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Crash-based Evaluation of Australian Design Rule 69 (Full Frontal Impact Occupant Protection)

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December 2006

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Abstract

In-depth data at MUARC was used to evaluate Australian Design Rule 69 (ADR 69), 'Full Frontal Impact Occupant Protection', with respect to both injury risk and cost of injury for drivers of passenger cars. The effectiveness of frontal airbag deployment was also examined. ADR 69 was introduced in Australia in mid-1995 and was based largely on the US occupant protection standard, FMVSS 208. The results of this evaluation indicate reductions of 80% and higher in the likelihood of sustaining AIS 2+ head and face injuries, with even greater gains associated with frontal driver airbag deployment. The frontal driver airbag was particularly important in reducing the probability of chest injuries. The average injury cost savings for drivers of post-ADR 69 manufactured passenger cars was found to be as high as AUD$19,000 depending on the body region, while the combined injury cost saving associated with head, face, neck and chest injuries combined was AUD$27,000 on average per driver. The findings do however point the way forward for improvements in vehicle safety design for the further protection of the spine and the lower extremity in particular, where the regulation has had little impact among this sample of belted drivers. Limitations of this research and implications of these findings are discussed. Recommendations to build on the success of ADR 69 are made.

Keywords

Occupant protection, frontal impact, Australian Design Rule, airbags

CONTENTS

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EXECUTIVE SUMMARY

ADR 69 was introduced by the Australian Government following continuing concern for the high number of serious injuries and the high fatality rate associated with frontal crashes throughout the 1980s. The Australian Government was committed to achieving reductions in the road toll, and so embarked on a research program to examine the feasibility and likely benefits of introducing a frontal impact protection standard. The three-stage research program involved the Monash University Accident Research Centre collecting information on a sample of crashes and analysing mass crash data to identify the extent of injuries associated with passenger car crashes, followed by a crash test program with tests conducted in accordance with the US Federal Motor Vehicle Safety Standard (FMVSS) No. 208. Following the third phase, ADR 69 was promulgated on 16th December 1992.

This report set out to examine the effectiveness of Australian Design Rule No. 69, ‘Full Frontal Impact Occupant Protection’, with respect to injury reduction benefits for belted drivers in passenger cars (Class MA vehicles) involved in real-world crashes. ADR 69 is a dynamic full frontal crash test at 48 km/h using belted Hybrid III 50th percentile male crash test dummies, and specifies the maximum acceptable injury tolerance values for the head, chest and femur. ADR 69 also specified a 4-second seat-belt warning light, illuminated on vehicle ignition. The regulation applied to passenger cars (MA vehicles) introduced as a new model from 1 July 1995, and all passenger cars from 1 January 1996. Notably, frontal airbags were not a mandatory requirement of ADR 69, however many manufacturers elected to install frontal airbag systems and optimised seat-belt systems as a means to meeting the requirements of the Standard.

RESEARCH OBJECTIVES

Using in-depth crash information collected from 285 crash-involved belted drivers in frontal impacts, the research objectives were as follows:

1. Establish the difference in injury risk for each body region associated with drivers of pre- and post-ADR 69 passenger cars, defined as pre-1995 and post-1995 (ADR build date) respectively.

2. For each body region, to establish the benefits or otherwise of exposure to frontal airbag systems.

3. Establish for each body region, the injury reduction benefits or otherwise associated with post-ADR 69 passenger cars with exposure to a frontal airbag systems compared to drivers of pre-ADR 69 passenger cars without a frontal airbag deployment.

4. Determine the probability of injury to each body region for drivers of pre- and post-ADR 69 passenger cars.

5. For each body region, to determine the injury cost savings, if any, associated with the implementation of ADR 69.

INJURY RISK ANALYSIS

The findings of this study, summarised in Table 1, demonstrate significant reductions in head and face injury risk for drivers of post-ADR 69 passenger cars relative to drivers of pre-ADR 69 passenger cars involved in frontal impact tow-away crashes resulting in injury and / or hospitalisation. The results also suggest that the presence and deployment of the frontal airbag has been instrumental in the injury reduction benefits observed for the head, face and chest. The combined effect of post-ADR 69 passenger cars with an airbag indicated benefits over and above the benefits associated with airbags or ADR 69 implementation alone.

Table 1 also indicates that drivers of post-ADR 69 passenger cars did not experience any injury reduction benefit for the neck, chest (in the absence of an airbag), and extremities, while experiencing an indicative increase in injury risk for the abdomen-pelvic contents, and a significantly higher risk of injuries of the spine, compared to drivers of pre-ADR 69 passenger cars.

Table 1: Change in injury risk for AIS 2+ injuries associated with ADR 69 status, airbag deployment and the combined effect.

Body region	Post-ADR 69 drivers[(a)]	Airbag exposed drivers[(b)]	Post-ADR 69 + Airbag exposed [(c)]
Head	78% reduction†	82% reduction‡	96% reduction‡
Face	88% reduction†	91% reduction‡	99% reduction‡
Neck	No statistical difference	No statistical difference	Indicative 80% reduction*
Chest	No statistical difference	79% reduction‡	74% reduction‡
Abdomen – Pelvic contents	No statistical difference	83% reduction†	No statistical difference
Spine	895% increase‡	82% reduction‡	No statistical difference
Upper Extremity	No statistical difference	No statistical difference	No statistical difference
Lower Extremity	No statistical difference	No statistical difference	No statistical difference

(a) Relative to pre-ADR 69 drivers; (b) Relative to driver's without an airbag deployment; (c) Relative to pre-ADR 69 drivers without an airbag deployment; * $p \leq 0.1$, †$p \leq 0.05$, ‡$p \leq 0.01$

Table 2 shows the probability, or risk, (and confidence intervals) of sustaining moderate and higher severity injuries (AIS 2+) at an impact speed of 48 km/h, the ADR 69 crash test speed. These estimates simply state, for example, that the risk for drivers of post-ADR 69 passenger cars of sustaining a moderate or higher severity injury to the head is 15% at an impact speed of 48 km/h, compared to 44% for drivers of pre-ADR 69 passenger cars. These estimates point to the chest and lower extremities as key priorities for future occupant protection countermeasures.

Table 2: AIS 2+ Injury probability estimates for drivers of pre-ADR 69 and post-ADR 69 passenger cars by body region at an EBS of 48 km/h

Body region	Body region			Post-ADR 69 drivers[(a)]		
	Probability	95th% CI		Probability	95th% CI	
		Lower	Upper		Lower	Upper
Head	0.44	0.23	0.67	0.15	0.05	0.37
Face	0.12	0.03	0.35	0.02	0.002	0.12
Neck	0.09	0.02	0.29	0.04	0.01	0.22
Chest	0.62	0.41	0.79	0.67	0.43	0.84
Abdomen-Pelvis	0.03	0.01	0.08	0.08	0.02	0.24
Spine	0.03	0.01	0.08	0.21	0.09	0.42
Upper Ex.	0.29	0.15	0.48	0.26	0.12	0.46
Lower Ex.	0.36	0.19	0.57	0.46	0.24	0.70

(a) Relative to pre-ADR 69 drivers

INJURY COST ANALYSIS

The final objective of this research was to determine the injury cost savings, if any, associated with the implementation of ADR 69. Using HARM as the cost of injury metric (year 1996 dollar value) and all injuries as the basis of cost, significant reductions in the cost of injury were associated with the head (AUD$18,970 saving on average per case), the face (AUD$6,730 saving on average per case), the neck (AUD$2,660 saving on average per case), while an increase in the cost of injury of the spine (AUD$1,290 on average per case) was observed. Of concern was the strong trend of an average per driver AUD$10,800 increase in injury cost for the lower extremity for drivers of post-ADR 69 passenger cars, and the finding of no cost of injury reduction for the chest. With respect to chest injuries, a cost reduction benefit would be observed if the comparison was based on exposure to the frontal airbag.

The cost savings for individual body regions are not additive, and so the cost of head, face, neck and chest injuries for post-ADR 69 drivers (mean: AUD$27,790) was compared to pre-ADR 69 drivers (mean: AUD$58,280), with the regression analysis indicating an average per driver cost saving of AUD$27,600. The whole-of-body injury cost analysis suggests a AUD$13,240 benefit, on average, for drivers of post-ADR 69 passenger cars, however this is not statistically significant and is substantially lower than the cost savings associated with the head, face, neck and chest; this result is, principally due to the high cost disbenefit associated with lower extremity injuries.

These cost injury estimates demonstrate significant cost savings in the regions most expected given the injury criteria specified in ADR 69, while pointing to the need for further improvements in controlling lower extremity injury risk.

CONCLUSIONS

This report set out to examine the effectiveness of ADR 69 in preventing injury among Australian passenger car drivers. The results presented in this report demonstrate significant benefits associated with the introduction of ADR 69 as well as the voluntary parallel introduction of frontal airbags in Australia. The results of this evaluation are applicable only to Class MA passenger cars however, as no consideration was given to the real-world crash performance of forward control passenger vehicles (Class MB), off-road passenger vehicles (Class MC), and light goods vehicles (Class NA, NA1).

This report demonstrated significant reductions in the risk of head, face, neck and chest injuries associated with the ADR 69 standard and airbag systems in particular. It is expected that the safety benefits associated with ADR 69 to these body regions will flow through the passenger car fleet over time, with the injury reduction benefits to be realised for generations to come. The findings do however point the way forward for improvements in design standards, with the aim of enhancing the protection of the abdomen and pelvic contents, the spine, and the lower extremity in particular, where the regulation has had little improvement in injury risk among this sample.

Future studies would be best placed to use a larger sample with a greater range of injury severities than was used here. Further, the benefit of sample weights based on complete Australian hospital presentation and admission data linked to Police reported casualty crashes in the evaluation of ADRs cannot be underestimated. The use of sample weights would ensure the results of future evaluations would be applicable to all Australian drivers and passengers.

This Report makes a number of recommendations for further study with the intent of examining methods to improve occupant protection standards, thereby reducing the number and severity of injuries for male and female passenger car occupants in Australia.

RECOMMENDATIONS

Recommendations 1 – 4 are made on the basis of the findings of this report, while Recommendation 5 stems from methodological considerations in the conduct of this report. In framing Recommendations 1 - 4, the authors are cognisant of the role of ADR 73, Australia's Frontal Offset regulatory test, in the current regulatory regime for passenger car occupants[1]. It is recommended therefore that an evaluation of ADR 73 be undertaken using the same methods used in this report so as to assess both the need, and if necessary the order of priority, of Recommendations 1 - 4.

1 ADR 73/00, Offset Frontal Occupant Protection was mandated to apply to all new model passenger car vehicles less than 2.5 tonnes from January 2000 and all passenger car vehicles less than 2.5 tonnes from January 2004. As of Determination No. 2 of 1998, Class MA passenger cars complying with the requirements of ADR 73 may be deemed to comply with ADR 69 provided that the vehicles are fitted with dual airbags and the manufacturer can demonstrate by other allowable methods that the vehicle complies with the requirements of ADR 69. Notably, ADR 73 does not apply to forward control passenger vehicles (Class MB), off-road passenger vehicles (Class MC), and light goods vehicles (Class NA, NA1), although these vehicles must meet the requirements of ADR 69.

This principal recommendation is made on the basis of the ADR 73 representing an updated frontal crash occupant protection standard, recognition of the significant regulatory hurdles in adopting any changes to the provisions of ADRs, and the preference of the Australian Government to harmonise vehicle safety regulations in accordance with the provisions of the United Nations Economic Commission for Europe (UNECE) 1958 Agreement concerning the adoption of Uniform Technical Prescriptions for vehicles.

1. Explore the feasibility and likely benefits of increasing the ADR 69 test speed from 48 km/h to a higher speed, with the aim of further reducing the probability of injury at higher impact speeds, as beyond the current 48 km/h test speed the probability of injury remains high. In doing so, consideration of potential disbenefits of higher test speeds with respect to vehicle aggressivity must be made.

2. That an assessment be made of the necessity and likely benefits of mandating dual frontal airbags as standard equipment in all passenger cars.

3. Explore the feasibility and likely benefits of inclusion of the 5th percentile female into the ADR 69 test regime as a means of addressing the increased risk of chest injury for short-statured drivers.

4. Examine the risk of lower extremity injuries among occupants of ADR 73 compliant passenger cars involved in frontal crashes. In the event of continuing high risk of injury, as reported in this study, improved injury criteria and new dummy instrumentation might be an appropriate method of addressing the high risk of lower extremity injury as highlighted in this study.

5. Examine the feasibility and value of establishing a national injury crash database, using linked hospital and police crash data. Alternatively, the feasibility of establishing an on-going national in-depth crash sampling system could be examined. These initiatives would add value to future vehicle safety evaluations as well as permitting the monitoring of current and emerging road safety concerns.

ABBREVIATIONS

AAAM	Association for the Advancement of Automotive Medicine
AAM	Alliance of Automobile Manufacturers (USA)
ADR	Australian Design Rule
AIS	Abbreviated Injury Scale
ANCIS	Australian National Crash In-depth Study
ANOVA	Analysis of variance
ANPRM	Advanced Notice of Proposed Rulemaking
ATSB	Australian Transport Safety Bureau (Australia)
BCR	Benefit Cost Ratio
BTE	Bureau of Transport Economics (Australia)
CDC	Collision Deformation Classification
CI	Confidence Interval
Clth of Aust.	Commonwealth of Australia
CRABI	Child Restraint/Air Bag Interaction (CRABI) dummy
CT imaging	Computerized axial tomography
CVF	Crashed Vehicle File
DoTARS	Department of Transport and Regional Services (Australia)
EBS	Equivalent Barrier Speed
EEVC	European Experimental Vehicles Committee
EU	European Union
EuroNCAP	European New Car Assessment Program
FCAI	Federal Chamber of Automotive Industries (Australia)
FMVSS	Federal Motor Vehicle Safety Standard (USA)
FORS	Federal Office of Road Safety (Australia)
FR	Federal Register (USA)
GN	Gazette Number (Australia)
GVM	Gross Vehicle Mass
HIC	Head Injury Criterion
ICD	The International Statistical Classification of Diseases and Related Health Problems
IIHS	Insurance Institute for Highway Safety (USA)
ISS	Injury Severity Score
km/h	Kilometres per hour
kN	Kilo Newton
LCI	Lower Confidence Interval
MA vehicles	Passenger cars
MAIS	Maximum Abbreviated Injury Scale

MRI	Magnetic Resonance Imaging
ms	Milli-seconds
m/s	Metres per second
MUARC	Monash University Accident Research Centre (Australia)
MY	Model Year
NASS	National Automotive Sampling System
NCAP	New Car Assessment Program
NHTSA	National Highway Traffic Safety Administration (USA)
Nij	Neck injury assessment measure
OR	Odds ratio
Pr	Probability
ROC	Receiver operating curve
RR	Relative Risk
SD	Standard deviation
SNPRM	Supplemental Notice of Proposed Rulemaking
TAC	Transport Accident Commission (Australia)
TBT	Technical Barriers to Trade
TCFC	Tibia Compression Force Criterion
TI	Tibia Index
UCI	Upper Confidence Interval
UN ECE	United Nations Economic Commission for Europe
US	United States
US DOT	United States Department of Transportation (USA)
VicRoads	Roads Corporation of Victoria (Australia)
WG-11	Working Group 11 (of the EEVC)
WTO	World Trade Organisation

1 INTRODUCTION

1.1 Background

Historically, Australia has been at the forefront of many road safety initiatives as evidenced by the introduction of mandatory fitment and wearing of seatbelts in 1972[2] and the continual investment in road safety countermeasures such as drink-driving and speed enforcement campaigns. The system of Australian Design Rules (ADR), introduced in 1969, mandated a variety of safety requirements with the intent of improving occupant protection standards, of which the mandatory fitting of seat belts is one example (Seyer, Makeham & McLennan, 1992). Despite impressive reductions in the number of fatalities on Australian roads throughout the 1980s compared to the 1960s and 1970s, approximately 1900 drivers and passengers were killed in motor vehicle crashes per annum, with the total road toll slightly fewer than 3000 fatalities per year (ATSB, 2004a). In the late 1980s the Australian Federal Government was committed to achieving further reductions in road trauma, and backed this sentiment by devoting significant resources to road safety research and public education (Seyer et al., 1992).

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2 ADR 4 & ADR 5 (modified to be 5A prior to formal introduction) specified the fitment of seatbelts and anchorage characteristics, respectively, with both approved in February 1967; these ADRs became effective 1 January 1969 for the front outboard seats and to the rear seats of vehicles manufactured from 1 January 1971. ADR 4 specified lap/sash belts fitted to the front outboard seats and lap belts fitted to other seats. ADR 4 was superseded by ADR 4A which specified fixed buckle locations of seat belts be fitted for vehicles manufactured on or after 1st April 1974 and ADR 4B introduced from 1 January 1975 with specifications designed to make further improvements to the comfort and ease of use, with further amendments made over the following years (i.e., ADR 4C, 4D) Likewise, ADR 5A was modified to ADR 5B in order to specify stricter location of upper anchorage points so as to improve the comfort of the seat belt for the user; this was effective 1 January 1975. ADR 32 and ADR32A cover seat belt fitment for heavy vehicles, and was effective from July 1977 (Cameron, 1979; Milne, 1985; DoTARS, 2004). In December 1970 Victoria legislated mandatory seatbelt wearing and NSW followed suit in October 1971. By 1972 seatbelt wearing was mandatory throughout Australia (Milne, 1985). The success of mandatory seat belt wearing is well documented (refer Milne, 1985); for example: seat belt wearing rates for South Australian drivers rose from 23.1% in 1964 to 90.7% in 1977 where seat belts were actually fitted. The availability of seatbelts in South Australia also rose from 60% to 94.7% of vehicles fitted with seatbelts in the driver position following legislation by the SA government in June 1967 specifying that seatbelts be fitted to front outboard seating positions although wearing remained voluntary until 1971. According to Milne (1985), the non-availability of seat belts in vehicles was solved by the introduction of the Australian Design Rule system, as previously manufacturers considered that after-market fitment would satisfy consumer demand for seat belts given the low demand indicated by low usage. A recent exposure survey in Victoria indicated that wearing rates were 97% for the driver position, slightly lower for the front left passenger and 85% for rear occupants (ARUP, 1995).

1.2 The development of a frontal protection standard for Australia

In 1989, the Australian Government commissioned a comprehensive research program in collaboration with the Monash University Accident Research Centre (MUARC) to determine the need and feasibility of introducing further vehicle-based regulations in order to reduce the number of fatalities and injury outcomes of frontal vehicle crashes. The research program was broadly comprised (based on published reports) of three stages and a brief description of each stage follows:

- Stage 1: MUARC crashed vehicle study (Fildes, Lane, Lenard & Vulcan, 1991)
- Stage 2: Standards Development program (Seyer, 1992, 1993; Seyer et al., 1992) involving crash testing seven Australian passenger cars, computer simulations and laboratory tests of components and their combinations, and
- Stage 3: Examination of the cost-effectiveness and feasibility of improved occupant protection devices (MUARC, 1992).

1.2.1 Stage 1: MUARC Crashed Vehicle Study

MUARC was commissioned in 1989 to undertake a comprehensive review of the current status of occupant protection in Australia with the brief to examine overseas developments in occupant protection (Fildes et al., 1991). MUARC consulted the international literature with the aim understanding mechanisms of injury, but also to detail global developments in occupant protection strategies. This process was undertaken to guide the development of a future occupant protection standard.

The review of the international literature was supported by the analysis of 7.5 years of mass crash casualty data from the Transport Accident Commission (TAC) Claims Database. The analysis examined the characteristics of crashes involving post-1981 passenger cars that occurred across Victoria from January 1982 to June 1988. Importantly, the TAC Claims Database was merged with the Victoria Police reported crash data supplied by VicRoads, with a 67% match between the two datasets achieved. The purpose of the analysis of the merged mass dataset was to provide a comprehensive picture of injury outcomes across all crash types and provide future directions for occupant protection strategies. The analysis of the mass data indicated that frontal crashes accounted for 47% (7876) of TAC Claimants, followed by occupants involved in side impact crashes (25%, n=4164), rear end crashes (23%, n=3999), and rollover crashes (5%, n=878). A further finding was that 64% of claimants were drivers, followed by front left passengers (24%), rear occupants (12.5%), and front-centre occupants (0.5%). With respect to injury outcomes, head, chest and lower extremity injuries were the most common injuries sustained in frontal crashes, while for side impact crashes major chest injuries were of most concern. On the basis of these mass data results, MUARC suggested that future occupant protection strategies be focussed on frontal crashes but noted that side impact crashes should also receive priority attention.

The final phase of the MUARC project was to conduct in-depth investigations of real-world crashes so as to provide causal information on injury contact sources, and to determine the overall crashworthiness of the vehicles involved. For consistency with the analysis of the mass casualty crash data, only post-1981 passenger cars and derivatives were included in the analysis. The study considered crashes occurring between 1st April 1999 and 31st August 1990 in metropolitan and rural Victoria. The injury outcomes of 269 hospitalised occupants, resulting from 227 real-world crashes (69% metropolitan), were examined with frontal crashes accounting for 60% of the study population, followed by side impact crashes (35%), and a smaller number of patients injured due to rollover crashes (5%). The proportion of injured occupants by seating position approximated the mass data analysis, with drivers representing 60% (n=167) of injured occupants in the sample, followed by front left passengers (25%), and rear occupants (13%). The description of injuries sustained by front seat occupants involved in frontal crashes was as follows (Fildes et al., 1991:117):

> ‘Front seat occupants sustained considerable numbers of body injuries (including both minor and serious injury) to their heads, chests, abdomens, and lower extremities from contacts with the steering wheel, seat belts, instrument panels, and windscreen and header. Occupants not wearing seatbelts sustained more head, face and upper extremity injuries and more contacts with the windscreen and header, and exterior objects.’

