workshop into likely injury reductions.

The Harm database developed and used in previous studies (eg; Monash University Accident Research Centre, 1992; Fildes, Digges, Carr, Dyte & Vulcan 1995) was again used as a basis for calculating the benefits of the proposed EEVC offset standard. Allowances were made for subsequent vehicle safety improvements such as ADR 69 in arriving at these injury reductions.

5.3.1 Annual Harm Benefits

Tables 4.1 from the previous Chapter demonstrated the range of annual benefits that would accrue for the range of possible test speeds and increases in driver airbag usage that could be attributed to the offset standard and is represented here in Table 5.1. As can be seen, the least annual Harm reduction that would accrue from the offset standard in addition to that achieved from ADR 69 was estimated to be A$297 million (a 15% reduction in frontal Harm) and at best, A$460 million or a 23% reduction in frontal Harm. These savings would apply when all vehicles in the fleet complied with both standards.

Table 5.1
Summary of Harm reductions estimated for the various outcomes dependent upon driver airbag fitment rates achieved in 1998.

PERCENT DRIVER AIRBAGS IN NEW CARS	56km/h TEST SPEED		60km/h TEST SPEED	
	ANNUAL HARM	% FRONT TRAUMA	ANNUAL HARM	% FRONT TRAUMA
70%	$418m	21%	$460m	23%
80%	$377m	19%	$420m	21%
90%	$337m	17%	$381m	19%
100%	$297m	15%	$342m	17%

5.3.2 Unit Harm Benefits

Unit Harm benefits (the average savings per car across its lifetime) were then determined using 5% and 7% discount rates and fleet life periods of 15 and 25 years. Again, Table 5.2 below is a repeat of Table 4.2 from the previous Chapter which shows unit Harm savings from A$296 to A$523 for a 56km/h crash test speed or A$341 to A4576 at 60km/h for this additional standard. In other words, the break-even cost for having to meet this new requirement would be somewhere between these figures.

Table 5.2
Summary of Unit Harm reductions for the various outcomes dependent upon discount rate, fleet life and driver airbag fitment rates achieved in 1998.

PERCENT	56km/h TEST SPEED				60km/h TEST SPEED			
AIRBAGS	15yr FLEET		25yr FLEET		15yr FLEET		25yr FLEET	
IN NEW CARS	5%	7%	5%	7%	5%	7%	5%	7%
70%	$471	$417	$523	$454	$518	$459	$576	$500
80%	$425	$376	$472	$410	$474	$420	$527	$457
90%	$380	$336	$422	$366	$430	$381	$478	$415
100%	$334	$296	$372	$322	$385	$341	$428	$372

5.4 DISCUSSION OF THESE BENEFITS

As noted earlier, the expert panel claimed that the benefits to be derived from this additional frontal standard for Australia come from three sources; a universal structural improvement, an increase in the provision (and subsequent benefits) of driver side airbags, and from specific measures aimed at meeting essentially the new lower limb and neck injury criteria, as well as more stringent head and chest requirements. On the basis of the assumptions agreed to by this expert panel, the subsequent benefits appear to be sizeable and make the proposition of adopting this standard in addition to ADR 69 very attractive indeed.

The most conservative estimate was for a 15% reduction in frontal Harm attributed directly to this standard with no benefit from increased airbag use. This would seem to be a worthwhile improvement in occupant protection alone. The minimum break-even cost to achieve this benefit would be A$296 per vehicle which seems very reasonable indeed (industry estimates to achieve the side impact standard improvements in Fildes et al, 1995, were A$100 per car).

It is important to stress that the fundamental basis for these improvements beyond those achieved from a full frontal standard lies in the lower limb injury criteria, essentially the Tibia Index (TI). The expert group agreed that these criteria are essential to ensure that vehicle design includes the level of structural improvements that would ensure the universal benefits claimed here. Moreover, without TI or some form of lower limb injury criteria, most of the specific countermeasure benefits claimed would also disappear. In short, it would be difficult to support this extra standard without a TI or equivalent requirement. Recent comments coming out of Europe suggest that there are those who propose removing the lower limb injury criteria from the EEVC offset proposal. From the evidence presented here, it is clear that such a step would be extremely undesirable and unproductive for advancing vehicle occupant protection.

The proposed EEVC frontal offset standard represents a bold new approach to improving occupant protection and is to be encouraged. The approach adopted in calculating the benefits of Australia adopting this standard attempted to use the best information available in arriving at these likely injury savings. The assumptions and the basis for them are clearly stated throughout the report based on the existing body of test data, scant injury data, biomechanics criteria, and expert opinion. These were the best information available at the time on which it was possible to estimate these benefits. As new information becomes available, these assumptions may be further refined and the benefits adjusted accordingly.