Fildes et al. (1991) reported agreement with injury contact sources noted in the international literature and showed that the sample of in-depth crashes reflected the overall pattern of crash types in the mass data analysis. A smaller number of side impact and rollover crashes were reported, however the analysis was preliminary in nature due to the focus being on injuries sustained in frontal crashes. With respect to the relative importance of crash types in setting priorities for vehicle countermeasures, the authors commented that…

> ‘…the overwhelming abundance of frontal collisions in vehicle crashes demands that they receive primary focus in improving vehicle occupant protection. Moreover, given the predominance of vehicles containing a driver and / or front passenger, these occupants also deserve special consideration.’ (Fildes et al., 1991:138).

In the analysis of frontal crashes, Fildes et al. (1991) noted ‘considerable’ intrusion into the front occupant space and this included intrusion of the toe pan and front floor, instrument panels, steering assemblies, side panels, and console. It was also noted that major structural failures by way of intrusion and deformations occurred, particularly of the roof and pillars. With respect to the performance of the steering column, Fildes et al. (1991) reported that ‘longitudinal movements generally performed up to ADR 10/01 requirements[3], although there were a sizeable number of upward and sideways movements of the column, not presently covered by this ADR [10]' (Fildes et al., 1991:140). By way of explanation, ADR 10, Steering Column, was designed to minimise crushing or penetrating injuries to drivers due to contact with the steering column as a result of frontal impact. ADR 10 was the first ADR directed specifically to injury mitigation in the event of frontal crashes. The regulation aimed to minimise crushing or penetrating injuries due to the collapse and deformation of the steering column. The necessity to comply with the requirements of ADR 10 was superseded by vehicles meeting the requirements of ADR 69, where a steering column mounted supplementary restraint system was fitted (see footnote 3 for greater detail).

In tying together the findings of the international literature review, the mass data injury analysis and the detailed in-depth study of occupant injury, Fildes et al. (1991) recommended a number of occupant protection countermeasure options, many of which were focussed on reducing the observed high frequency of severe head, chest and lower extremity injuries in frontal crashes. As part of the research program, MUARC (1992) examined the feasibility and cost-benefit of implementing a range of occupant protection countermeasures designed to reduce the risk and severity of injury in the event of crashes, the extent of which was highlighted by the analysis of mass data and detailed examination of in-depth cases (Fildes et al., 1991). The countermeasures suggested by MUARC (1992) to combat the high frequency of injuries seen in the analysis of real world data were categorised into five broad categories, and covered steering assemblies, improved restraint systems, modifications to the instrument panel, structural improvements such as modification of the toe pan and instrument panel, and finally windscreens and associated surfaces. Two key occupant protection countermeasures were the proposed introduction of frontal airbag systems, acting as a supplementary restraint given high seat belt wearing rates, and the introduction of a barrier performance based frontal crash test standard potentially based on US Federal Motor Vehicle Safety Standard (FMVSS) 208, Occupant Crash Protection (MUARC, 1992). The earlier reports (Fildes et al., 1991; MUARC, 1992) also highlighted the need for a frontal offset test, which on having been demonstrated to be cost-effective (Fildes,

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3 The intent of ADR 10 was to minimise crushing or penetrating injuries to drivers from impacts with the steering wheel in frontal crashes by collapsing (axially) or deforming on contact (to align with the chest/abdomen to spread the load across the contact area) and hence absorb energy otherwise absorbed by the driver (Cameron, 1979; DoTARS, 2004). ADR 10 sought to limit column intrusion and specify a degree of energy attenuation by the assembly. ADR 10 was effective for passenger cars and derivatives manufactured on and after 1 January 1971 (known as ADR 10A). ADR 10 was modified such that a test of rearward displacement was added, effective for passenger cars and derivatives manufactured on and after 1 January 1973 to protect the restrained occupant from contact with the steering wheel (known as ADR 10B). Compliance with ADR 10 was determined by testing the performance of the steering column by using a body block '…moving at a speed of not less than 6.7 m/s…that at no time shall the load exerted on the body block by the 'Steering Column' assembly which is actuated by the driver exceed 11.1 kN, except for intervals whose cumulative duration is not more than 3 milliseconds' (ADR10/01) (DoTARS, 2004). A number of alternative standards and test procedures were permitted. Later Determinations ensured that vehicles are exempt from the requirements of ADR 10 by meeting the requirements of ADR 69/… (Determination 4 of 1992) by using a steering column mounted supplementary restraint system, or where a vehicle 'meets the requirements of ADR 73/… (Determination 1 of 1998 issue) where a supplementary restraint system is available for both frontal outboard positions (DoTARS, 2004).

Lane, Lenard, Gantzer, Vulcan & Wenzel, 1994; Fildes, Digges, Dyte, Gantzer & Seyer, 1996) was later implemented as ADR 73 (DoTARS, 2004).

1.2.2 Stage 2: Standards Development Program

The research conducted by MUARC (Fildes et al., 1991; MUARC, 1992) provided further impetus and direction for the Australian Government to explore possibilities for improved occupant protection by demonstrating that significant reductions in injury risk and cost could be made by implementing a number of countermeasure options. The adoption of a performance-based frontal impact protection standard, similar to the US FMVSS 208 Occupant Protection Standard, was a major consideration. The Federal Office of Road Safety embarked on a AUD$1 million standards development program that ultimately culminated in the development and implementation of ADR 69, Full Frontal Impact Occupant Protection (Seyer, 1993). Australian Design Rule 69 – Full Frontal Impact Occupant Protection, was introduced in a 4-year phased-in program from 1 July 1995.

The Standards Development Program (Stage 2) consisted of three distinct phases, each of which is described briefly below (see Seyer, 1993; Seyer et al., 1992).

Phase 1 - Seven locally produced (Australian) passenger cars were subjected to crash tests, with one model selected for modification and further testing. The purpose of the crash tests was to provide baseline data of injury risk, benchmarked against the US FMVSS 208 standard. Tests were conducted in accordance with the procedures of FMVSS 208 using Hybrid III dummies and conducted at 48 km/h.

Test results indicated that the main performance differences between the vehicles were in the recorded Head Injury Criterion (HIC) values. The observed HIC values were higher for the driver (HIC_{36} median: 820; HIC_{36} range: 622-1012; Limit: 1000) in all but one case, where significant head contact with the instrument panel was observed for the front left passenger (HIC_{36} median: 611; HIC_{36} range: 322-872; Limit: 1000); notably the head of the front left passenger contacted the instrument panel in four of the seven vehicles tested. The principal head contact points for the driver were the steering wheel or the instrument panel. With respect to the chest, deceleration was higher for the driver (Median: 47.7g; Range: 46.7-59.4g; Limit: 60g) than for the front left passenger (Median: 46.2g; Range: 41.1-50.8g; Limit: 60g), and driver chest contact with the steering wheel was observed in all seven cases. Similarly, chest deflection was greater for the driver (Median: 41.9 mm; Range: 36.6-49.0 mm; Limit: 76.2 mm) compared to the front left passenger in all but one case (Median: 33.1 mm; Range: 29.2-39.1 mm; Limit: 76.2 mm). Passengers did however record lower femur loadings (Median: 1.51 kN; Range: 0.91-3.10 kN; Limit: 10 kN) in all cases compared to drivers (Median: 2.82 kN; Range: 1.03-15.40 kN; Limit: 10 kN).

On the basis of the Phase 1 results, it was concluded that '…while there were some injury levels near the threshold of a possible significant injury, none of the vehicles produced dummy responses which were considered life-threatening'. Following this, a single high volume selling small vehicle was selected for restraint optimisation and further testing (Seyer et al., 1992: 14). In the Phase 1 tests, five of the seven vehicles tested met all injury criteria. There was one case where a driver dummy left femur load exceeded the threshold 10 kN, while another driver dummy marginally exceeded the HIC_{36} 1000 limit.

Phase 2 - This phase involved the analysis of the Phase 1 crash tests and the optimisation of advanced restraint technologies by Autoliv in Germany. The components used in the optimisation process for the selected vehicle were airbags, buckle pretensioners, webbing clamps and energy absorbing steering wheels, and three combinations of these optimised technologies. These countermeasure options were selected as they were seen to be highly cost effective and likely to have considerable influence in reducing injury risk (MUARC, 1992; Seyer et al., 1992).

Phase 3 - Following the development and optimisation of the three combinations of enhanced safety systems, three vehicles of the same vehicle model were crash-tested to determine improvements in occupant protection performance. As with Phase 1, tests were conducted in accordance with the procedures of FMVSS 208 using Hybrid III dummies and conducted at 48 km/h. The three combinations of advanced restraint systems were based on (Seyer, 1993):

1. Energy absorbing steering wheel PLUS buckle pretensioners PLUS webbing clamps
2. Standard restraint system PLUS driver airbag
3. Driver airbag PLUS buckle pretensioners PLUS webbing clamps

The results of phase 3 demonstrated that significant gains could be achieved by fitting optimised combinations of safety systems. Importantly though, further laboratory testing demonstrated that fitting various components in a non-optimised manner to a vehicle may offer little benefit, and in some cases proved counterproductive, highlighting the importance of specific optimisation.

Further issues of note stemming from Stage 2, Standards Development Program

1. The debate of the HIC measurement interval: HIC_{36} vs. HIC_{15}

Seyer (1993) observed that HIC_{15} was being argued by manufacturers to be a more appropriate measure of HIC, particularly with the emerging use of Hybrid III crash test dummies. Debate stemmed from high non-contact HIC_{36} values being recorded, it was believed, due to the ‘whipping’ motion of the improved biofidelity of the Hybrid III dummy neck compared to the Hybrid II dummy. In the early 1990’s, US manufacturers petitioned NHTSA to use a 15 ms integration period to calculate HIC when Hybrid III dummies were used. Seyer (1993) noted that the argument that the shorter integration period did not alter the HIC value when hard contact is made, but gave a more representative HIC, or accurate assessment of injury risk, when no head contact occurred in long duration pulses (Seyer, 1993: 6). Indeed, Prasad and Mertz (1985) reported that there were increased neck loads and hence increased risk of neck injury in the long pulse duration where no head contact was evident, and recommended, though did not specify, a limit on neck loads when the head of the 3-point belt restrained occupant does not contact the forward interior components in crash tests.

The Phase 1 test results presented both HIC_{36} and HIC_{15} and it was found that for cases where there was no head contact, HIC_{15} values were 42%-55% lower than HIC_{36} values (Seyer, 1993). This relationship was later shown to approximate $HIC_{15}=0.7*HIC_{36}$ using US NCAP test results (Eppinger, Sun, Bandak et al., 1999). Previously, Transport Canada had suggested an 80g limit on resultant head deceleration rather than HIC to overcome high HIC_{36} values in non-head contact situations; this was later adopted as a requirement in vehicles not equipped with airbags under Canadian Motor Vehicle Safety Regulations Standard 208. In support of this proposal, Seyer (1993) reported that head deceleration figures in the Phase 1 tests were similar when taken over pure maxima (g max, no time interval) or using a 3 ms clip, and stated that … 'specifying a head deceleration limit could be one way of addressing the non-head contact HIC' (p.110). In cases of head strikes, HIC_{15} values were the same or up to 30% lower than HIC_{36} values, while head decelerations using the 3 ms clip ranged from 10-59% different to those measured over corresponding maximum decelerations. Seyer (1993) concluded that the comparison of HIC_{36} and HIC_{15} values provided an indication of the severity of the head strike, while no such correlation was evident when decelerations were calculated using either a 3 ms clip or maxima.

The comments by Seyer (1993) with respect to HIC_{15} were extremely pertinent in the context of future rulemaking. Indeed, ADR 69/00 was modified by Determination No.2 of 1995 to specify that either HIC_{15}700 or a neck injury tolerance be met in instances of non-contact head acceleration pulses (DoTARS, 2004). In 2000, NHTSA adopted a HIC_{15} value not exceeding 700 under FMVSS 208 as part of the 'Advanced Airbag Regulation', with the regulation meeting a mandated phase-in schedule (NHTSA, 2000). Using data presented by Mertz, Prasad and Irwin (1987), a HIC_{15} of 700 is estimated to represent a 5% risk of an AIS 4+ injury, while risk values for skull fracture (AIS 2+) reported by Hertz (1993) using logistic regression for HIC_{36}1000 was 47% and for HIC_{15}700 was 31% (Eppinger et al., 1999; Kleinberger, Sun, Eppinger et al., 1998). NHTSA was able to change the HIC measurement interval from 36 ms to 15 ms and the reduction in the HIC value from 1000 to 700 due to the development and use of Nij to set a neck injury tolerance. In doing so, NHTSA has made the HIC tolerance level more stringent for short duration pulses where head injuries, such as skull fracture, have been observed to occur, thus providing a better fit to the underlying biomechanical data (Eppinger et al., 1999). Following the work of Hertz (1993) and the interpretation of Eppinger et al. (1999) and Kleinberger et al. (1998), the change from HIC_{36}1000 to HIC_{15}700 sets the 'accepted' risk of skull fracture 34% lower than previously, however this applies only for short duration pulses with hard head contact. The longer duration HIC_{36}1000 essentially acted as a surrogate for neck injury risk as well as its primary function as measuring head injury risk, and was deemed no longer required due to mandating the neck injury risk parameter Nij which sets the tolerance for neck injury risk. With respect to NHTSA FMVSS 208, HIC_{15}700 applies to the 50th percentile male dummy, the 5th percentile female dummy and 6 year old dummies, while scaled values of HIC_{15}570 apply to the 3-year-old and HIC_{15}390 to the 12-month infant (CRABI) dummy scaled from the mid-sized male (NHTSA, 2000).

In the context of this debate, this report will seek to examine head injury risk for drivers of post-ADR 69 passenger cars compared to those manufactured prior to the introduction of ADR 69, i.e., pre-July 1995.

Risk of lower extremity fractures

Analysis of mass injury data and detailed examination of in-depth crashes indicated that lower extremity injuries were common in frontal crashes (Fildes et al., 1991). Indeed, further analysis by MUARC demonstrated the most common severe lower limb injuries were fractures with floor and toe-pan intrusion, the instrument panel and steering column being the most common contact sources. Axial loading of the thigh and lower leg, loading of the knee and crushing or extreme inversion / eversion / dorsiflexion of the foot and ankle were found to be the most common injury mechanisms (Fildes, Lane, Lenard, Gantzer, Vulcan & Wenzel, 1994).

It must be noted that assessing the risk of lower extremity injuries has proved a challenge from the outset in crash test programs due to difficulties associated with instrumentation of the Hybrid III lower leg (NHTSA, 2005). This section briefly examines this issue as it is of direct relevance to the evaluation of ADR 69 lower extremity injury risk.

In the conduct of the Standards Development Program, Seyer (1993) reported that femur loads in the Phase 1 tests (recorded by a single axis load transducer) were low due to intrusion into the cabin causing articulation of the dummy knee joint. The tolerance value tested was a femur axial load not exceeding 10 kN, representing a 35% risk of an AIS 2+ injury (Mertz et al., 1989 cited in Eppinger et al., 1999).

At the time, Seyer (1993) argued that improved instrumentation of the dummy lower leg combined with the development of lower leg injury risk indices could result in an improved understanding of lower extremity injury risk and drive future reductions in injury risk. Seyer (1993) noted that while lower leg risk indices were not mandated by current vehicle regulations, the frontal offset crash test procedure under consideration (at that time) by the European Experimental Vehicles Committee (EEVC) Working Group (WG-11) would include a lower limb injury criteria, and argued that such criteria be adopted for full frontal tests if proved of value through standards development work.

Australia adopted the provisions of UN ECE Regulation No. 94 as ADR 73, Offset Frontal Impact Occupant Protection; this regulation was mandated to apply from 1 January 2000 to all new passenger car vehicle models (Class MA) and extended to all passenger cars by 1 January 2004 with a GVM of less than 2.5 tonnes. The goal of the offset frontal regulation was to 'improve the level of protection…where only part of the front structure of the car is engaged in the crash' (Clth Aust, 1998: ii). The offset test involves a 56 km/h offset impact with a deformable barrier with 40% +/-20 mm overlap.

The offset regulation paid particular attention to the lower extremity, and includes the Tibia Compression Force criterion (TCFC) (not > 8 kN) and the Tibia Index (TI). The TI was originally developed by Mertz (1993 cited in Eppinger et al., 1999) and modified by Hobbs (1997 cited in Eppinger et al., 1999) for use by the EEVC, and is measured at proximal/distal ends of the tibia with injury assessment values not exceeding 1.3 at either location. The offset regulation also mandated that the movement of the sliding knee joint not exceed 15 mm (peak displacement), and also adopted a stricter axial Femur Force Criterion than ADR 69 (not greater than 9.07 kN @ 0 ms, and not greater than 7.58 kN @ 10 ms) (DoTARS, 2004). Using the same measures, EuroNCAP also assesses lower extremity injury risk in a 64 km/h offset frontal test for the Hybrid III 50th percentile male. EuroNCAP also tests the TNO P1½ child dummy and a TNO P3 dummy in suitable Child Restraint Systems, although the child dummies are not assessed on lower extremity criteria (EuroNCAP, 2004a; 2004b).

With respect to the United States, considerable long-term effort on the part of NHTSA has been made on assessing the value or of including an offset frontal test and lower leg injury risk measurement as part of the FMVSS 208 Occupant

Protection Standard. Notably, the Insurance Institute for Highway Safety (IIHS, cited in NHTSA, 1997: 7-8) has been testing US vehicles under the EU offset test protocol at 64 km/h since 1994, and argues that the full frontal test allows for '…the safety of the combination of the structure, belt and airbag [to] be evaluated…' and is especially demanding on restraint systems, while the offset test is especially demanding on structure and most useful in assessing intrusion, making it a better test of lower leg injury risk.

In the context of lower extremity injury risk, it is interesting to note that NHTSA (1997: 2) state:

> The FMVSS No. 208 Standard is most effective in preventing head, femur and chest injuries and fatalities. However it does not directly address lower limb and neck injuries.

In 1997, NHTSA stated that the addition of a frontal offset test as a supplement to the FMVSS 208 was under consideration if '…the benefits to lower limb injuries are demonstrated and proven to be cost-effective. The following year, NHTSA (1998) proposed the inclusion of an offset frontal test for the belted 5th percentile female (in the full-forward seat position) only, however NHTSA did not include lower leg criteria in any test procedure. In the Supplementary Notice of Proposed Rulemaking (SNPRM) (NHTSA, 1999), considerable discussion was given to the possibility of an unbelted offset deformable barrier crash test in the order of 48-56 km/h as a means of producing benefits related to injury from intrusion, and two alternative testing regimes were noted: Alternative One involved including an offset test for the belted 5th percentile female only; Alternative Two involved an offset test for the belted 50th percentile male and the belted and unbelted 5th percentile female. The key points raised in the SNPRM concerning the offset test was the need for the development and selection of appropriate injury indices as well as the need for significant development work to appropriately instrument the Hybrid III lower leg for the 5th percentile female and the 50th percentile male. On this point, Eppinger et al. (1999: 5-3) noted that '…the response of the Hybrid III leg is different than that of a human under similar impact conditions', with concern being expressed of the value of the TI and TCFC. The Final Rule for FMVSS 208 (NHTSA, 2000) included a 40 km/h offset test for the belted 5th percentile female only, with no specification of lower leg injury criteria.

Ongoing concern regarding lower leg injuries led NHTSA to call for public comment concerning the appropriate instrumentation of the 50th percentile male and the 5th percentile female Hybrid III dummies for use in both full and offset frontal crash tests (NHTSA, 2002). Following a crash test program to assess the value of including a high speed offset test requirement, NHTSA was concerned about increases in vehicle aggressivity by manufacturers increasing stiffness so as to perform better in high-speed offset frontal crash tests, particularly with respect to SUVs, and called for public comment on the way forward (NHTSA, 2003). Following receipt of public comments and further crash testing, NHTSA withdrew the rulemaking to amend FMVSS 208 to include a high speed offset frontal test, principally due to concern for adverse effects on collision partner occupants and concern for increasing fleet incompatibility (NHTSA, 2005). NHTSA also withdrew the related rulemaking concerning instrumentation of the lower leg for use in test protocols until further refinement of fleet benefit estimates can be obtained. Importantly though, while no specifications exist for either a high speed offset frontal test or lower leg injury risk measurement at present in the US, NHTSA (NHTSA, 2005: 49254) remain committed to these additions to FMVSS 208 stating that:

> …we believe that a fixed offset deformable barrier crash test, with applicability limited to a segment of the vehicle fleet (i.e., passenger cars) and in the range of 56-60 km/h using advanced dummy instrumented legs, would provide the best opportunity to reduce lower extremity injuries without exacerbating vehicle incompatibility.

In the final rulemaking process for the revised FMVSS 208 protocol to commence ‘phase-in’ for MY2007, NHTSA reaffirmed the Femur Force Criterion tolerance value of 10 kN for the 50th percentile Hybrid III male and stipulated a tolerance value of 6.8 kN for the 5th percentile Hybrid III. Notably, the Alliance of Automobile Manufacturers (AAM) suggested slightly lower axial force values in response to the SNPRM (NHTSA, 1999), however NHTSA (2000: 30718) stated:

> …the slightly higher axial force limits we are applying today may provide design flexibility for manufacturers to optimise head, neck and chest protection for the 50th percentile male and the 5th percentile female. Of course, vehicle manufacturers are free to voluntarily meet more stringent force limits than those included in the Standard No. 208.

Evidently, considerable controversy exists concerning the measurement of lower extremity loading with differing perspectives on measurement between the US and the UNECE R94 / ADR 73 regulations, and the trade-off to other body regions in countermeasure design. Notably, lower leg injury criteria (TI; TCFC) have yet to be applied to ADR 69 (as at November 2005) however it is critical to note that the Amendments to ADR 69 by Determination No. 2 of 1998 (DOTARS, 2004: ii) rules that:

> …accept that vehicles complying with the new ADR 73 Offset Frontal Impact Protection, can be deemed to comply to this rule (ADR 69) provided they are fitted with dual airbags and the manufacturer can demonstrate by other means that the vehicles would comply with ADR 69.

It remains important, therefore, to quantify the lower extremity injury risk to drivers of pre-ADR 69 and post-ADR 69 vehicles, as from 2004 all new vehicles in Australia are tested using the offset frontal test. In doing so, this analysis may highlight the need or otherwise of the adoption of either a stricter femur axial load tolerance threshold or the addition of lower leg injury criteria for the full frontal test, and will also permit an examination of the effectiveness of the lower extremity measures some time in the future. Further discussion of the role of ADR 73 is presented in Section 1.3 and the Discussion of this report.

1.2.3 Stage 3: The Cost-effectiveness & Feasibility of Occupant Protection Devices

Following the initial MUARC report (Fildes et al., 1991) and the Standards Development Program (Seyer et al., 1992; Seyer, 1993), MUARC was commissioned to examine the economic benefits of 16 frontal crash protection countermeasures identified and tested in the earlier stages of the research program, as well as three combinations, or ‘packages’, of measures to provide direction for a potential frontal impact regulatory standard (MUARC, 1992). Estimations of the injury reduction effectiveness of the devices were either based on published literature, or in the absence of such information the consensus of an expert panel.

In order to determine the total cost of introduction, industry input was sought in order to elucidate any potential barriers and difficulties associated with the introduction of the suggested countermeasures, while approximate costs of devices and necessary structural modifications were obtained from local and international manufacturers and specialist part suppliers.

The Benefit-Cost analysis indicated positive values for the widespread fitting of frontal airbags acting as supplementary restraint systems, seat-belt webbing clamps and seat-belt pretensioners. Individual countermeasures regarded as 'highly beneficial' (BCR>3) were energy absorbing padded steering wheel (3.2-16:1; 1.9% total cost injury saved), improved belt and seat geometry (7.3:1; 1.7%), and knee bolsters (2.9-4.3:1; 5.3%). Other countermeasures with positive BCRs were the fitting of seat-belt webbing clamps (1.1-3.5:1; 1.2%), improved lower panels (1.6-18:1; 2.6%) and full-size driver airbag (1.2:1, 14%) while seatbelt pretensioners fitted were marginal (0.8-1.1; 2.7%). BCR estimates for measures to mitigate harm resulting from floor / toepan intrusion and steering column intrusion were unable to be calculated despite these intrusions having a per unit societal harm estimate of AUD$151 (the highest) and AUD$62 respectively; MUARC (1992) noted that both remain areas of priority as the potential reduction in harm was AUD$200 million per annum, equating to a 6% cost saving in vehicle occupant trauma. The analysis indicated fitting front full-size passenger airbags would not be cost-beneficial despite holding an overall 2.4% reduction in total cost of injury. A number of individual countermeasures were shown to have negative BCRs, such as improved interior padding and certain airbag configurations.

The feasibility study also explored the BCR of fitting a highly visible and audible seatbelt warning device, reporting BCRs ranging from 4.1–7.2 depending on the complexity and effectiveness (up to a 40% increase in restraint use) of the device. The cost saving associated with a seatbelt warning device was estimated to be 1.9% of the total cost of trauma. The report is careful to note that the reported BCR is for all crash types, and that the benefits of such a device, hence BCR, would require shifting downward if other devices mitigated seatbelt effectiveness, such as airbags. Recently, the matter of seat belt warning devices has again become of interest, largely due to moves by EuroNCAP to award up to three additional points to vehicle models in the calculation of the NCAP score (although not a requirement for NCAP assessment), depending upon the number of seats to which the device applies (EuroNCAP, 2005). The ATSB recently commissioned MUARC to estimate the value of mandating seatbelt warning devices to all new vehicle models and the feasibility of retrofitting seatbelt warning devices to inform the ADR Review Process (Fildes, Fitzharris, Koppel et al., 2002; Fildes, Fitzharris, Vulcan et al., 2003).

The combinations of countermeasures packages used in the Stage 2 Standards Program (Phase 3) were seen to return BCRs ranging from 1.2-3.4 depending on the countermeasure combination package considered. In cost reduction terms, the societal cost-saving ranged from a 17-25% depending on the countermeasure package. Fitting a driver airbag, either full-size or facebag, in combination with other countermeasures, resulted in the best injury savings. The best combination of countermeasures with respect to total cost of injury saved (25% of total injury cost saved; BCR 1.4-1.6:1) was the fitting of a fullsize driver airbag in combination with an energy absorbing steering wheel, a front left passenger seat attached belt pretensioner, a front passenger inertia wheel attached webbing clamp, improved belt / seat geometry, and knee bolsters across the full lower dash. BCRs were calculated using the equilibrium method, where it is assumed that the entire vehicle fleet is fitted with a particular countermeasure, or group of countermeasures. Seyer et al. (1992) stated that with the age profile of the Australian vehicle fleet, penetration of countermeasures to the whole vehicle fleet may take over 10 years.

Finally, the potential benefits of Australia adopting requirements based on US FMVSS 208 were considered. It was not possible to provide cost estimates for the entire vehicle fleet due to unknown modifications required by manufacturers to meet test requirements. It was noted by the Federal Chamber of Automotive Industries (FCAI) that manufacturers would require a three year minimum lead-time to meet FMVSS 208 requirements, and suggested a 48 months minimum lead-time for driver airbags and a 60 month lead time for passenger airbags (MUARC, 1992).

1.3 Introduction of Australia's frontal protection standard

The research program summarised in Section 1.2 demonstrated the frequency and severity of injuries occurring in frontal crashes, as well as the potential worth of a range of countermeasures with the principal goal of mitigating injuries resulting from frontal collisions.

Seyer et al. (1992) noted the distinction between components versus performance certification, and stated that while vehicles meet an extensive array of existing design rules based on individual components, such as seat belts and anchorage strength, occupants of vehicles continued to be seriously injured in frontal impact crashes. The Standards Development Program demonstrated the value of optimising individual components into a single system, tailored for each vehicle model. The recommendation was to shift from component specification to a system performance-based requirement, where the 'vehicle manufacturer is clearly accountable for the performance of the vehicle safety system as a whole' (Seyer et al., 1992: 43).

Seyer et al. (1992: 45) concluded that the research program confirmed that the implementation of an Australian Design Rule based on US FMVSS 208 would 'bring about the fitment of a range of cost effective emerging safety technology including airbags and would lead to significant improvements in occupant protection'. Australia's superior seatbelt wearing rates compared to the United States resulted in adapting US FMVSS 208 to ensure test dummies were tested with seat belts fastened.

As a consequence of the research program, and the perceived need to improve Australian vehicle safety standards with the fundamental long term view of reducing the road toll, Australian Design Rule No. 69/00 (ADR 69/00), Full Frontal Impact Occupant Protection, was introduced under Section 7 of the Motor Vehicle Standard Acts 1989 (Clth.).

The function and scope of ADR 69/00 (i) is to:

> '…specify vehicle crashworthiness requirements in terms of forces and accelerations measured on anthropomorphic dummies in outboard front seating positions in full fontal crashes so as to minimise the likelihood of injury to occupants of those seating positions' (DoTARS, 2004).

The specifications of ADR 69/00, as per that published in the Commonwealth of Australia Gazette No. GN 50 of 16 December 1992, were to be met according to a phased-in schedule, defined as follows:

- from 1 July 1995, all new model MA vehicles (Passenger car)
- from 1 January 1996, all MA vehicles
- from 1 January 1998, all new model MB (forward control passenger vehicle) and MC vehicles (off-road passenger vehicles)
- from 1 July 1998, all new model NA1 vehicles (Light goods vehicle)
- from 1 January 2000, all MB and MC vehicles
- from 1 July 2000, all NA1 vehicles.

Vehicles are classified as a ‘new model’ based on the ‘Date of Manufacture’ that the model is introduced. For example, for passenger car vehicles, the rule is binding for all new model passenger cars from 1 July 1995. All passenger cars, introduced as a ‘new model’ or an existing model, must meet the performance specifications from 1 January 1996.

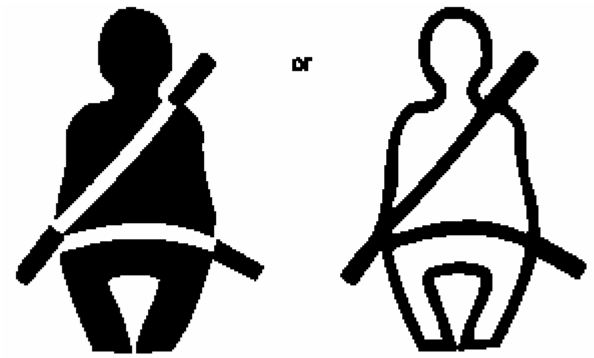
The performance specifications to be met are presented in Table 3.

Table 3: ADR 69 Full Frontal Impact Occupant Protection Criteria

Test parameter	Criteria
Impact velocity	48 km/h (30 mph)
BARRIER	Fixed collision barrier perpendicular to the line of travel, conforming to SAE document J850, ‘Barrier Collision Test’, February 1963.
Test dummy: Driver & front left passenger	Until 1 January 1998, either Hybrid II or Hybrid III, restrained by seatbelt From 1 January 1998, Hybrid III; Restrained by seatbelt
Injury criteria	
Head	Head Injury Criterion not to exceed 1000 over 36 ms ($HIC_{36}1000$) Following Determination No 2 of 1995, where no head contact has been made aside from with the seatbelt or femur/knee, head injury criteria is met by meeting either: For the Hybrid II dummy: resultant acceleration measured at the centre of gravity is not to exceed 75g, except for intervals whose cumulative distribution is not more than 3 ms, or For the Hybrid III dummy: the neck injury measurements shall not exceed 3300 N of tension force in the inferior-superior direction, or For the Hybrid III dummy: HIC is not to exceed 700 over 15 ms ($HIC_{15}700$).
Thorax	Chest deceleration measured by accelerometers in the dummy’s chest must not exceed the limit of 60g, except for values whose cumulative duration is not more than 3 ms
Sternum	Compression deflection of the sternum relative to the spine must not exceed 76.2 mm (Hybrid III only)
Femur	Axial force through each femur not to exceed 10 kN
Other vehicle requirements	
Seat belt	A continuous or flashing ‘Visual Indicator’ for a period of not less than 4

warning system	seconds when the ignition switch is moved to ‘on’/’start’ position
	The warning system is not required to operate when either:
	the restraint is fastened, or
	the restraint is withdrawn more than 10 cm from the retractor
	The words ‘Fasten Seatbelts’ or ‘Fasten Belts’ used or the symbol in Figure 1
	A seat belt warning device complying with US FMVSS 208 meets the requirement

Figure 1: Seat belt warning system telltale, S.5.5.2 ADR 69/00



At the time of the original research program the EEVC were exploring the feasibility of implementing a frontal offset impact test. Following the adoption of a frontal offset test by the EEVC as United Nations Economic Commission for Europe Regulation 94/01 (UNECE R 94/01), the Australian Government adopted the test procedures that were to be known as ADR 73/00, Offset Frontal Impact Occupant Protection, with the specific intent of minimising injuries as a consequence of offset frontal impacts. ADR 73 was binding for all new model MA vehicles less than 2.5 tonnes (passenger cars) from 1 January 2000 and all MA vehicles from 1 January 2004 less than 2.5 tonnes. The determination of ADR 73 was published in the Commonwealth Of Australia Gazette No P 18 of 20 July 1998. Adoption of UNECE R 94/01 as ADR 73/00 represented a significant step in the harmonisation of vehicle safety standards in accordance with the UNECE 1958 Agreement concerning the Adoption of Technical Prescriptions for Wheeled Vehicles.

Of direct relevance to ADR 69 was Determination No. 2 of 1998, which stated that vehicles complying with the requirements of ADR 73 may be deemed to comply with ADR 69 provided that the vehicles are fitted with dual airbags and the manufacturer can demonstrate by other allowable methods that the vehicle complies with the requirements of ADR 69.

The performance requirements of ADR 73 are different in some respects to that of ADR 69, quite aside from the difference in the degree of overlap with the barrier (40% with deformable barrier compared to complete overlap with non-deformable barrier). ADR 73 uses different head injury criteria (HIC_{36}1000 and acceleration not > 80g for more than 3 ms; HIC not applicable when no head contact), neck injury risk criteria (neck tension, neck shear, neck bending moment), thorax risk criteria (Thorax Compression Criterion & Viscous Criterion), a different force by time femur criterion and lower maximum value (9.07 kN), lower leg indices (Tibia Compression Force Criterion and the Tibia Index), restriction on the extent of knee joint movement (15 mm), and finally, limits on upwards vertical and rearward horizontal direction movement of the steering wheel.

The analysis presented in this report includes vehicles manufactured up to and including 2000. It will be important then to determine whether any of the vehicles included in the evaluation are new models since 1 January 2000 and hence compliant with ADR 73.

1.4 Previous research by MUARC

MUARC was commissioned by the Federal Office of Road Safety (FORS) to conduct a case-control study during 1995 to evaluate the impact of ADR 69 on passenger car safety. Research examining the effectiveness of ADR 69 was reported recently for the ATSB [Morris, Barnes, Fildes et al., 2001]. Briefly, the report found reductions in head, face, neck and chest injuries among occupants of airbag-deployed vehicles. In addition, using the HARM method, the mean HARM per driver was 60% higher in non-airbag vehicles compared to airbag equipped and deployed vehicles. While the findings of the report were extremely positive, the level of statistical control exercised to account for differences in crash and occupant characteristics between the airbag and non-airbag group was limited. Furthermore, the report by Morris et al. (2001) is more appropriately considered an evaluation of the performance of frontal airbags, as no distinction was drawn between vehicles based on year of manufacture.

MUARC was recently commissioned to conduct an examination of the potential worth of mandating the fitment of a more aggressive seatbelt reminder system than the one specified by ADR 69. This concern was driven by the observation that a large proportion of seriously injured and fatally injured crash-involved occupants were unrestrained, and the apparent plateau in seat belt usage rates with no observed improvement since the introduction of ADR 69 (Fildes et al., 2002; Fildes et al., 2003). Fildes et al. (2002) argued that in most current model cars the warning system is generally easy to ignore or deactivate, and that mandating a seat belt reminder system similar to that specified by EuroNCAP (2005) with both an audible and visual warning with intensity linked to vehicle speed would be highly desirable and cost effective. The system mandated by ADR 69 was a less demanding system than what MUARC (1992) originally had specified when calculating the BCR for this device, largely due to concerns of the safety of other roadusers and that of the non-compliant driver; the system called for a reminder system that would cause the hazard lights of the vehicle to continually flash thereby potentially embarrassing front seat occupants who failed to wear their seat belts. The reader is referred to Fildes et al. (2002; 2003) for a full discussion of the potential benefits of the mandatory fitting of seat belt reminder systems more aggressive than that currently specified by ADR 69. At the outset, it is important to state that this current report does not consider the effectiveness or otherwise in the 4 second seat belt ‘tell-tale’ or text warning, rather its focus is the success or otherwise of the specified injury performance criteria.

1.5 Project objectives

This study aims to evaluate the effectiveness of both ADR 69 and frontal airbag deployment on injury risk, severity and cost associated with belted drivers involved in frontal crashes in Australia using more sophisticated analysis techniques than used previously.

This report examines drivers involved in frontal crashes and studied in-depth by researchers of MUARC for the period 1989–2002, with the year of manufacture ranging from 1986-2000. Vehicles manufactured during 1995 were excluded from the analysis as the build date was not specified in the dataset, and ADR 69 states that all MA vehicles (passenger cars) must comply with ADR 69 performance specifications.

Using advanced regression techniques, this paper will report differences in the likelihood of injury and injury cost benefits for each body region, adjusted for influential differences in driver and crash characteristics between the two vehicle groups, defined by those manufactured pre-1995 and post-1995.

1.6 Use of the report

This report is a scientific evaluation of the benefits or otherwise of the injury criteria specified by ADR 69. The fundamental building block for this analysis is in-depth crash data collected by researchers at the Monash University Accident Research Centre, where an individual was involved in a motor vehicle crash.

The intent of this evaluation is to determine the success or otherwise of ADR 69 in driving improvements in full frontal occupant crash protection in Australia. In doing so, it is expected that the analysis conducted herein might point to the way to future improvements in occupant protection. In formulating recommendations that may stem from the analysis, the authors recognise the significant regulatory hurdles in adopting any changes to the provisions of ADRs, and the preference of the Australian Government to harmonise vehicle safety regulations in accordance with the provisions of the United Nations Economic Commission for Europe (UNECE) 1958 Agreement concerning the adoption of Uniform Technical Prescriptions for vehicles. It is imperative to note that many of the issues requiring consideration for any regulatory change are beyond the scope of this document, and any future changes to ADR 69 would need to be made in accordance with Australian Government policy.

2 METHOD

2.1 Study participants

This evaluation pools in-depth crash and injury data from three in-depth vehicle crash studies conducted by MUARC:

1. The Crashed Vehicle File (CVF) conducted from 1989 – 1993;
2. The In-depth tow-away study funded by FORS (now Australian Transport Safety Bureau, ATSB) to evaluate ADR 69 and conducted from 1995–2000;
3. The current Australian National Crash In-Depth Study (ANCIS)[4] from 2000 onwards.

The recruitment of in-depth cases to the CVF and ANCIS study differed to that of the FORS-funded study. More specifically, the CVF and ANCIS projects enrolled patients admitted to hospital as a consequence of a traffic crash, while inclusion in the FORS study was based on involvement in a tow-away crash.

The value of combining the three datasets is that tow-away and hospitalised crashes are combined and analysed to fully evaluate ADR 69 and airbag effectiveness in reducing injuries across a broad spectrum of crash severities. It was possible to combine the separate databases due to the use of common core data points, as well as the inclusion of EBS to control for crash severity (and other variables) in regression models. Sample weights designed to provide a fully representative view of injuries across the fleet were unavailable at this stage (see Section 4.5.3, p.99). A brief description of the collection procedures is presented below.

Recruitment procedures for hospital-based studies - CVF and ANCIS

Study participants were recruited to the studies following admission to a participating public hospital as a consequence of being injured in a road traffic crash. Participants were required to provide informed consent if medically fit to do so; Next-of-Kin consent was required for those medically unfit to provide informed consent themselves. For those under 18 years of age, parental consent or that of a legal guardian was obtained. Finally, for occupants of vehicles legally owned by another party, the consent of the vehicle owner was required in order to permit a vehicle inspection to be undertaken.

For both the CVF and ANCIS study, a short interview was undertaken with the participating occupant whilst an in-patient of the participating hospital. The interview included information concerning the vehicle, including vehicle registration, to facilitate the Vehicle Inspection Process. Injury data was obtained from medical records, including the patient history and diagnostic imaging reports.

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

Recruitment procedures for the FORS funded tow-away study

The FORS funded tow-away study was conducted from 1995–2000 and was principally funded to evaluate ADR 69. The entry to the study was a tow-away criterion, with an effort to ensure matching of pre-ADR 69 and post-ADR 69 vehicles. Researchers received voluntary notifications from registered tow-truck operators with a nominal spotter's fee being paid. The researchers were informed of the crash location, the location of the involved vehicle(s) and the name and contact phone number of the occupant.

Once contacted by a towing agency, the researchers sought written informed consent of the crash involved party. This involved a telephone conversation where the study was explained followed by a written explanation of the study with a consent form attached. The 'case' would only proceed following receipt of informed consent from the vehicle occupant, and vehicle owner if different.

Following consent, a short telephone interview was conducted with the vehicle occupant detailing the nature of injuries sustained as well as a description of the crash event itself. For those hospitalised, injury data was obtained from medical records, such as the patient history and diagnostic imaging reports.

2.2 Ethics approvals

For each of the three projects, The Monash University Standing Committee on Ethics involving Research on Humans (SCERH) had approved the studies. For the CVF and ANCIS studies, Institutional Ethics Committees at each of the study hospitals was also obtained.

2.3 Vehicle inspection procedures

Vehicle inspections were conducted in accordance with standard international practice (National Automotive Sampling System-NHTSA). Vehicle damage was coded as per SAE Recommended Practice J224b (SAE, 1980). Delta-V and Equivalent Barrier Speed (EBS) were determined using Calspan Reproduction of Accident Speeds on the Highway Version 3 (CRASH3, 1992).

For this report the EBS was used as a measure of crash severity. Following Morris et al. (2001: 16), EBS is defined as:

> Equivalent Barrier Speed (EBS) is defined as the speed in the case vehicle at which equal energy would be absorbed in a frontal energy impact into a test barrier; i.e. an estimation of the velocity change at impact that would be required of a crash test if it were to re-create the same amount of crush that occurred in the real crash with a vehicle of equal mass and stiffness. Calculation of EBS also requires measurement of the crush profile of the damage, but only of the vehicle being studied.

Delta-V is defined as the change in velocity from the moment of impact until the study vehicle separates from its impacting source (MUARC, 1992). While delta-V is often viewed as the preferred index velocity change due to consideration of the characteristics of collision counterpart as well the type of damage profile of both vehicles, the calculation was not possible for a significant number of cases due the inability to conduct a vehicle inspection on the opposing, non-case, vehicle. The calculation of delta-V requires knowledge of the opposing vehicles mass, stiffness, and damage profile, and when the vehicle collides with a stationary object such as a tree, pole or lamp-post. For this reason, EBS was used as a measure of crash severity in this evaluation.

The reader is referred to Morris et al. (2001) for a comprehensive description of vehicle inspection procedures used in all three crash databases.