The strength of the Harm Reduction method used here is that the basis for arriving at these benefits is objective and transparent and subject to close scrutiny. If one wishes to challenge any of the assumptions, it is possible to re-calculate the benefits based on alternative outcomes. Indeed, the analysis performed here included a number of sensitivity tests on the basis of alternative crash test speeds, airbag usage figures in Australia pre-standard, and varying discount factors and time period over which the benefits are calculated.

It was especially noteworthy that the expert panel assembled for this exercise comprising specialists from manufacturers, researchers, and government officials throughout the USA, Canada and Europe were in general agreement about the savings that would be achieved in vehicle improvement by this standard. Manufacturers in particular were forthcoming about how they would respond to this standard and the improvements that could be expected. The degree of consensus was quite outstanding and the authors are extremely grateful for the efforts of the expert panel. It should be highlighted that there was a strong call by many of these people for a single world standard for offset crash protection to focus attention on ensuring the best possible outcome for vehicle occupants.

5.5 RECOMMENDATION

On the basis of the evidence presented here, it would seem desirable for Australia to seriously consider introducing an offset frontal crash standard similar to that being proposed in Europe. The benefits likely to accrue would be somewhere between A$297 million and A$460 million annually with 100% fleet compliance. The break-even cost per car across its lifetime would be on average somewhere between A$296 and A$576. This finding is conditional on all aspects of the EEVC proposal outlined here and would likely be severely compromised if any of the injury criteria were to be removed or downgraded over that currently proposed.

References

Cromark J.R., Schneider D. & Blaisdell D. (1990). Occupant kinematics and belt markings in crash tests with unrestrained and partially restrained test dummies, Proceedings of the 34th Conference of the Association for the Advancement of Automotive Medicine, *34*, pp203-225.

Cameron M., Newstead S., Le T, & Finch C. (1994). Relationship between vehicle crashworthiness and year of manufacture, Report TS 94/6, Royal Automobile Club of Victoria (RACV) Limited, Melbourne.

Department of Finance (1991). ***Handbook of Cost-Benefit Analysis***, Australian Government Publishing Service, Canberra.

Fildes B.N., Lane J.C., Lenard J & Vulcan A.P. (1991). Passenger cars and occupant protection, Report CR95, Federal Office of Road Safety, Canberra.

Fildes B.N. & Vulcan A.P. (1994). Workshop report on side impact regulations for Australia, Report CR149, Federal Office of Road Safety, Canberra (in press).

Fildes B.N., Digges K., Carr, D., Dyte D. & Vulcan A.P. (1995). Side impact regulation benefits, Report CR 154, Federal Office of Road Safety, Commonwealth Department of Transport, Canberra.

Fildes B.N. & Vulcan A.P. (1995). Workshop report on side impact regulations for Australia, Report CR 149, Federal Office of Road Safety, Commonwealth Department of Transport, Canberra (in press).

Kallina I. (1995). Offset testing program at Mercedes-Benz AG, Paper presented to the International Conference on Pelvic and Lower Extremity Injuries (PLEI), National Highway Traffic Safety Administration, Washington DC.

Lowne R. (1994). EEVC Working Group on the development of a front impact test procedure, Paper 94-S8-O-05, Proceedings of the 14th International Technical Conference on the Enhanced Safety of Vehicles, US Department of Transportation, National Highway Traffic Safety Administration, Washington DC, pp 1334-1351.

Malliaris A.C., Hitchcock R. & Hedlund J., A search for priorities in crash protection, *SAE 820242, International Congress and Exposition*, Society of Automotive Engineers Inc., Warrendale, PA; 1982.

Malliaris A.C., Hitchcock R. & Hansen M., *Harm causation and ranking in car crashes*, SAE 850090, Society of Automotive Engineers, Warrendale, PA, 1985

Malliaris A.C. & Digges K., Crash protection offered by safety belts, *International Technical Conference on Research Safety Vehicles, 11(31),* National Highway Traffic Safety Administration, Washington, DC; 1987.

Mertz, H.J. (1993). Anthropomorphic test devices, Accidental Injury; Biomechanics and Prevention, Springer-Verlag, New York.

Miller T.R., Pindus N.M., Leon T.S. & Douglass J.B. (1990). Motor vehicle injury costs by body region and severity, Proceedings of the 34th Annual Conference, Association for the Advancement of Automotive Medicine, Scottsdale, AZ.

Monash University Accident Research Centre (1992). Feasibility of occupant protection measures, Report CR100, Federal Office of Road Safety, Commonwealth Department of Transport, Canberra.

Seyer K. (1996). Calculation of new passenger car sales with and without airbags fitted, Unpublished information provided by the Federal Office of Road Safety, Canberra.

Steadman L.J. & Bryan R.J. (1988). Cost of Road Accidents in Australia, Occasional Paper 91, Bureau of Transport and Communications Economics, Australian Government Printing Service, Canberra.