2.4 Injury data and the Abbreviated Injury Scale

Injury data were gathered on each occupant involved in the collision. For hospitalised occupants, injury details were recorded from medical records of the treating hospital. Participants were also administered a structured interview by a research nurse. For persons killed in the crash, injury details were obtained from coronial records. For occupants not requiring hospital treatment, a research nurse conducted a structured telephone interview to gather crash and injury details. All injuries, whether self-reported or medically verified, were coded according to the Abbreviated Injury Scale (AIS), 1990 revision (AAAM, 1998).

The AIS is best regarded as a threat-to-life scale and stemmed from the need of road safety researchers and the automotive industry in the late 1960s to have a single standardised injury classification system (AAAM, 1998). Since its introduction in 1971, the AIS has undergone substantial revision and expansion in order to meet the growing needs of injury structure and severity specificity required by researchers and clinicians alike.

The AIS is based on anatomical injury and scores the severity of each injury. The AIS system does not assess the impairment or disability resulting from the injury. The AIS classifies individual injuries by body region on a six point ordinal scale (see Table 4), from AIS 1 (minor injury) to AIS 6 (maximum, currently untreatable).

Each injury is represented by a 7 digit code, with the seventh digit preceded by a '.' representing the associated severity for the body region and involved structure and associated type of damage (AAAM, 1998). For example, the code 420210.5 is the injury code of a thoracic aorta injury, with the digits in order representing the thorax (4), vessels (system) (2), the specific structure, in this case the aorta (02), a major laceration (10), with the overall threat-to-life AIS severity score of 5, representing a 'critical' injury.

Table 4: Abbreviated Injury Scale Severity Scores

AIS Severity Score	AIS Severity Descriptor
1	Minor
2	Moderate
3	Serious
4	Severe
5	Critical
6	Maximum, currently untreatable
9	Unknown

The AIS permits the expression of injuries in two other ways, the first being the maximum AIS (MAIS) which can be taken to be the maximum, or highest, injury for the entire body, or each body region, and secondly, the Injury Severity Score (ISS). The ISS is calculated for each case, and acts as a global index of injury severity and reportedly is a ‘better fit between overall severity and survival’ (AAAM, 1998: viii). The ISS is derived from the AIS and ranges from 0 (uninjured) – 75 (un-survivable).

2.5 Cost of injury: The harm concept

HARM is a metric for quantifying societal injury costs from road trauma and involves a frequency and a unit cost component. The HARM metric has been used in a number of studies at MUARC as a means of estimating societal benefits from the introduction of new countermeasures, and was first used in Australia for determining the feasibility of introducing ADR 69 (MUARC, 1992) as well as a means for quantifying the financial benefits to society in evaluation studies (Fildes, Deery, Lenard, et al., 1996; Fildes, Fitzharris, Koppel et al., 2002). HARM benefits, or total injury cost differences, associated with drivers of pre- and post-ADR 69 manufactured vehicles are presented in the Results.

In its most general form, HARM is used as a measure of the total cost of road trauma. Injury costs by body region and injury severity were reported earlier and were determined using the human capital method (MUARC, 1992). Included within the HARM estimates are treatment, rehabilitation, loss of productivity and wages, pain and suffering allowances and administration costs. The HARM values were originally based on total societal crash costs published by Steadman and Bryan (1988). For the purpose of this report, the HARM values have been re-factored (by 2.5) to reflect more recent estimates of road crash costs published by the BTE (2000) that were 2.5 times higher than those estimated by Steadman and Bryan (1988), and these are equivalent to 1996 dollars. The proportional differences do however remain the same. Table 5 shows the cost of injury by body region and AIS severity.

Table 5: Average cost of injury (HARM) by body region and AIS severity (AUD$'000)

Body Region	AIS severity					
	Minor	Moderate	Serious	Severe	Critical	Maximum
	AIS 1	AIS 2	AIS 3	AIS 4	AIS 5	AIS 6
Head	5.25	24.50	100.75	232.25	820.50	830.75
Face	5.25	24.50	100.75	133.00	272.25	830.75
Neck	5.25	24.50	100.75	133.00	272.25	830.75
Chest	3.75	20.75	58.00	94.25	136.75	830.75
Abdomen-Pelvis	3.75	20.75	58.00	94.25	136.75	830.75
Spine	3.75	20.75	135.50	1167.50	1396.00	830.75
Upper Ex.	5.25	36.00	85.25	N/A	N/A	N/A
Lower Ex.	3.75	36.00	108.25	160.00	272.25	830.75

Note: Values scaled up by 2.5 to reflect increased cost of injury (BTE, 2000)

2.6 Inclusion criteria for the evaluation study

The current study aims to evaluate the injury reduction benefits, if any, associated with the introduction of ADR 69. The fundamental comparison will be the injury outcomes of occupants of vehicles manufactured before and after the introduction of ADR 69. The analytical challenge in the conduct of this evaluation is to control for potential confounding variables that may unequally influence the injury outcome comparison of the two groups. An example of this might be that group 1 had a lower overall average cost of injury measured using the HARM metric than group 2, but that the overall crash severity of group 1 was, say, 20 km/h lower on average than group 2; in this case the interpretation of the injury reduction effect associated with group 1 is confounded by that group having a lower crash severity.

It is important therefore that the two comparison groups are evenly matched. The analysis reported in this evaluation is not a classic case-control study by design due to the combination of cases from three separate databases. A broad-based control over group differences is achieved to some degree by setting rigorous study inclusion criteria.

In-depth cases (crash-involved occupants) are included in the study if they meet the following inclusion criteria:

- Driver only
- Passenger cars (small, medium, large)
- Frontal impact defined by the Collision Deformation Classification (CDC) system, under the specifications of SAE Recommended Practice J224b (SAE, 1980). It was not possible to further sub-divide the frontal impact collisions into fully distributed, narrow or wide offset due to sample numbers once the data was categorised according to the ADR 69 status; this would split the cases into six categories as opposed to two categories

- Crash severity, indexed by EBS (km/h) being known
- No rollover in the collision
- Collision partner known (i.e., tree, pole, vehicle type)
- Vehicles manufactured pre-1995 (referred to as ‘pre-ADR 69’, 1986-1994) and post-1995 (referred to as ‘post-ADR 69’, 1996-2000)
- Airbag status known (fitted and deployed, fitted & not deployed, not fitted)
- At least one AIS 1 injury sustained with all injury data known
- Seat belt worn
- Demographics known, including age, gender, height and weight of the driver
- Cases were excluded if either of the following were met:
- Fatalities were excluded from the analysis due to very few being present in the databases
- Vehicles manufactured in 1995 were excluded from the analysis due to uncertainty surrounding build date and potentially inappropriate classification of vehicles as ‘new models’ for the purposes of the ADR 69 regulation phase-in requirements.

2.7 Statistical analysis

Descriptive analysis of vehicle and driver characteristics is presented, split on drivers of pre-ADR 69 and post-ADR 69 vehicles. Analysis of vehicle and driver characteristics was undertaken to explore potential differences between the two groups and to describe the sample. To test for differences in sample group means, t-tests and 2-way ANOVAs were used (Keppel, 1991), while chi-square tests were used to test for differences in distributions between the two groups (Siegel & Castellan, 1988).

2.7.1 Injury Risk Analysis

Logistic regression was used to determine the relative odds, or likelihood, of drivers sustaining an AIS 2+ injury for each body region between drivers of pre- and post-ADR 69 manufactured vehicles (Hosmer & Lemeshow, 2000; DuPont, 2002). Regression modelling allows for the statistical control of differences in crash and occupant characteristics associated with drivers between the ADR 69 groups, while also examining the effect of airbag fitment and deployment and the ADR 69 regulation itself. The combined impact of the ADR 69 regulation and airbag deployment for AIS 2+ injury risk was also determined. The interaction between ADR 69 group and airbag fitment was examined to determine whether the injury reduction benefits of airbag deployment differed across the ADR 69 groups.

Potential confounders in the analysis were assessed and adjusted for if required, and included differences in impact speed indexed by EBS (km/h); collision partner; age; gender; driver weight, and driver height. All logistic regression models included EBS and the deployment of the driver airbag or otherwise; other variables in the logistic regression models are noted for each body region.

In the preliminary model building strategy, variables with a significance value of p = 0.2 were accepted and formed the basis of the multivariable logistic regression model. Linearity of continuous variables (EBS, age) was assessed using fractional polynomials, with transformations undertaken where necessary (Hosmer and Lemeshow, 2000; Royston and Altman, 1994). Outliers were assessed using leverage and residuals statistics.

The primary feature of logistic regression is that the outcome is dichotomous in nature, and in this report is taken to be either injured or not (AIS 1+), or sustaining an AIS 2+ injury or not. The formulae listed below underpin the logistic regression analysis of injury risk and are presented in the form of Odds Ratios comparing one group to another, or probability values based on one or more characteristics. The probability of a 'case' having an injury of interest under a logistic function x, $\pi[x]$ is:

$$\pi[x] = \exp[\alpha + \beta x] / (1 + [\alpha + \beta x]) \qquad [1]$$

where α and β are unknown parameters estimated from the data

If we are able to determine the probability of injury, then equally the probability of being uninjured can be calculated, and is represented in Equation [2]

$$1 - \pi[x] \qquad [2]$$

Then, to determine the *odds of injury of interest* we use Equation [3]

$$\pi[x] / 1 - \pi[x] \qquad [3]$$

And to determine the log odds of injury we use Equation [4]

Error! Objects cannot be created from editing field codes. $= \alpha + \beta x$ [4]

Hence for any number between 0 and 1, the logit function is defined by Equation [5]

$$\text{logit } [\pi] = \log[\pi/1-\pi] \qquad [5]$$

And Eq.4 can be rewritten as logit $[\pi[x_i]] = \alpha + \beta_{xi}$

The Odds Ratio of two groups can then be calculated as the exponentiated difference in their individual logits or risk, $\exp(\beta)$, and is interpreted to be the odds ratio, in this case, of injury associated with a single unit increase in x. The ratio remains constant for all values of x, assuming that the relationship between the particular parameter and the outcome variable is linear.

In a practical example Mertz et al. (1989, cited in Eppinger et al., 1999) reported that the risk of an AIS 2+ femur injury can be given by the probability formula:

Pr (AIS 2+) = $1 / 1 + e^{(5.795-0.5196*F)}$, where F = femur force in kN

2.7.2 Injury Cost (HARM) Analysis

The difference in average harm between drivers of pre- and post-ADR 69 manufactured vehicles was estimated using a Poisson regression model compensating for variance over-dispersion (Agresti, 2002). A Poisson regression model was considered appropriate as the HARM measure is essentially cost-weighted injury counts. The Poisson error structure of the regression model is appropriate to reflect the count nature of the data, while the cost weighting leads to the variance over-dispersion for which the model also accounts. To control for differences in average crash severity between the two groups, EBS was included as a covariate in the regression model, as was vehicle market class. It was not possible to separate the effect of ADR 69 group and airbag deployment in the Poisson cost model, and therefore the cost effectiveness of post-ADR 69 compared to pre-ADR 69 vehicles is presented. Consequently, the cost of injury for the analysis contains an unspecified airbag effect.

Analysis was conducted using Stata Intercooled V8.2 (Stata Corp, 2003), and SAS V.8 (SAS Institute, 1999). A value of $p \leq 0.05$ was used to assess statistical significance.

3 RESULTS

3.1 Vehicle, crash and driver demographics

3.1.1 Vehicle and crash characteristics

A total of 285 cases in the dataset satisfied the study entry criteria. Table 6 shows that of the 285 drivers, 129 (45.3%) were drivers of post-ADR 69 vehicles (1996-2000), while the remaining 156 (54.7%) were drivers of pre-ADR 69 vehicles (1986-1994). Of drivers in post-ADR 69 manufactured vehicles, 82.2% (106) had a frontal airbag system deploy, compared to 30.7% (48) in the pre-ADR 69 group, $\chi^2(1)=75.1$, $p\leq0.001$. The correlation between ADR 69 group and airbag system status was $r=0.51$ ($p\leq0.001$).

Table 6: Number and percent of drivers by ADR 69 and airbag status

Airbag status	Pre-ADR 69		Post-ADR 69	
	Freq.	%	Freq.	%
Fitted & deployed	48	30.7	106	82.2
Not fitted, or Fitted & not deployed	108	69.3	23	17.8
TOTAL	156	100	129	100

The majority of drivers in both ADR 69 groups were occupants of large passenger vehicles (Table 7). There were significantly more drivers in large vehicles and fewer in small vehicles among the pre-ADR 69 group compared to the post-ADR 69 group, $\chi^2(2)=7.5$, $p\leq0.05$.

Table 7: Number and percent of drivers by ADR 69 status & vehicle group

Vehicle market class	Pre-ADR 69		Post-ADR 69	
	Freq.	%	Freq.	%
Small	21	13.50	32	24.8
Medium	9	5.80	11	8.5
Large	126	80.70	86	66.7
TOTAL	156	100	129	100

Cars and passenger car derivatives represented approximately 57% of collision partners, while poles or trees represented approximately 28% of collision partners (Table 8). There were a small number of other collision partners, and there was no difference in the distribution of collision partners between the ADR 69 groups, $\chi^2(4)=4.1$, $p\geq0.05$.

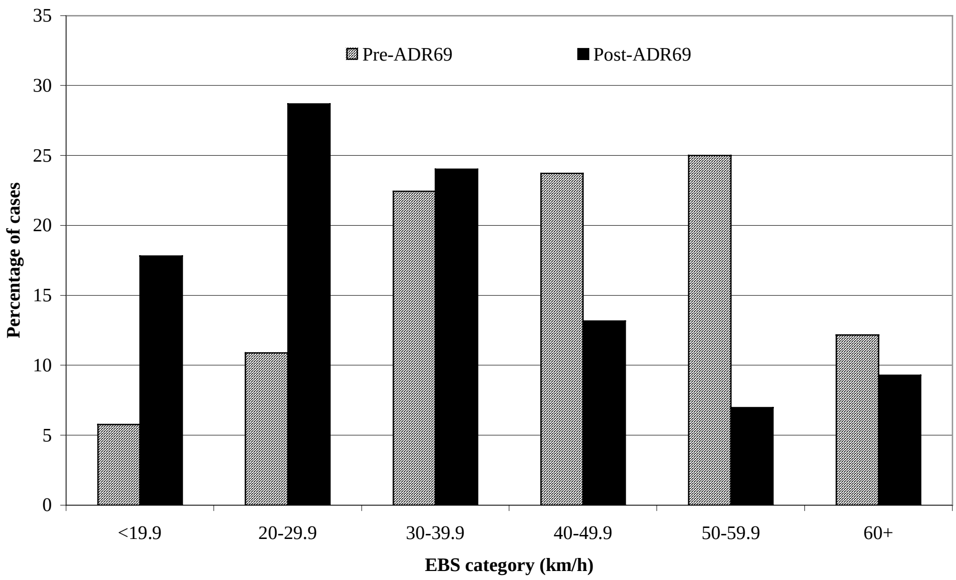
Table 8: Number and percent of drivers by collision partner & ADR 69 group

Collision partner	Pre-ADR 69		Post-ADR 69	
	Freq.	**%**	**Freq.**	**%**
Car / Ute	88	56.4	74	57.4
SUV, van	10	6.4	7	5.4
Pole / tree	40	25.6	40	31.0
Truck / bus	13	8.3	4	3.1
Roadside object	5	3.2	4	3.1
Total	156	100	129	100

3.1.2 Crash Severity

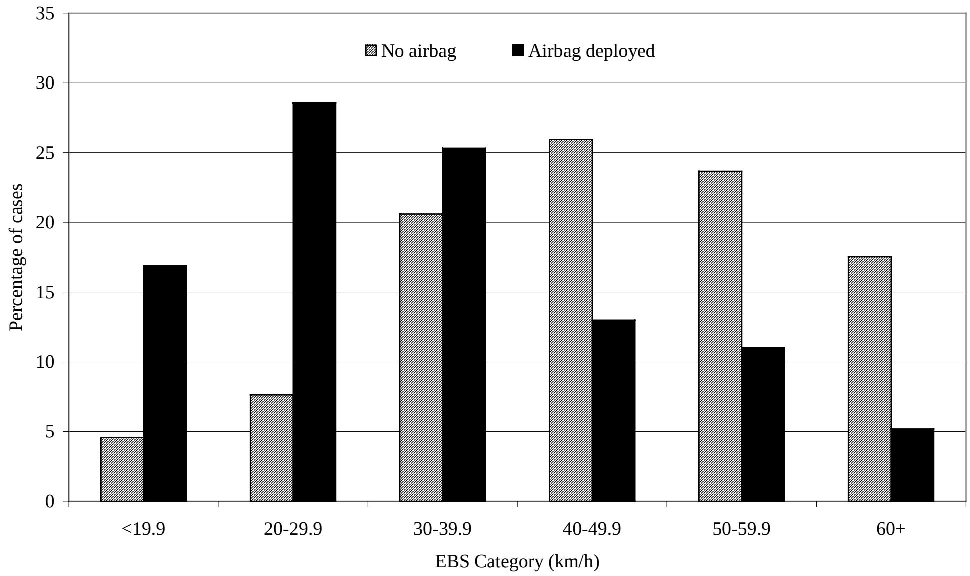
The crash severity, indexed as EBS (km/h), differed between the pre- and post-ADR 69 groups. The mean EBS for the pre-ADR 69 drivers (41.2 km/h, SD=14.9 km/h) was significantly higher than for drivers of post-ADR 69 vehicles (34.9 km/h, SD=17.3 km/h), $t(283)=4.8$, $p\leq0.001$. The EBS distribution (see Figure 2) between the two groups was also statistically different, $\chi^2(5)=39.3$, $p\leq0.001$. The median EBS for the pre-ADR 69 cases was 44.1 km/h while for drivers of the post-ADR 69 vehicles the median EBS was 31.3 km/h. As the distribution of crash severity differs between the ADR 69 groups, EBS must be included in all regression models in order to account for this difference.

Figure 2: Percentage of drivers by EBS category and ADR 69 group



Given the observed difference in EBS between the pre- and post-ADR 69 cases, it is also important to determine whether a similar difference is evident among drivers with (n=154) and without (n=131) a frontal driver airbag deployment. Figure 3 clearly demonstrates the differences in the crash severity distribution between the two groups, $\chi^2(5)=49.5$, $p\leq0.001$. The mean EBS for drivers without an airbag deployment (or fitted) was 46.8 km/h (SD = 16.1 km/h), significantly higher than the mean EBS for the driver airbag group of 34.2 km/h (SD=14.8 km/h), t(283)=6.9, p≤0.001. Similarly, the median EBS for the non-airbag deployment group (46 km/h) was higher than for the airbag deployment group (31.8 km/h). As noted above, EBS must be included in any regression model comparing injury outcomes between groups defined by the deployment of an airbag or otherwise; failure to do so would result in confounded, and therefore invalid, results.

Figure 3: Percentage of drivers by EBS category and airbag deployment status



3.1.3 Driver Characteristics

Driver Gender - Of the 285 drivers, 66% were male (188) and 34% were female (97). Table 9 indicates that there was no difference in the distribution of male and female drivers across the two samples, $\chi^2(1)=0.2$, p≥0.05.

Table 9: Number and percent of drivers by gender by ADR 69 status

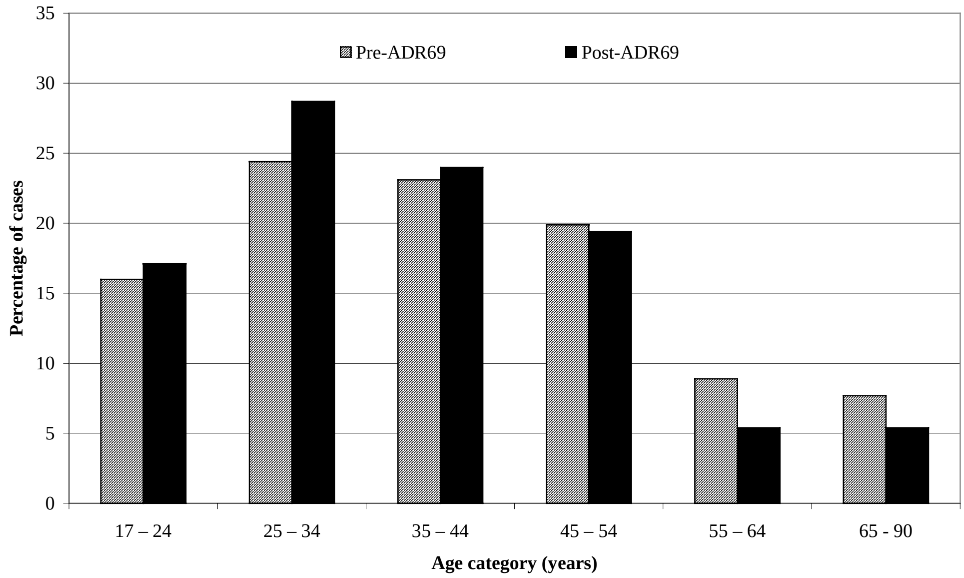
Gender	Pre-ADR 69		Post-ADR 69	
	Freq.	**%**	**Freq.**	**%**
Male	101	64.7	87	67.4
Female	55	35.3	42	32.6
Total	156	100	129	100

Driver Age - The overall mean age of pre-ADR 69 drivers (40.2 yrs, SD=14.6 yrs; Median: 39 yrs) and post-ADR 69 drivers (38.4 yrs, SD=14.4 yrs, Median: 36 yrs) did not differ (p≥0.05). The median values were also similar to the mean, indicating a relatively normal distribution. Furthermore, there was no difference in the mean age of males and females either within or between the two ADR 69 groups (p≥0.05). Table 10 and Figure 4 show the age distribution indicating no difference between the two groups, $\chi^2(5)=2.3$, p≥0.05.

Table 10: Number and percent of drivers by age category and ADR 69 group

Age category (years)	Pre-ADR 69		Post-ADR 69	
	Freq.	%	Freq.	%
17 – 24	25	16.0	22	17.1
25 – 34	38	24.4	37	28.7
35 – 44	36	23.1	31	24.0
45 – 54	31	19.9	25	19.4
55 – 64	14	8.9	7	5.4
65 - 90	12	7.7	7	5.4
Total	156	100	129	100

Figure 4: Age distribution of drivers by ADR group status

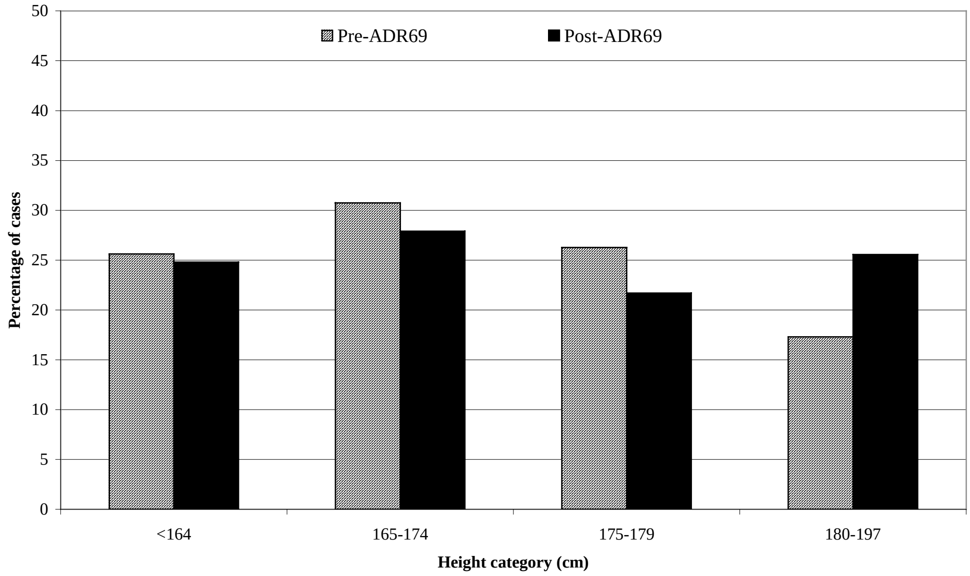


Driver height - The overall mean height for males was 178 cm (SD=6.1 cm, Median: 178 cm; Range: 155-196 cm) and 164.5 cm for females (SD=7.3 cm, Median: 165 cm; Range: 149-180 cm). A two-way ANOVA indicated that while the mean height of males and females was statistically different [$F(1,281)=236.4$, $p \leq 0.001$], the difference in height between males and females was equivalent across the ADR groups ($p \geq 0.05$). The median height values were also similar to the mean, indicating relatively normal distribution. Analysis of driver height using 5 cm intervals indicated that the height distributions of the pre-ADR 69 drivers and post-ADR 69 drivers was evenly matched, $\chi^2(5)=4.7$, $p \geq 0.05$. The overall height distribution (Table 11, Figure 5) is skewed, reflecting the higher proportion of males in the sample than female.

Table 11: Number and percent of drivers by height category and ADR 69 group

Height category (cm)	Pre-ADR 69		Post-ADR 69	
	Freq.	%	Freq.	%
≤164	40	25.6	32	24.8
165-174	48	30.8	36	27.9
175-179	41	26.3	28	21.7
180-197	27	17.3	33	25.6
Total	156	100	129	100

Figure 5: Height distribution of drivers by ADR 69 group

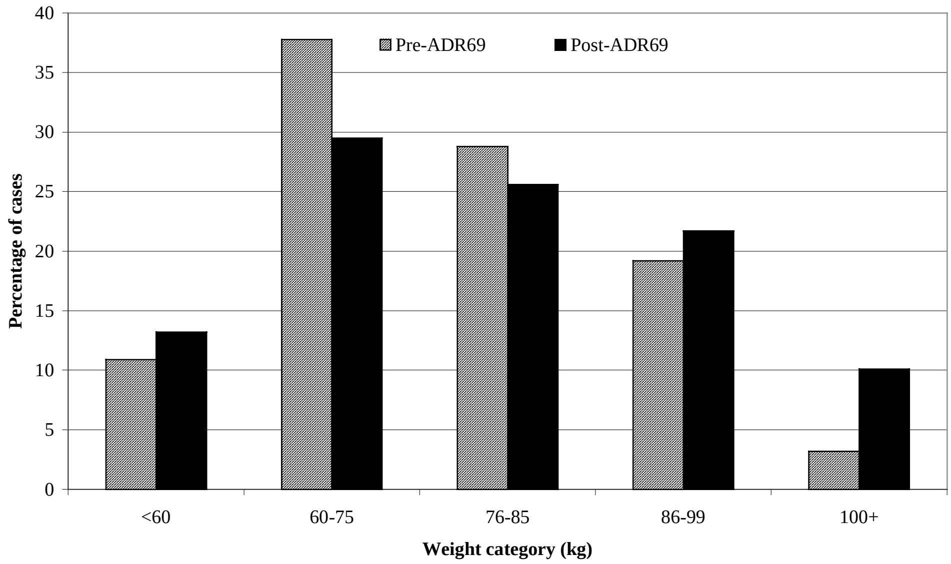


Driver weight - The overall mean weight for males (82.4 kg, SD=13.9 kg, Median: 81 kg; Range: 50-175 kg) was greater than for females (66.2 kg, SD=13.3 kg, Median: 64 kg; Range: 35-102 kg), [$F(1,281)=89.2$, $p \leq 0.001$]. A 2-way ANOVA indicated that the weight difference between males and females was equivalent across the ADR groups ($p \geq 0.05$). The median weight values were also similar to the mean, indicating a relatively normal weight distribution. Table 12 and Figure 6 presents driver weight using 10 kg intervals, and analysis indicated that the weight distribution of the pre-ADR 69 drivers and post-ADR 69 drivers was evenly matched, $\chi^2(5)=7.5$, $p \geq 0.05$.

Table 12: Number and percent of drivers by weight category and ADR 69 group

Weight category (kg)	Pre-ADR 69		Post-ADR 69	
	Freq.	%	Freq.	%
<60	17	10.9	17	13.2
60-75	59	37.8	38	29.5
76-85	45	28.8	33	25.6
86-99	30	19.2	28	21.7
100+	5	3.2	13	10.1
Total	156	100	129	100

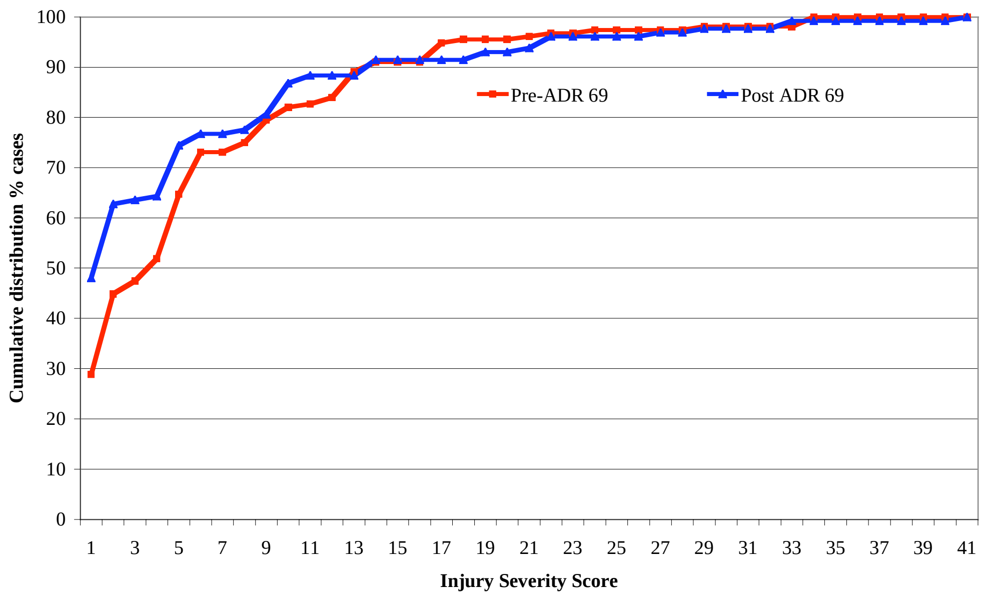
Figure 6: Weight distribution of drivers by ADR 69 group



3.2 Global injury severity measures

The overall injury severity as indexed by the injury severity score (ISS) of the pre-ADR 69 drivers and post-ADR 69 drivers did not differ, as can be seen in Figure 7 ($t(283)=0.8$, $p\geq0.05$). The mean ISS for drivers of pre-ADR 69 vehicles was 6.0 (SD=6.7, Range: 1-34, Median: 4) compared to 5.3 (SD=7.5, Range: 1-41, Median: 2) for drivers of post-ADR 69 vehicles. Analysis indicated no difference in the proportion of drivers' injuries being classified as minor (ISS<15) or major (ISS>15) trauma between the ADR 69 groups, $\chi^2(1)=0.1$, $p\geq0.05$. Approximately 9% of drivers in each group sustained an ISS of greater than 15. While the ISS shows that drivers of the two ADR 69 groups sustained similar levels of injury, it must also be remembered that the crash severity of the two groups differed, with the post-ADR 69 group experiencing a lower, on average, crash severity indexed by EBS (km/h). It is important to explore the individual body regions to examine the specific effect of the ADR 69 standard on mitigating injury risk.

Figure 7: Cumulative distribution of Injury Severity Score for drivers of pre-ADR 69 and post-ADR 69 vehicles

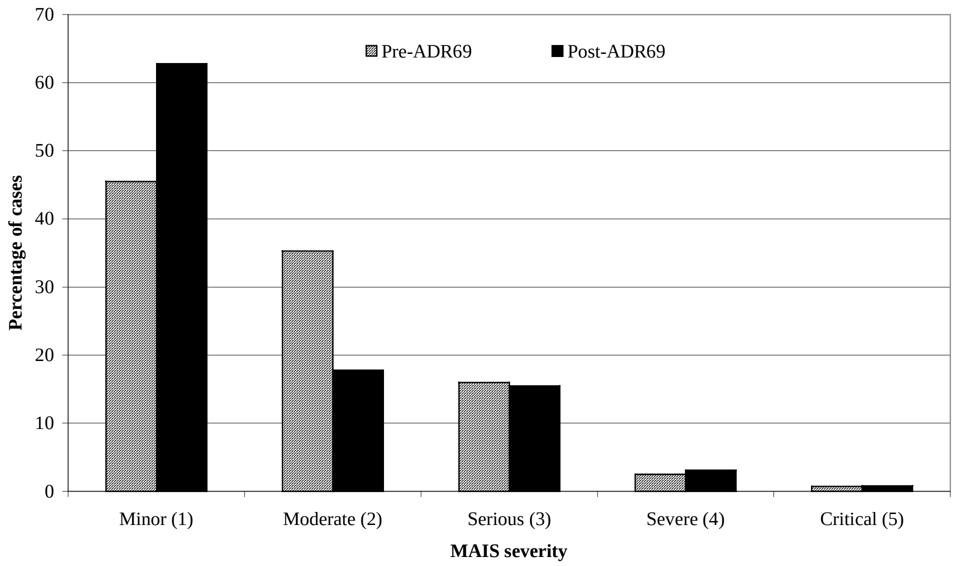


An alternative way to examine the overall injury severity is to examine the highest AIS score, irrespective of body region. In an evaluation of a standard this where different performance criteria are used for each body region, a global evaluation such as MAIS provides little information. In any case it remains interesting to note that the distribution of Maximum Abbreviated Injury Scale scores (MAIS) for drivers of pre- and post-ADR 69 vehicles differed significantly in Table 13, $\chi^2(4)=11.9$, $p\leq 0.01$. A higher proportion of drivers of post-ADR 69 vehicles sustained AIS 1 (minor) injuries and a correspondingly lower proportion sustained AIS 2+ injuries compared to drivers of pre-ADR 69 vehicles, although this may simply reflect differences in EBS (km/h) crash severity. For injuries of AIS 3 and higher, there was no difference between the groups (see also Figure 8).

Table 13: MAIS distribution for pre- & post-ADR 69 drivers

MAIS	Pre-ADR 69		Post-ADR 69	
	Freq.	**%**	**Freq.**	**%**
Minor (1)	71	45.5	81	62.8
Moderate (2)	55	35.3	23	17.8
Serious (3)	25	16.0	20	15.5
Severe (4)	4	2.5	4	3.1
Critical (5)	1	0.7	1	0.8
TOTAL	156	100	129	100

Figure 8: Distribution of cases by AIS severity and ADR 69 vehicle group



3.3 Injury risk analysis

The analysis in this Section, Injury Risk Analysis, will focus on determining the proportions of drivers sustaining an injury (AIS 1+), as well as those sustaining AIS 2+ injuries, for each body region. The adjusted relative odds ratios of drivers of pre- & post-ADR 69 vehicles, the impact of airbag deployment and their combined effect, adjusted for covariates. Adjusted relative odds ratio estimates are presented for three comparisons:

Comparison 1 - For drivers of post-ADR 69 vehicles relative to drivers of pre-ADR 69 vehicles, irrespective of airbag deployment status, referred to as 'Post-ADR 69' in all relevant Tables

Comparison 2 - For drivers of airbag deployed vehicles relative to drivers of vehicles without an airbag deployment, irrespective of ADR 69 status, referred to as 'Airbag deployment' in all relevant Tables

Comparison 3 - For drivers of ADR 69 compliant vehicles with an airbag deployment relative to drivers of pre-ADR 69 manufactured vehicles without an airbag deployment, referred to as 'ADR 69+Airbag' in all relevant Tables; this is presented to highlight their combined impact on injury risk.

Critically, in interpreting the 'ADR 69' result (Comparison 1) the estimate is the relative odds, or likelihood, of injury irrespective of frontal airbag deployment status, and as such includes drivers with and without frontal airbag deployment. For the ADR 69 comparison, inclusion of the airbag variable in the logistic regression model simply adjusts for differences, if any, in airbag effectiveness between the pre- and post-ADR 69 groups, but does not remove the impact of the airbag on injury risk. Consequently, the ADR 69 result contains an unspecified impact of airbag deployment on injury risk.

Similarly, in interpreting the 'airbag' result (Comparison 2), the odds ratio is the relative odds or likelihood of injury irrespective of ADR 69 status, and consequently contains an unspecified impact of the ADR 69 regulation within the airbag estimate itself.

The inability to separate the individual influence of the ADR 69 regulation and frontal airbags separately has arisen because drivers within both pre- and post-ADR 69 groups experienced frontal airbag deployments, and also to a lesser and unknown extent that some vehicles in the pre-ADR 69 sample would likely meet the ADR 69 design regulation.

In more general terms, the introduction of ADR 69, while not mandating the fitment of frontal airbag systems, provided the impetus for many manufacturers to do so, hence the difficulty in isolating the impact of the impact of the ADR 69 regulation from the impact of the airbag itself. Comparison 3, 'ADR 69 + Airbag' is the combined benefit compared to pre-ADR 69 vehicles without an airbag, and represents the improvement in vehicle safety through advances in design technology due to ADR 69 changes plus airbag fitment and deployment.

The relative odds ratios describe the difference in odds, or likelihood, of sustaining the specified injury between drivers of post-ADR 69 vehicles relative to drivers of pre-ADR 69 manufactured vehicles for the specified injury severity (Injured AIS 1+ & AIS 2+) body region. A p-value of ≤ 0.05 indicates a statistically significant reduction (<1) or increase (>1) in the odds of injury for each of the three specified comparisons. Each model has been adjusted for influential covariates either related to the injury of interest, or to adjust for differences between the comparison groups, e.g., EBS. All models were adjusted for EBS with other covariates noted within each body region. For ease of presentation, each body region will be considered individually and significant emphasis given to the analysis of AIS 2+ (moderate) injuries.

3.3.1 Head Injury Risk

Head injury risk is addressed in ADR 69 by specifying performance requirements defined by the Head Injury Criteria (HIC). More specifically, the head injury performance requirements that must be met are:

- Head Injury Criterion not to exceed 1000 over 36 ms (HIC_{36}1000)
- Following Determination No 2 of 1995, where no head contact has been made aside from with the seatbelt or femur/knee, head injury criteria are as follows:
  - For the Hybrid II dummy: resultant acceleration measured at the centre of gravity is not to exceed 75g, except for intervals whose cumulative distribution is not more than 3 ms, or
  - For the Hybrid III dummy: the neck injury measurements shall not exceed 3300 N of tension force in the inferior-superior direction, or
  - For the Hybrid III dummy: HIC is not to exceed 700 over 15 ms (HIC_{15}700).

Table 14 provides an indication of the types of head injuries by AIS severity. This description is important as it places into context the injury outcomes of the current sample of drivers.

Table 14: Examples of head injuries by AIS severity (AAAM, 1998)

AIS severity	Head Injury example
Minor (1)	Scalp lacerations & contusions; Headache/dizziness resulting from head contact
Moderate (2)	Laceration or avulsion – major (size), and nerves; Simple fracture vault of skull; Loss of consciousness (LOC)<1 hour; Concussion
Serious (3)	Artery compromise; Cerebellar & Cerebral contusion; Base of skull fracture; Cerebrum–subarachnoid haemorrhage; Vault fracture – comminuted; compound; 1-6 hours LOC
Severe (4)	Laceration intracranial vessels; Cerebellum – large contusion / haematoma / petechial & subcortical haemorrhage; Complex fracture base of skull; 6-24 hours LOC, 1-6 hours LOC with on-going neurological deficit
Critical (5)	Major penetrating injury; Laceration intracranial vessels; Injury to brain stem; large extra/sub-dural haematoma – cerebellar/cerebrum; LOC > 24 hours; LOC 6-24 hours with on-going neurological deficit
Maximum (6)	Massive destruction of cranium and skull

The distribution of head injuries by AIS severity for drivers in the pre-ADR 69 and post-ADR 69 groups is presented in Table 15. The most apparent point of difference is the higher proportion of drivers of pre-ADR 69 vehicles (21%) sustaining AIS 2 (moderate) head injuries compared to drivers of post-ADR 69 vehicles (1.5%). The distribution of injuries by the other severities between the ADR 69 groups is similar. The data presented in Table 15 is simply designed to provide an indication of the pattern of injury severity and cannot be used to calculate risk due to previously stated differences in EBS between the ADR 69 groups.

Table 15: Distribution of AIS severity head injuries for pre- & post-ADR 69 drivers

AIS	Pre-ADR 69		Post-ADR 69	
	Freq.	% of drivers	Freq.	% of drivers
Minor (1)	10	6.4	5	3.9
Moderate (2)	33	21.1	2	1.5
Serious (3)	3	1.9	3	2.3
Severe (4)	3	1.9	2	1.5
Critical (5)	2	1.3	Nil	Nil

To determine the difference in head injury risk between drivers in the pre- and post-ADR 69 group, logistic regression was used to adjust for influential variables, if any, in order to obtain non-confounded estimates of the difference in injury risk.

Head Injury Risk

Table 16 presents the finding that 28.2% of drivers in pre-ADR 69 vehicles sustained a head injury compared to 7.7% of drivers in post-ADR 69 vehicles. In calculating the difference in injury risk, analysis indicated that it was necessary to adjust for EBS (km/h), vehicle market group (small, medium, large), and collision partner/struck object; the model displayed ‘excellent’ discrimination with the Area under the ROC curve being 0.81.

The analysis indicates that the risk of head injury for drivers of post-ADR 69 vehicles was 69% lower than their pre-ADR 69 driver counterparts (OR: 0.31, 0.12-0.77, p≤0.01). The head injury risk reduction associated with airbag deployment was borderline statistically significant, and the results are suggestive of a 54% reduction in the risk of sustaining an injury to the head in the event of a frontal crash relative to those without an airbag deployment (OR: 0.46, 0.20-1.05, p=0.06). The risk reduction effect for drivers in post-ADR 69 vehicles with an airbag deployment was 0.14 relative to drivers in pre-ADR 69 vehicles where an airbag was unavailable, indicating an 84% lower risk of head injury (OR: 0.14, 0.06-0.37, p≤0.001).

Table 16: Percent of drivers sustaining an injury to the head and AIS 2+ head injuries, & the adjusted relative odds ratios for drivers of post-ADR 69 vehicles compared to pre-ADR 69 vehicles, airbag deployments, and the dual effect

Body region	Pre-ADR 69 (n=156)	Post-ADR 69 (n=129)	95% CI (L-U)	P
Injured / AIS 1+	28.2%	7.7%		
Post-ADR 69		OR: 0.31	0.12-0.77	≤0.01
Airbag deployment		OR: 0.46	0.20-1.05	0.06
ADR 69+Airbag		OR: 0.14	0.06-0.37	≤0.001
AIS 2+ injury	23.1%	3.9%		
Post-ADR 69		OR: 0.22	0.06-0.79	≤0.05
Airbag deployment		OR: 0.18	0.06-0.58	≤0.01
ADR 69+Airbag		OR: 0.04	0.01-0.18	≤0.001

AIS 2+ Head Injury Risk

Table 16 also shows that approximately 23% of drivers of pre-ADR 69 vehicles sustained an AIS 2+ head injury, compared to 4% of drivers of post-ADR 69 vehicles. In calculating the difference in injury risk, analysis indicated that it was necessary to adjust for EBS (km/h), vehicle market group (small, medium, large), and occupant weight. The variables of gender, height, and collision partner were not useful predictors of AIS 2+ head injury risk and were excluded from the regression model. The logistic regression model displayed ‘excellent’ discrimination with the Area under the ROC curve being 0.88.

As shown in Table 16 above, the odds ratio associated with drivers of post-ADR 69 vehicles relative to drivers of pre-ADR 69 vehicles was 0.22 (78% reduction), with 95% confidence intervals stating that the reduction in risk might be as great as 94% to as low as 21% (OR: 0.22, CI: 0.06-0.79, p≤0.05). Similarly, the relative odds of sustaining AIS 2+ head injuries associated with a frontal airbag deployment compared to drivers of vehicles without an airbag deployment was 0.18 (OR: 0.18, CI: 0.06-0.58, p≤0.01, 82% reduction). The odds ratio for drivers of post-ADR 69 vehicles with an airbag deployment was 0.04 relative to drivers of pre-ADR 69 vehicles without an airbag deployment (OR: 0.04, CI: 0.01-0.18, p≤0.001, 96% reduction). One interpretation of these results is that the frontal airbag is the single most effective change impacting upon head injury risk.

Of importance were the findings that EBS was significantly related to injury risk such that a 1 km/h increase translated to a 6% increase in the risk of sustaining an AIS 2+ head injury (OR: 1.06, CI: 1.04-1.09, p≤0.001). The EBS effect was equivalent for pre-ADR 69 and post-ADR 69 drivers, as well as the two airbag groups, and was seen to be linear in the logistic regression model.

Vehicle market class was an important factor to adjust for in the statistical model, and there was some evidence of a trend indicating that the risk of sustaining an AIS 2+ head injury was lower for occupants of medium sized vehicles compared to those in small vehicles, OR: 0.13, CI: 0.01-1.30, p≥0.05. Similarly for drivers of large vehicles, the point estimate suggests some benefit relative to drivers of small vehicles, however the odds ratio is not statistically significant (OR: 0.47, CI: 0.16-1.34, p≥0.05).

Figure 9 presents the probability curves associated with pre-ADR 69 drivers and post-ADR 69 drivers by EBS (km/h), with the vertical line indicating the ADR 69 test speed of 48 km/h. The equations in Equation Box 1, Section 7.1.1, were used to calculate the probability estimates. The probability curve for drivers of post-ADR 69 vehicles sits to the right of the pre-ADR 69 probability curve, producing a highly desirable reduction in head injury risk. For instance, the EBS at which a driver of a pre-ADR 69 vehicle has a 50% chance of sustaining an AIS 2+ head injury is 52 km/h compared to 76.5 km/h for drivers of post-ADR 69 vehicles. Table 17 presents the same probability estimates in 10 km/h increments.

Figure 9: Observed probability distribution for AIS 2+ head injuries for drivers of pre-ADR 69 and post-ADR 69 vehicles; vertical line is ADR 69 test speed

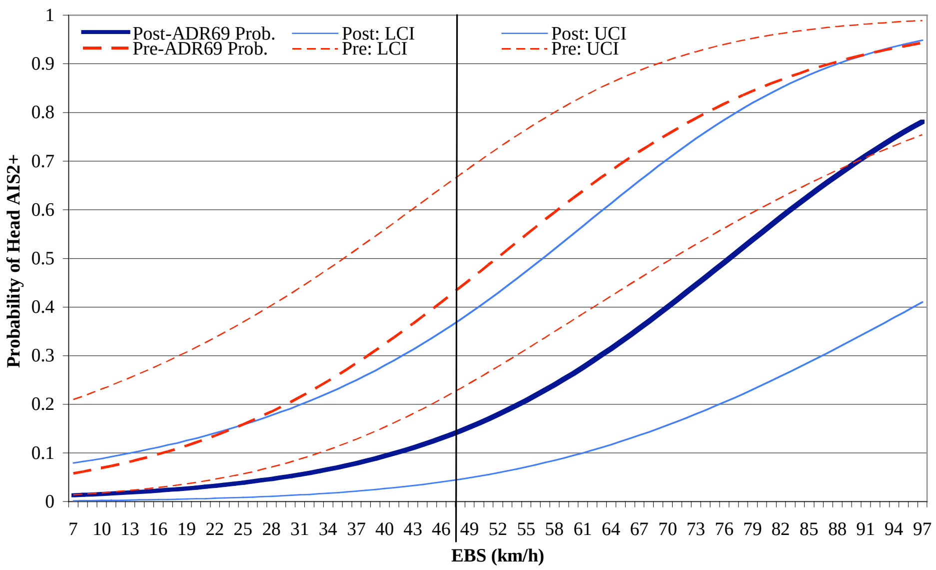


Table 17: Probability estimates for AIS 2+ head injuries for drivers of post-ADR 69 and pre-ADR 69 vehicles by EBS (km/h) with ADR 69 test speed in bold

EBS (km/h)	Pre-ADR 69 cases			Post-ADR 69 cases		
	Probability	95th% CI		Probability	95th% CI	
		Lower	Upper		Lower	Upper
20	0.12	0.04	0.32	0.03	0.01	0.13
30	0.20	0.08	0.43	0.05	0.01	0.19
40	0.32	0.15	0.56	0.09	0.03	0.28
48	**0.44**	**0.23**	**0.67**	**0.15**	**0.05**	**0.37**
50	0.47	0.25	0.70	0.16	0.05	0.40
60	0.62	0.37	0.82	0.26	0.09	0.55
70	0.76	0.49	0.91	0.40	0.16	0.70
80	0.85	0.60	0.96	0.55	0.24	0.83
90	0.91	0.70	0.98	0.70	0.34	0.91

Figure 10 presents the probability curve associated with airbag deployment status by EBS (km/h), with the vertical line indicating the ADR 69 test speed of 48 km/h, while Table 17 presents the same probability estimates although in 10 km/h increments, from 20 km/h – 90 km/h. The equations in Equation Box 1, Section 7.1.1, were used to calculate the probability estimates. The difference in the probability estimates is readily apparent, with a shift of the curve to the right for those in airbag deployed vehicles. Table 18 indicates that for drivers of airbag deployed vehicles, the injury risk at an EBS impact of 60 km/h is 0.23 (CI: 0.06-0.60), compared to the risk for drivers without an airbag deployment of 0.62 (CI: 0.37-0.82).

Figure 10: Observed probability distribution for AIS 2+ head injuries for drivers of vehicles with and without frontal airbag deployments; vertical line is ADR 69 test speed

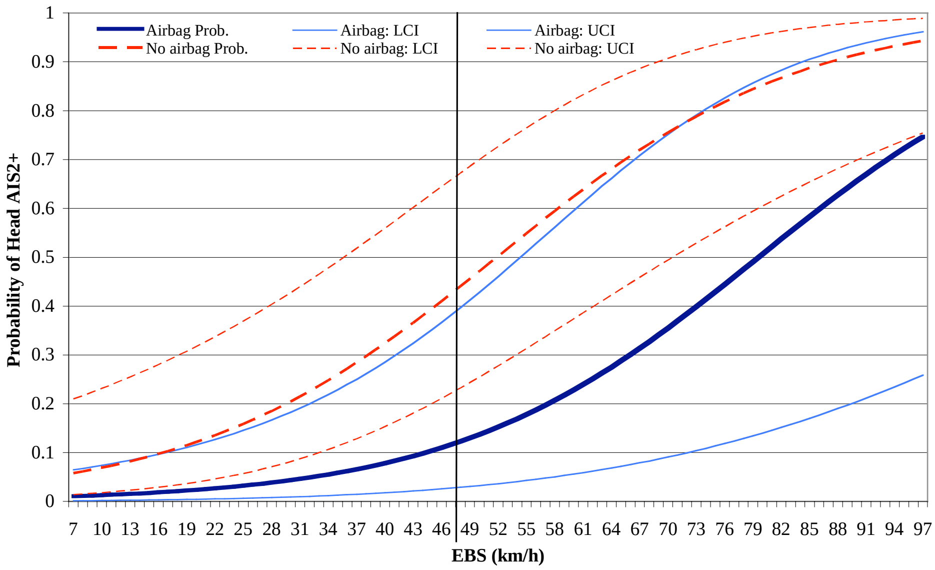


Table 18: Probability estimates for AIS 2+ head injuries for drivers of vehicles with and without airbag deployment by EBS (km/h) with ADR 69 test speed in bold

EBS (km/h)	Non-airbag deployed cases			Airbag deployed cases		
	Probability	95th% CI		Probability	95th% CI	
		Lower	Upper		Lower	Upper
20	0.12	0.04	0.32	0.02	0.005	0.12
30	0.20	0.08	0.43	0.04	0.01	0.18
40	0.32	0.15	0.56	0.08	0.02	0.29
48	**0.44**	**0.23**	**0.67**	**0.12**	**0.03**	**0.40**
50	0.47	0.25	0.70	0.14	0.03	0.43
60	0.62	0.37	0.82	0.23	0.06	0.60
70	0.76	0.49	0.91	0.36	0.09	0.75
80	0.85	0.60	0.96	0.51	0.14	0.87
90	0.91	0.70	0.98	0.66	0.20	0.93

3.3.2 Face Injury Risk

ADR 69/00 did not provide for any specification designed directly to reduce injury risk for the face, however the head injury criteria of ADR 69 would be expected to provide injury reduction benefits. Table 19 provides an indication of the types of face injuries by AIS severity and places into context the injury outcomes of the current sample of drivers.

Table 19: Examples of face injuries by AIS severity (AAAM, 1998)

AIS severity	Face Injury example
Minor (1)	Superficial lacerations, contusions & penetrating injuries, ear injury, eye injuries (corneal abrasions) except globe ruptures/avulsions, mandibular fracture – minor, nose fracture – closed, teeth injuries
Moderate (2)	Penetrating injury with tissue loss; major (size/depth) skin, muscle, subcutaneous laceration / avulsion; optic nerve contusion / laceration; eye globe ruptures/avulsions; retinal detachment; alveolar ridge fracture with or without teeth involvement; subcondylar or open mandibular fracture; Maxilla Leforte I & II fractures; Open nose fracture; Zygoma fracture
Serious (3)	large blood loss due to injury to skin, muscle, subcutaneous laceration / avulsion; external carotid – major; LeForte III; Open/displaced/comminuted orbit fracture
Severe (4)	LeForte III with >20% blood loss by volume

Table 20 presents the distribution of face injuries by AIS severity for drivers in the pre-ADR 69 and post-ADR 69 groups. Approximately 39% of pre-ADR 69 drivers sustained an AIS 1 face injury compared to 24.8% of drivers of post-ADR 69 vehicles. A larger proportion of drivers of pre-ADR 69 vehicles sustained AIS 2 face injuries compared to 1.5% of drivers of post-ADR 69 vehicles.

Table 20: Distribution of AIS severity face injuries for pre-& post-ADR 69 drivers

AIS	Pre-ADR 69		Post-ADR 69	
	Freq.	**% of drivers**	**Freq.**	**% of drivers**
Minor (1)	61	39.1	32	24.8
Moderate (2)	18	11.5	2	1.5
Serious (3)	1	0.6	1	0.8
Severe (4)	Nil	Nil	Nil	Nil

Face Injury Risk

Table 21 presents the finding that 39.7% of drivers in pre-ADR 69 vehicles sustained a face injury (AIS 1+) compared to 25.6% of drivers in post-ADR 69 vehicles. In calculating the difference in injury risk, analysis indicated that it was necessary to adjust for EBS (km/h), vehicle market group (small, medium, large), and collision partner/struck object; the model displayed ‘excellent’ discrimination with the Area under the ROC curve being 0.88 while the Hosmer-Lemeshow Goodness of fit test indicated good model fit, p=0.9.

The analysis suggests that the risk of face injury for drivers of post-ADR 69 vehicles was 29% lower than their pre-ADR 69 driver counterparts, though the difference was not statistically significant (OR: 0.71, 0.36-1.38, $p \geq 0.05$). Similarly, there was some evidence of an injury risk reduction benefit associated with airbag deployments, although this was also not statistically significant (OR: 0.60, 0.31-1.16, $p \geq 0.05$). Importantly though, there was a statistically significant 58% injury reduction benefit for drivers of post-ADR 69 vehicles with an airbag deployment when compared to drivers of pre-ADR 69 vehicles where an airbag was unavailable (OR: 0.42, 0.22-0.84, $p \geq 0.05$).

AIS 2+ Face Injury Risk

Table 21 shows that a higher proportion of drivers of pre-ADR 69 vehicles (11.5%) sustained an AIS 2+ face injury compared to post-ADR 69 drivers (1.5%). The statistical model building process indicated that ADR 69 status, airbag status, EBS, vehicle market class (small, medium, large) and collision partner / object struck were important variables to control for in the calculation of AIS 2+ face injury risk, with the overall model being statistically significant, $\chi^2(7)=53.7$, $p \leq 0.001$. The statistical model displayed ‘outstanding’ discrimination with the Area under the ROC curve being 0.90 while the Hosmer-Lemeshow Goodness of fit test indicated good model fit, p=0.9.

The odds ratio, or likelihood, of drivers of post-ADR 69 vehicles sustaining an AIS 2+ face injury relative to that of drivers of pre-ADR 69 vehicles was 0.12, indicating an 88% reduction in ‘moderate’ and more serious injuries to the face (OR: 0.12, CI: 0.02-0.83, $p \leq 0.05$). For drivers where an airbag was available and deployed, the odds of sustaining an AIS 2+ facial injury was 0.09 relative to drivers without a frontal airbag deployment (OR: 0.09, CI: 0.01-0.91, p≤0.05; 91% reduction). The benefits of ADR 69 status and airbag deployment appear additive in that the relative odds of sustaining AIS 2+ face injuries for drivers of post-ADR 69 vehicles with an airbag deployment relative to drivers of pre-ADR 69 vehicles without a frontal airbag system deployment was 0.01 (CI: 0.001-0.18, p≤0.001).

Table 21: Percent of drivers sustaining an injury to the face and AIS 2+ face injuries, & the adjusted relative odds ratios for drivers of post-ADR 69 vehicles compared to pre-ADR 69 vehicles, airbag deployments, and the dual effect

Body region	Pre-ADR 69 (n=156)	Post-ADR 69 (n=129)	95% CI (L-U)	P
Injured / AIS 1+	39.7%	25.6%		
Post-ADR 69	OR: 0.71		0.36-1.38	≥0.05
Airbag deployment	OR: 0.60		0.31-1.16	≥0.05
ADR 69+Airbag	OR: 0.42		0.22-0.84	≤0.01
AIS 2+ injury	11.5%	1.5%		
Post-ADR 69	OR: 0.12		0.02-0.83	≤0.05
Airbag deployment	OR: 0.09		0.01-0.91	≤0.01
ADR 69+Airbag	OR: 0.01		0.001-0.18	≤0.001

The model building process revealed that EBS (km/h) was significantly related to AIS 2+ face injury risk, such that for every 1 km/h increase in EBS there was an 8% increase in the likelihood of sustaining an AIS 2+ face injury, and this relationship was seen to be linear (OR: 1.08, CI: 1.04-1.12, p≤0.001). While the comparisons are not statistically significant, vehicle market class was an important variable to adjust for in the derivation of the effectiveness of both ADR 69 and airbags on face injury risk. There was, however, some indicative evidence that drivers of medium and large vehicles being associated with a lower risk of AIS 2+ face injury risk compared to drivers of small vehicles (Medium: OR: 0.34, CI: 0.03-3.81, p≥0.05; Large: OR: 0.37, CI: 0.10-1.40, p≥0.05). The object struck was an important predictor of AIS 2+ face injuries, such that those impacting poles and trees were seven times more likely to sustain a moderate or worse face injury (OR: 7.10, 1.92-26.1, p≤0.01) relative to those impacting another sedan or derivative. Although the confidence intervals are wide, there was a trend toward higher injury risk for drivers striking vehicles in the 4WD / van / truck / bus grouping compared to sedan or derivative vehicles (OR: 3.50, 0.78-15.64, p≥0.05).

Figure 11 presents the observed probability distribution for AIS 2+ face injuries for drivers of pre-ADR 69 vehicles and post-ADR 69 vehicles, while Table 22 presents the probability estimates in 10 km/h EBS increments. The equations in Equation Box 2, Section 7.1.2, were used to calculate the probability estimates, and these are adjusted estimates. The difference in injury risk is evident with the post-ADR 69 probability curve sitting to the right of the pre-ADR 69 curve, reflecting the odds ratio presented in Table 21 (OR: 0.12, CI: 0.02-0.83, p≤0.05). The risk beyond 48 km/h (indicated by the vertical line) increases, however the overall probability of injury for drivers of post-ADR 69 vehicles remains relatively low, reaching a maximum of 40% compared to pre-ADR 69 drivers reaching a maximum probability risk of 83% at an EBS of 97 km/h.

Figure 11: Observed probability distribution for AIS 2+ face injuries for drivers of post-ADR 69 vehicles; vertical line is ADR 69 test speed

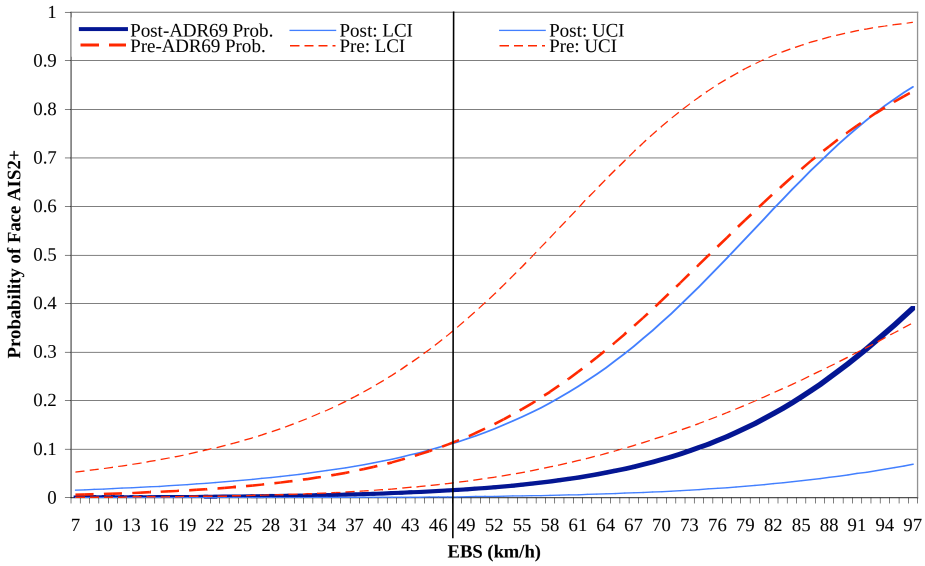


Table 22: Probability estimates for AIS 2+ face injuries for drivers of post-ADR 69 and pre-ADR 69 vehicles by EBS (km/h) with ADR 69 test speed in bold

EBS (km/h)	Pre-ADR 69 cases			Post-ADR 69 cases		
	Probability	95th% CI		Probability	95th% CI	
		Lower	Upper		Lower	Upper
20	0.016	0.003	0.094	0.002	0.000	0.029
30	0.033	0.007	0.149	0.004	0.000	0.046
40	0.068	0.017	0.240	0.009	0.001	0.076
48	**0.117**	**0.031**	**0.350**	**0.016**	**0.002**	**0.115**
50	0.133	0.036	0.384	0.019	0.003	0.128
60	0.245	0.072	0.576	0.039	0.006	0.218
70	0.406	0.126	0.765	0.079	0.013	0.362
80	0.590	0.199	0.893	0.153	0.026	0.554
90	0.752	0.289	0.958	0.276	0.047	0.746

Figure 12 presents the observed probability distribution for AIS 2+ face injuries for drivers of vehicles with and without airbag deployments, while Table 23 presents the probability estimates in 10 km/h EBS increments.

The difference in injury risk between the airbag deployed and non-airbag group is evident, with the curves appearing to separate as EBS increases, however the confidence intervals are also increasingly wide. The risk among drivers of airbag deployed vehicles is very low in comparison to the non-airbag group, with the probability at 60 km/h being 3% compared to 24%, although as noted the confidence intervals are wide. Importantly though, the odds ratio indicates a highly beneficial airbag effect (OR: 0.09, CI: 0.01-0.91, p≤0.05; 91% reduction).

Figure 12: Observed probability distribution for AIS 2+ face injuries for drivers of airbag deployed and non-airbag fitted/deployed vehicles; vertical line is ADR 69 test speed

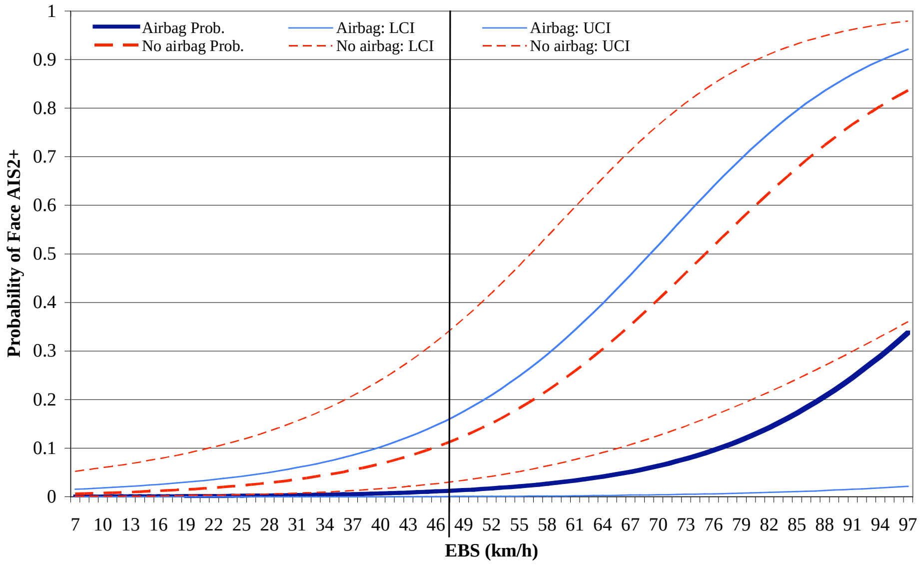


Table 23: Probability estimates for AIS 2+ face injuries for drivers of vehicles with and without airbag deployment by EBS (km/h) with ADR 69 test speed in bold

EBS (km/h)	Non-airbag deployed cases			Airbag deployed cases		
	Probability	95th% CI		Probability	95th% CI	
		Lower	Upper		Lower	Upper
20	0.016	0.003	0.094	0.002	0.000	0.032
30	0.033	0.007	0.149	0.003	0.000	0.057
40	0.068	0.017	0.240	0.007	0.000	0.103
48	**0.117**	**0.031**	**0.350**	**0.013**	**0.001**	**0.166**
50	0.133	0.036	0.384	0.015	0.001	0.187
60	0.245	0.072	0.576	0.031	0.002	0.326
70	0.406	0.126	0.765	0.064	0.004	0.518
80	0.590	0.199	0.893	0.126	0.008	0.715
90	0.752	0.289	0.958	0.232	0.015	0.860

3.3.3 Neck Injury Risk

When first mandated, ADR 69/00 used the head injury tolerance of $HIC_{36}1000$. As noted in Section 1.2, the US regulators specified the 36 ms integration interval to provide a degree of protection for the neck. Following debate and evidence of differences in the risk of injury between $HIC_{36}1000$ for short duration hard contact pulses and long duration no head contact pulses, the US FMVSS 208 regulation was changed to introduce $HIC_{15}700$ as well as a Neck Injury Risk tolerance parameter. In Australia, DoTARS regulators also adopted $HIC_{15}700$ for instances of no head contact, and also a neck injury tolerance value such that the neck injury measurements shall not exceed 3300N of tension force in the inferior-superior direction; additionally, head acceleration was not permitted to exceed 75g. These regulatory changes are important to evaluate and are the focus of this sub-section.

To provide context with respect to the type of neck injuries and their associated severity, Table24 details common neck injuries.

Table 24: Examples of neck injuries by AIS severity (AAAM, 1998)

AIS severity	Neck Injury example
Minor (1)	Superficial lacerations, contusions & penetrating injuries; laceration internal/external jugular vein;
Moderate (2)	Penetrating injury with tissue loss; major (size/depth) skin, muscle, subcutaneous laceration / avulsion; minor vessel (carotid artery - external, jugular vein, vertebral artery) injury; phrenic nerve injury; larynx contusion; hyoid fracture
Serious (3)	large blood loss due to injury to skin, muscle, subcutaneous laceration / avulsion; carotid – internal, artery injury; vertebral injury; larynx perforation; pharynx contusion
Severe (4)	Carotid and vertebral artery disruption with neurological deficit; larynx perforation with vocal cord involvement
Critical (5)	Major carotid artery injury; larynx & pharynx tear
Maximum (6)	Decapitation

Table 25 presents the distribution of neck injuries by AIS severity for drivers in the pre-ADR 69 and post-ADR 69 groups. Table 25 indicates that 25% of pre-ADR 69 drivers sustained an AIS 1 neck injury compared to 18.6% of drivers of post-ADR 69 vehicles. A larger proportion of drivers (4.5%) of pre-ADR 69 vehicles sustained AIS 2+ neck injuries compared to 1.5% of drivers of post-ADR 69 vehicles.

Table 25: Distribution of AIS severity neck injuries for pre-& post-ADR 69 drivers

AIS	Pre-ADR 69		Post-ADR 69	
	Freq.	**% of drivers**	**Freq.**	**% of drivers**
Minor (1)	39	25	24	18.6
Moderate (2)	5	3.2	2	1.5
Serious (3)	2	1.3	Nil	Nil
Severe (4)	Nil	Nil	Nil	Nil
Critical (5)	Nil	Nil	Nil	Nil

Neck Injury Risk

This section deviates somewhat from the other body region sections in that it examines AIS 1+ injuries in detail due to the small number of drivers sustaining AIS 2+ neck injuries in the sample. It is important to note that 'whiplash' injuries are coded as AIS 1 (minor) injuries in the Spine body region (Section 3.3.6) as per the AIS coding system. For reasons of consistency, AIS 2+ neck injury risk via the presentation of odds ratios is discussed, although probability charts are not presented.

Table 26 presents the finding that 30% of drivers in pre-ADR 69 vehicles sustained a neck injury compared to 20% of drivers in post-ADR 69 vehicles. In calculating the difference in injury risk, analysis indicated that it was necessary to adjust for EBS (km/h) and driver age. Age was transformed using fractional polynomials as the effect of increasing age did not translate to a linear increase in neck injury risk. The variables, vehicle market class (small, medium, large), collision partner/struck object, and driver weight, height, and gender were of no predictive value to the final statistical model and were therefore excluded. The logistic regression model displayed 'borderline acceptable' discrimination, with the Area under the ROC curve being 0.65.

The analysis indicates that the risk of neck injury for drivers of post-ADR 69 vehicles was 27% lower than their pre-ADR 69 driver counterparts, although the difference was not statistically significant (OR: 0.73, 0.38-1.43, $p \geq 0.05$). This estimate is adjusted for airbag deployment status, EBS (km/h) and age. The benefit associated with airbag deployment was higher, such that the results suggest that frontal airbag deployment is associated with a statistically significant 53% reduction in the risk of sustaining an injury to the neck (OR: 0.47, 0.24-0.93, $p \leq 0.05$). Drivers in post-ADR 69 vehicles with an airbag deployment had a neck injury risk of 0.35 relative to drivers of pre-ADR 69 vehicles where an airbag was unavailable, indicating a 65% lower risk of neck injury (OR: 0.35, 0.17-0.70, $p \leq 0.01$).

Table 26: Percent of drivers sustaining an injury to the neck and AIS 2+ neck injuries, & the adjusted relative odds ratios for drivers of post-ADR 69 vehicles compared to pre-ADR 69 vehicles, airbag deployments, and the dual effect

Body region	Pre-ADR 69 (n=156)	Post-ADR 69 (n=129)	95% CI (L-U)	P
Injured / AIS 1+	29.5%	20%		
Post-ADR 69	OR: 0.73		0.38-1.43	≥0.05
Airbag deployment	OR: 0.47		0.24-0.93	≤0.05
ADR 69+Airbag	OR: 0.35		0.17-0.70	≤0.01
AIS 2+ injury	4.5%		1.5%	
Post-ADR 69	OR: 0.62		0.10-3.67	≥0.05
Airbag deployment	OR: 0.33		0.05-0.2.04	≥0.05
ADR 69+Airbag	OR: 0.20		0.03-1.40	≥0.05

EBS was also seen to be predictive of neck injury outcome, with the interesting result of decreasing risk of injury with increasing EBS. More specifically, a 1 km/h increase in EBS translated to a 2% reduction in neck injury risk, OR: 0.98, CI: 0.96-0.99, $p \leq 0.05$). This result is consistent with the large body of scientific literature that demonstrates that AIS 1+ 'whiplash' type injuries are more common at lower impact speeds, and while 'whiplash' injuries are coded to the Spine AIS body region, AIS 1 neck injuries do include superficial lacerations and contusions, injuries likely to be associated with 'whiplash'. In interpreting this result, it is also important to note the small number of AIS 2+ neck injuries in the sample.

Figure 13 presents the observed probability distribution for AIS 1+ neck injuries for drivers of pre-ADR 69 and post-ADR 69 vehicles, while Table 27 presents the probability estimates in 10 km/h EBS increments. The equations in Equation Box 3, Section 7.1.3, were used to calculate the probability estimates. The two most important observations concerning the probability estimates presented is the lack of difference in injury risk between the two ADR 69 groups, and the finding of reducing injury risk with increasing EBS as noted above.

Figure 13. Observed injury (AIS 1+) probability distribution for neck injuries for drivers of pre-ADR 69 and post-ADR 69 vehicles; vertical line is ADR 69 test speed

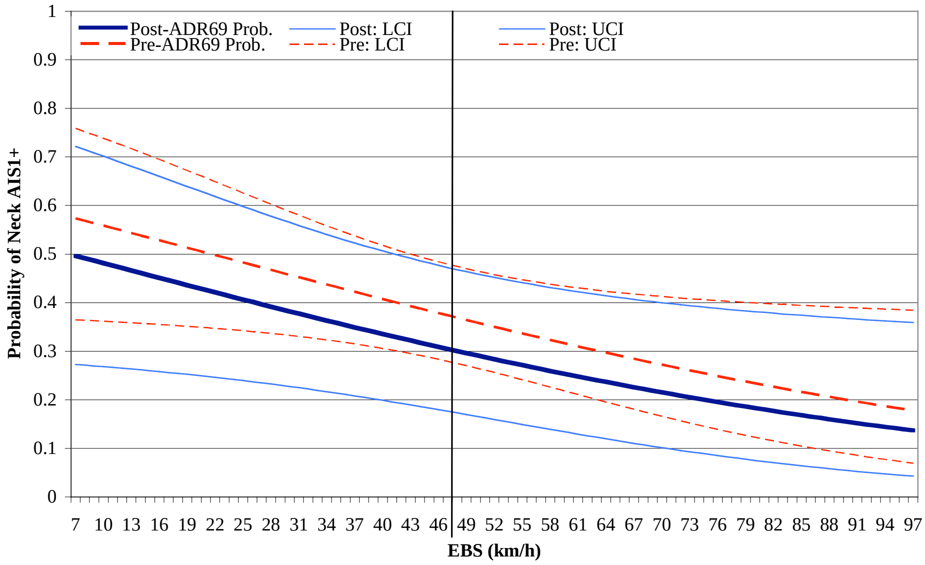


Table 27: Probability estimates for AIS 1+ neck injuries for drivers of pre-ADR 69 and post-ADR 69 vehicles; ADR 69 test speed shown in bold

EBS (km/h)	Pre-ADR 69 cases			Post-ADR 69 cases		
	Probability	95th% CI		Probability	95th% CI	
#		Lower	Upper		Lower	Upper
10	0.56	0.36	0.74	0.48	0.27	0.70
20	0.51	0.35	0.66	0.43	0.25	0.63
30	0.46	0.33	0.59	0.38	0.23	0.57
40	0.41	0.31	0.52	0.34	0.20	0.51
48	**0.37**	**0.27**	**0.47**	**0.30**	**0.17**	**0.47**
50	0.36	0.27	0.47	0.29	0.17	0.46
60	0.31	0.22	0.43	0.25	0.13	0.43
70	0.27	0.17	0.41	0.22	0.10	0.40
80	0.23	0.12	0.40	0.18	0.08	0.38
90	0.20	0.09	0.39	0.15	0.05	0.37

Figure 14 presents the observed probability distribution for neck AIS 1+ injuries for drivers of vehicles with and without airbag deployments, while Table 28 presents the probability estimates in 10 km/h EBS increments. The equations in Equation Box 3, Section 7.1.3, were used to calculate the probability estimates. The difference in neck injury risk between the airbag deployed and non-airbag group is evident (OR: 0.47, CI: 0.24-0.93, p≤0.05; 53% reduction), and the risk among drivers of airbag deployed vehicles is consistently lower than the non-airbag group. The probability estimates also demonstrate that the risk of injury decreases with increasing EBS.

Figure 14: Observed injury (AIS 1+) probability distribution for neck injuries for drivers of vehicles with and without airbag deployments; vertical line is ADR 69 test speed

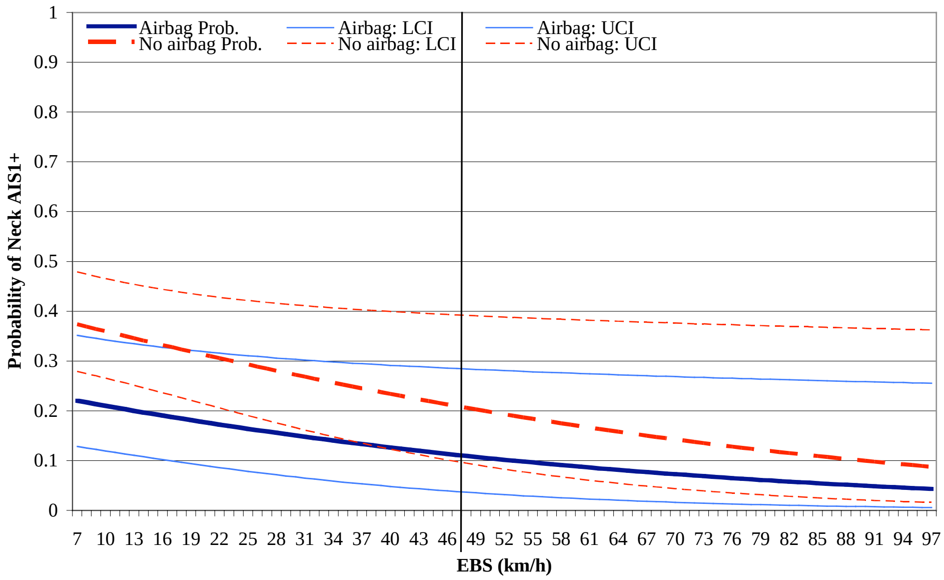


Table 28: Probability estimates for AIS 1+ neck injuries for drivers of vehicles with and without airbag deployments; ADR 69 test speed shown in bold

EBS (km/h)	Non-airbag deployed cases			Airbag deployed cases		
	Probability	95th% CI		Probability	95th% CI	
		Lower	Upper		Lower	Upper
10	0.36	0.27	0.47	0.21	0.12	0.34
20	0.31	0.22	0.43	0.18	0.09	0.32
30	0.27	0.17	0.41	0.15	0.07	0.30
40	0.23	0.12	0.40	0.13	0.05	0.29
48	**0.21**	**0.09**	**0.39**	**0.11**	**0.04**	**0.28**
50	0.20	0.09	0.39	0.11	0.03	0.28
60	0.17	0.06	0.38	0.09	0.02	0.28
70	0.14	0.04	0.38	0.07	0.02	0.27
80	0.12	0.03	0.37	0.06	0.01	0.26
90	0.10	0.02	0.37	0.05	0.01	0.26

In the construction of the logistic regression model to obtain estimates of the impact of ADR 69 and airbags on neck injury outcome, driver age was an important predictor variable of neck injury outcome. Figure 15 and Table 29 presents the probability of neck injury by driver age and the most striking observation is that neck injury risk is not linear. Using fractional polynomials (Royston and Altman, 1994) age can be transformed to account for the non-linear relationship to neck injury risk. The probability of neck injury increases rapidly from 17 years to 30 years of age, and then decreases in a largely linear manner. The equations presented in Equation Box 3, Section 7.1.3, were used to calculate these probability estimates, with the transformation of age noted. Notably, driver gender was not seen to hold any predictive value in the calculation of neck injury risk, however bony structures of the cervical spine are included in the Spine AIS body region (Section 3.3.6).

Figure 15: Observed probability distribution for neck injuries by driver age

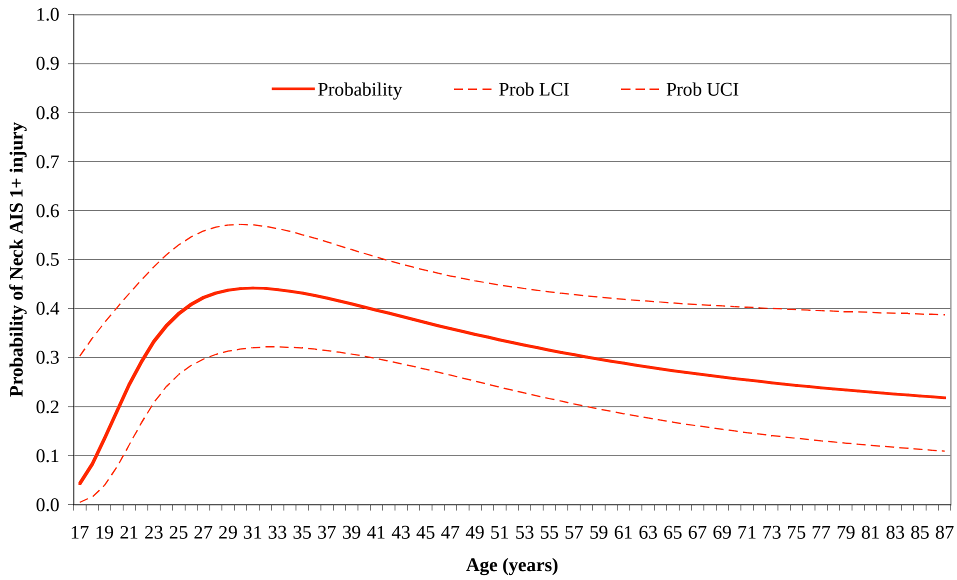


Table 29: Observed injury (AIS 1+) probability estimates for Neck AIS injuries for drivers by age; ADR 69 test speed shown in bold

Age (years)	Probability estimate	95th% CI	
		Lower CI	Upper
20	0.19	0.08	0.40
30	0.44	0.32	0.57
40	0.40	0.30	0.51
48	**0.35**	**0.26**	**0.46**
50	0.34	0.25	0.45
60	0.29	0.19	0.42
70	0.26	0.15	0.40
80	0.23	0.12	0.39

AIS 2+ Neck Injury Risk

Among drivers of pre-ADR 69 vehicles, 4.5% sustained AIS 2+ neck injuries compared to 1.5% of post-ADR 69 drivers (Table 26). Although not statistically significant, the point estimate of the odds ratio associated with drivers of post-ADR 69 vehicles was 38% lower than for drivers of pre-ADR 69 manufactured vehicles (OR: 0.62, 0.10-3.67, $p \geq 0.05$), while a 67% reduction in the likelihood of injury associated with airbag deployment was observed, although this was also not statistically significant (OR: 0.33, 0.05-2.04, $p \geq 0.05$). The relative odds for drivers of post-ADR 69 vehicles with an airbag deployment compared to drivers of pre-ADR 69 vehicles without an airbag deployment sustaining an AIS 2+ neck injury was 0.20, representing an indicative 80% reduction in the likelihood of sustaining AIS 2+ neck injuries (OR: 0.20, CI: 0.03-1.40, $p \geq 0.05$), although as with the above estimates this was also not statistically significant.

In calculating the difference in injury risk for AIS 2+ neck injuries, analysis indicated that it was necessary to statistically ‘force’ the variables of ADR 69 group, airbag status and EBS (km/h) into the model, as indicated by the above odds ratios as well as the overall logistic regression model failing to reach statistical significance, $\chi^2(3)=4.4$, $p\geq0.05$. Other parameters assessed were: vehicle market group; collision partner/struck object; driver characteristics of height, weight, age and gender, none of which were of any predictive value. The observed probability chart for AIS 2+ neck injuries among drivers of post-ADR 69 vehicles and airbag deployed vehicles are not presented due to the probability curve being essentially flat and the 95th percentile confidence intervals being extremely wide, reflecting the extremely low number of cases with AIS 2+ neck injuries. The failure to detect statistically significant differences is most likely due to low sample numbers, combined with a small risk of AIS 2+ injuries among this sample.

Finally, the probability of AIS 2+ injury was low at the ADR 69 test speed of 48 km/h, with the estimate being 9% (CI: 0.004-0.31) among the drivers of pre-ADR 69 cars compared to 4% (CI: 0.01-0.22) for drivers of post-ADR 69 passenger cars. Similarly, the probability of AIS 2+ neck injuries among drivers of without an airbag deployment was 9% (CI: 0.004-0.31) compared to 4% (CI: 0.02-0.29) among drivers exposed to an airbag deployment. The equations presented in Equation Box 4, Section 7.1.4, were used to calculate these probability estimates.

3.3.4 Chest Injury Risk

ADR 69/00 mandated two criteria specifically focussed on chest injury risk, these being:

1. Chest deceleration measured by accelerometers in the dummy’s chest must not exceed the limit of 60g, except for values whose cumulative duration is not more than 3 ms
2. Compression deflection of the sternum relative to the spine must not exceed 76.2 mm (Hybrid III only)

This sub-section aims to evaluate the risk of chest injury among drivers of pre-ADR 69 vehicles and post-ADR 69 vehicles. Common chest (thorax) injuries are presented in Table 30.

Table 30: Examples of chest injuries by AIS severity (AAAM, 1998)

AIS severity	Chest Injury example
Minor (1)	Superficial lacerations, contusions & penetrating injuries; rib cage contusion; fracture of 1 rib; sternum contusion; myocardial contusion
Moderate (2)	Penetrating injury with tissue loss; major (size/depth) skin, muscle, subcutaneous laceration / avulsion; contusion diaphragm, pericardial contusion; Fracture of 2 – 3 ribs, fracture of sternum
Serious (3)	large blood loss due to injury to skin, muscle, subcutaneous laceration / avulsion; vessel injuries (minor); lung laceration; haemo-pneumothorax
Severe (4)	Aortic artery injury; Venous injuries; Fracture bronchus, major myocardial contusion; bilateral lung lacerations; > 3 ribs with haemo-pneumothorax
Critical (5)	Major vessel tears; heart perforation; lung laceration with tension pneumothorax; > 3 ribs bilateral with haemo-pneumothorax
Maximum (6)	Bilateral destruction of skeletal, vascular, organ and tissue systems

Table 31 presents the distribution of chest injuries by AIS severity for drivers in the pre-ADR 69 and post-ADR 69 group. The table indicates that 51% of pre-ADR 69 drivers sustained an AIS 1 chest injury compared to 45.7% of drivers of post-ADR 69 vehicles. A larger proportion of drivers of pre-ADR 69 vehicles (23.7%) sustained AIS 2 chest injuries compared to 8.5% of drivers of post-ADR 69 vehicles. A larger proportion of post-ADR 69 drivers sustained AIS 3+ chest injuries (10.8%) compared to 6.4% of pre-ADR 69 drivers.

Table 31: Distribution of AIS severity chest injuries for pre-& post-ADR 69 drivers

AIS	Pre-ADR 69		Post-ADR 69	
	Freq.	% of drivers	Freq.	% of drivers
Minor (1)	80	51.2	59	45.7
Moderate (2)	37	23.7	11	8.5
Serious (3)	7	4.5	12	9.3
Severe (4)	3	1.9	2	1.5
Critical (5)	Nil	Nil	Nil	Nil

Table 32 presents the finding that 61% of drivers in pre-ADR 69 vehicles sustained a chest injury compared to 50% of drivers in post-ADR 69 vehicles. In calculating the difference in injury risk, analysis indicated that it was necessary to adjust for EBS (km/h), collision partner / struck object, driver age, and driver height. The final logistic regression model displayed ‘acceptable’ discrimination, with the Area under the ROC curve being 0.73.

The analysis indicates that the risk of chest injury for drivers of post-ADR 69 vehicles was not statistically different to that of their pre-ADR 69 driver counterparts (OR: 1.11, CI: 0.61-2.04, $p \geq 0.05$). The action of the airbag appears to have some injury mitigation value when considering all injuries, though the reduction was not statistically significant (OR: 0.58, 0.31-1.10, $p \geq 0.05$). Drivers in post-ADR 69 vehicles with an airbag deployment had a chest injury risk of 0.65 relative to drivers in pre-ADR 69 vehicles where there was no driver airbag either available or deployed; this result is indicative of a 35% lower risk of chest injury, although the effect was not statistically significant (OR: 0.65, 0.34-1.24, $p \geq 0.05$). It appears from this analysis that chest injury reductions seen in post-ADR 69 vehicles are due largely to the action of the driver airbag.

In the derivation of chest injury risk, it was necessary to adjust for collision partner / object struck, driver age and driver height. With respect to object struck, those involved in collisions with poles / trees were 73% more likely to sustain injuries of the chest compared to those involved in collisions with another sedan (or similar), though this was of borderline statistical significance (OR: 1.73, CI: 0.97-3.11, $p=0.06$); there was however no difference in chest injury risk where the collision partner was a vehicle in the 4WD /van /truck / bus group (OR: 0.87, 0.38-1.97, $p \geq 0.05$). Notably, for every one year increase in driver age the risk of sustaining a chest injury rises by 3% (OR: 1.03, CI: 1.01-1.05, $p \leq 0.001$), while for every 1 cm increase in driver height, the risk of sustaining a chest injury was seen to decrease by 4% (OR: 0.96, CI: 0.93-0.99, $p \leq 0.01$), indicating significantly greater risk for shorter drivers.

Table 32: Percent of drivers sustaining an injury to the chest and AIS 2+ chest injuries, & the adjusted relative odds ratios for drivers of post-ADR 69 vehicles compared to pre-ADR 69 vehicles, airbag deployments, and the dual effect

Body region	Pre-ADR 69 (n=156)	Post-ADR 69 (n=129)	95% CI (L-U)	P
Injured / AIS 1+	60.9%	50.4%		
Post-ADR 69	OR: 1.11		0.61-2.04	p≥0.05
Airbag deployment	OR: 0.58		0.31-1.10	p≥0.05
ADR 69+Airbag	OR: 0.65		0.34-1.24	p≥0.05
AIS 2+ injury	26.9%	16.3%		
Post-ADR 69	OR: 1.24		0.52-2.97	p≥0.05
Airbag deployment	OR: 0.21		0.09-0.52	p≤0.001
ADR 69+Airbag	OR: 0.26		0.12-0.60	p≤0.001

AIS 2+ Chest Injury Risk

Table 32 shows that 27% of drivers of pre-ADR 69 vehicles sustained an AIS 2+ chest injury compared to 16% of post-ADR 69 drivers. While the ADR 69 estimate is not significant (1.24, 0.52-2.97, $p \geq 0.05$), the effect of a frontal airbag deployment represents a 79% reduction in the likelihood of sustaining an AIS 2+ chest injury versus non-deployment (OR: 0.21, 0.09-0.52, $p \leq 0.001$). The airbag effect clearly drives the benefits associated with post-ADR 69 vehicles with an airbag deployment relative to drivers of pre-ADR vehicles without an airbag deployment (OR: 0.26, 0.12-0.60, $p \leq 0.001$).

In calculating the difference in injury risk, analysis indicated that it was necessary to statistically adjust for the effect of EBS (km/h), vehicle market group (small, medium, large), driver age and driver height, as they were all seen to influence the risk of chest injury. Due to the non-linear relationship for age and height to chest AIS 2+ injury risk, these two variables were transformed by method of fractional polynomials (Royston & Altman, 1994). The final logistic regression model displayed ‘excellent’ discrimination, with the Area under the ROC curve being 0.84, and the Hosmer-Lemeshow goodness of fit test indicating good model fit, $p=0.5$.

EBS (km/h) was significantly related to the outcome of AIS 2+ chest injuries, with the relationship translating to a 2.6% increase in risk for every 1 km/h increase in EBS (OR: 1.026, CI: 1.00-1.04, $p \leq 0.05$). The vehicle market class in which the driver was travelling was also an important predictor of AIS 2+ chest injuries, such that drivers in large vehicles were significantly less likely to sustain a moderate or worse chest AIS 2+ injury (OR: 0.41, 0.17-0.98, $p \leq 0.05$) relative to drivers of small vehicles, while there was no difference in injury risk for drivers of medium sized vehicles compared to small vehicles (OR: 0.92, 0.24-3.4, $p \leq 0.05$). In addition, driver height was significantly related to injury risk; while the probability chart is not presented here, it is important to note the injury risk relationship is not linear and appears as an inverted bath-tub.

Figure 16 and Table 33 presents the observed probability distribution for AIS 2+ chest injuries for drivers of pre-ADR 69 and post-ADR 69 vehicles by EBS (km/h), and it may be observed that there is no discernible difference between the two groups. The probability of an AIS 2+ chest injury at the ADR 69 test speed of 48 km/h is seen to be 0.67 (CI: 0.43-0.84) for drivers of post-ADR 69 vehicles and 0.62 (CI: 0.41-0.79) for drivers of pre-ADR 69 vehicles. The high probability of chest AIS 2+ injuries at relatively low speeds for drivers of post-ADR 69 vehicles is cause for some concern. The formula in Equation Box 5, Section 7.1.5, was used to derive the probability estimates.

Figure 16: Observed injury probability distribution for AIS 2+ chest injuries for drivers of post-ADR 69 vehicles. (Black vertical line indicates 48 km/h; ADR 69 test speed)

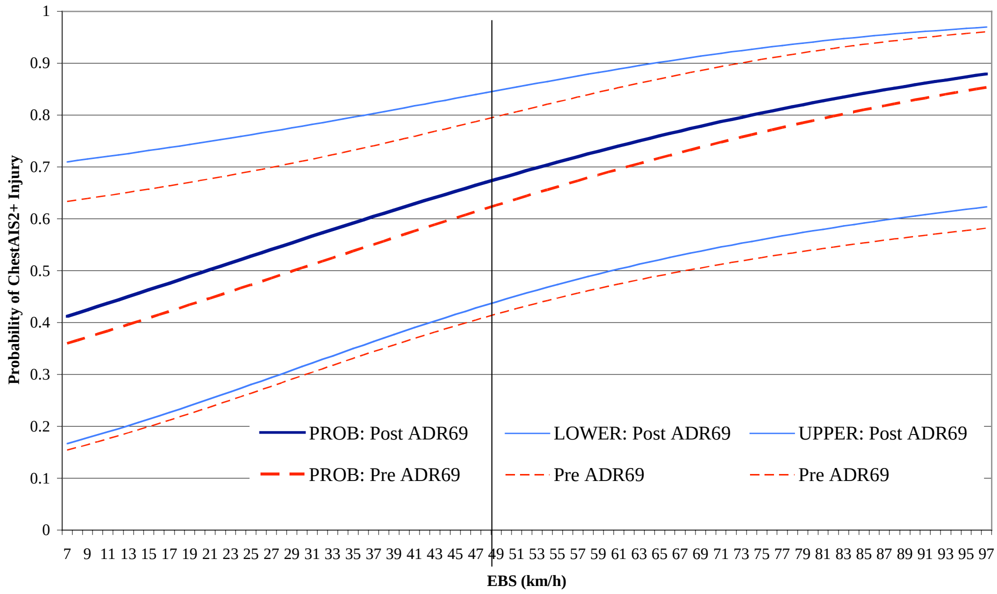


Table 33: Probability estimates for AIS 2+ chest injuries for drivers of pre-ADR 69 and post-ADR 69 vehicles; ADR 69 test speed shown in bold

EBS (km/h)	Pre-ADR 69 cases			Post-ADR 69 cases		
	Probability	95th% CI		Probability	95th% CI	
		Lower	Upper		Lower	Upper
20	0.44	0.23	0.67	0.50	0.25	0.75
30	0.51	0.30	0.71	0.56	0.32	0.78
40	0.57	0.36	0.75	0.62	0.38	0.81
48	**0.62**	**0.41**	**0.79**	**0.67**	**0.43**	**0.84**
50	0.63	0.42	0.80	0.68	0.45	0.85
60	0.69	0.47	0.85	0.74	0.50	0.89
70	0.74	0.51	0.89	0.78	0.54	0.92
80	0.79	0.54	0.92	0.82	0.58	0.94
90	0.83	0.57	0.95	0.86	0.61	0.96

Figure 17 presents the observed probability distribution for AIS 2+ chest injuries for drivers of vehicles with and without airbag deployment by EBS (km/h). There is a clear difference in the injury risk distribution between the two groups; this can also be seen in the probability of injury estimates in Table 34. For drivers of vehicles where an airbag deployed, the probability of an AIS 2+ chest injury at the ADR 69 test speed of 48 km/h is seen to be 0.26 (CI: 0.09-0.54) compared to a probability of 0.62 (CI: 0.41-0.79). The highest probability of AIS 2+ chest injuries for drivers in a vehicle where the frontal airbag deployed was 0.55 (CI: 0.17-0.88) compared to 0.85 (CI: 0.58-0.96) for drivers of non-airbag fitted / deployed vehicles, indicating that the airbag deployment was the most significant improvement in frontal impact protection for the chest.

Figure 17: Observed injury probability distribution for AIS 2+ chest injuries for drivers with and without frontal airbag deployments. (Black vertical line indicates 48 km/h; ADR 69 test speed)

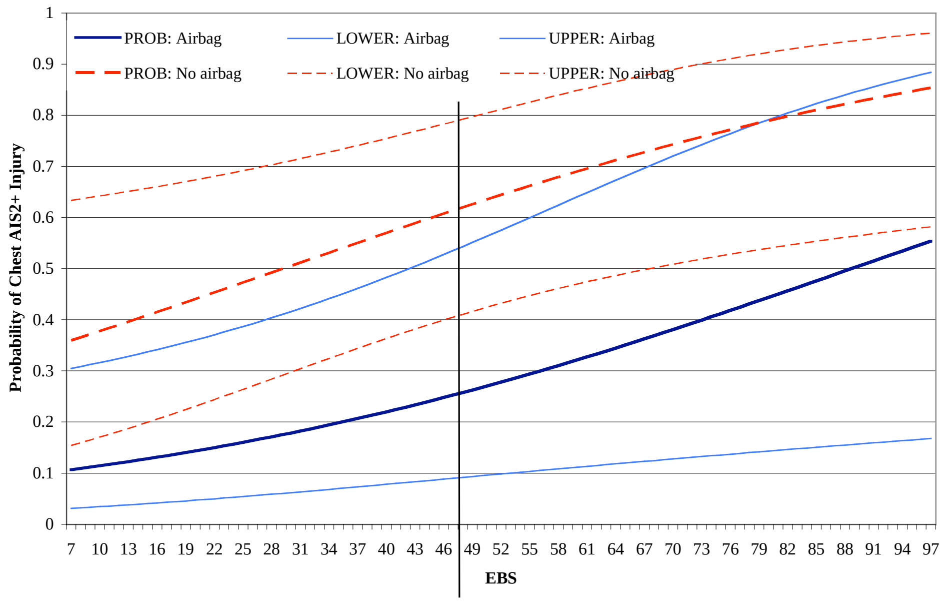


Table 34: Probability estimates for AIS 2+ chest injuries for drivers of vehicles with and without an airbag deployment; ADR 69 test speed shown in bold

EBS (km/h)	Non-airbag deployed cases			Airbag deployed cases		
	Probability	95th% CI		Probability	95th% CI	
		Lower	Upper		Lower	Upper
20	0.44	0.23	0.67	0.14	0.05	0.36
30	0.51	0.30	0.71	0.18	0.06	0.42
40	0.57	0.36	0.75	0.22	0.08	0.48
48	**0.62**	**0.41**	**0.79**	**0.26**	**0.09**	**0.54**
50	0.63	0.42	0.80	0.27	0.10	0.56
60	0.69	0.47	0.85	0.32	0.11	0.64
70	0.74	0.51	0.89	0.38	0.13	0.72
80	0.79	0.54	0.92	0.44	0.14	0.79
90	0.83	0.57	0.95	0.51	0.16	0.85

As noted earlier, age was associated with AIS 2+ chest injuries, although importantly the relationship was not linear. Using fractional polynomials, age was transformed to allow for the non-linear relationship with AIS 2+ chest injury probability, the results of which can be seen in Figure 18 and Table 35. The probability of sustaining an AIS 2+ injury increases dramatically from 17 years of age until approximately 40 years of age where the increase in risk is seen to slow and plateau above 70 years of age. That the risk of chest injury increases with increasing age is unsurprising, and is consistent with previous research (see for example, Foret-Bruno, Trossielle, Le Coz et al., 1998). These results demonstrate that further countermeasure work is required to improve the protection afforded to occupants, particularly older adults.

Figure 18: Observed probability distribution for AIS 2+ chest injuries by driver age

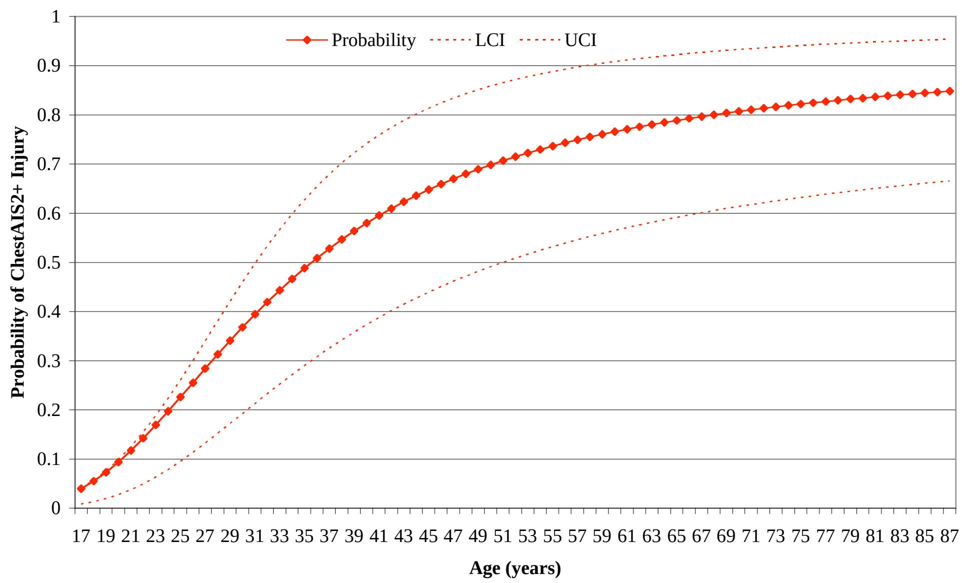


Table 35: Probability estimates for Chest AIS 2+ injuries for drivers by age

Age (years)	Probability estimate	95^{th}% CI	
		Lower CI	Upper
20	0.09	0.03	0.10
30	0.37	0.19	0.46
40	0.58	0.37	0.74
50	0.70	0.49	0.86
60	0.77	0.56	0.91
70	0.81	0.61	0.93
80	0.83	0.65	0.95

3.3.5 Abdomen / Pelvic contents Injury Risk

ADR 69/00 did not directly specify injury risk performance criteria for the abdomen and pelvic contents, however some benefit might be expected in reducing abdominal and pelvic content injuries from the introduction of the thorax injury criteria noted above, and the 10 kN axial load limit on the femur.

Table 36 provides common injury examples for the abdomen and pelvic region by increasing AIS severity. Note that the skeletal structures of the pelvis are included in the lower extremity. The major components of this region are organ systems.

Table 36: Examples of abdominal / pelvic content injuries by AIS severity (AAAM, 1998)

AIS severity	Abdomen / pelvic injury example
Minor (1)	Superficial lacerations, contusions & penetrating injuries; contusions to selected internal abdominal/pelvis contents
Moderate (2)	Penetrating injury with tissue loss; major (size/depth) skin, muscle, subcutaneous laceration / avulsion; splenic, liver & kidney contusions / simple lacerations; some duodenal injuries
Serious (3)	Large blood loss due to injury to skin, muscle, subcutaneous laceration / avulsion; minor (no disruption) tears to vessels (e.g., inferior vena cava); major disruption of vessels; perforation of colon; kidney, liver, pancreas lacerations
Severe (4)	Injury to vessels (minor tears or lacerations, e.g., abdominal aorta); massive disruption of internal organs
Critical (5)	Avulsion injuries of kidney & spleen, and other internal organs; major vessel disruption (perforation/puncture)
Maximum (6)	Total avulsion of all vascular attachments of liver (hepatic avulsion)

Table 37 provides a breakdown of the distribution of injuries by AIS severity for drivers of pre-ADR 69 and post-ADR 69 vehicles. Approximately 40% of drivers of pre-ADR 69 vehicles sustained an AIS 1 (minor) injury compared to 30% of drivers of post-ADR 69 vehicles. A smaller proportion of drivers sustained injuries of AIS 2 or above.

Table 37: Distribution of AIS severity abdomen/pelvic injuries for pre-& post-ADR 69 drivers

AIS	Pre-ADR 69		Post-ADR 69	
	Freq.	% of drivers	Freq.	% of drivers
Minor (1)	62	39.7	39	30.2
Moderate (2)	7	4.5	4	3.1
Serious (3)	1	0.6	3	2.3
Severe (4)	Nil	Nil	1	0.8
Critical (5)	Nil	Nil	1	0.8

Abdomen / Pelvic content Injury Risk

A higher proportion of drivers of pre-ADR 69 vehicles sustained an injury of the abdomen and pelvic contents (42.3%) compared to drivers of post-ADR 69 vehicles (33%), and the odds ratios (see Table 38) suggest no benefit between the two groups; in fact there is some indicative evidence of a higher injury risk associated with airbag deployments (OR: 1.43, 0.76-2.68, $p \geq 0.05$). For drivers of post-ADR 69 vehicles where an airbag deployed, there was no apparent benefit in reducing injury risk of the abdomen-pelvis compared to drivers of pre-ADR 69, non-airbag deployed vehicles.

In calculating the injury risk estimates, analysis indicated that it was necessary to adjust for EBS (km/h) and driver gender. EBS was significantly related to injury outcome, such that the risk of abdomen-pelvic injuries increases by 5% for every 1 km/h increase in EBS (OR: 1.05, CI: 1.03-1.07, $p \leq 0.01$), while males were 58% less likely to sustain abdomen-pelvic injuries relative to females in the sample (OR: 0.42, CI: 0.24-0.73, $p \leq 0.01$). Overall, the statistical model significantly predicted the occurrence of abdomen-pelvis injuries, and displayed 'acceptable' discrimination with the Area under the ROC curve being 0.73, $\chi^2(4)=43.20$, $p \leq 0.001$.

Table 38: Percent of drivers sustaining an injury to the abdomen/pelvis and AIS 2+ abdomen/pelvis injuries, & the adjusted relative odds ratios for drivers of post-ADR 69 vehicles compared to pre-ADR 69 vehicles, airbag deployments, and the dual effect

Body region	**Pre-ADR 69 (n=156)**	**Post-ADR 69 (n=129)**	**95% CI (L-U)**	**P**
Injured / AIS 1+	42.3%	33.3		
Post-ADR 69	OR: 0.89		0.48-1.63	p≥0.05
Airbag deployment	OR: 1.43		0.76-2.68	p≥0.05
ADR 69+Airbag	OR: 1.27		0.66-2.45	p≥0.05
AIS 2+ injury	4.5%	6.2%		
Post-ADR 69	OR: 2.61		0.72-9.43	p≥0.05
Airbag deployment	OR: 0.17		0.03-0.82	p≤0.05
ADR 69+Airbag	OR: 0.44		0.10-2.01	p≥0.05

Figure 19 presents the observed probability distribution for injuries of the abdomen-pelvic contents for drivers of pre-ADR 69 vehicles and post-ADR 69 vehicles, while Table 39 presents the probability estimates in 10 km/h EBS increments. The equations in Equation Box 6, Section 7.1.6, were used to calculate the probability estimates, and these are adjusted estimates for gender and the deployment or otherwise of the frontal airbag. Of note is the high degree of similarity in the probability of injury for drivers of pre-ADR 69 and post-ADR 69 vehicles, and this is reflected non-statistically significant odds ratio (OR: 0.89, CI: 0.48-1.63, $p \geq 0.05$). The risk at 48 km/h (indicated by the vertical line) for post-ADR 69 drivers was seen to be 54% (CI: 37-71%) compared to 57% (CI: 44-69%) for drivers of pre-ADR 69 vehicles.

Figure 19: Observed probability distribution for AIS 1+ injuries of the abdomen-pelvic contents for drivers of pre- and post-ADR 69 vehicles

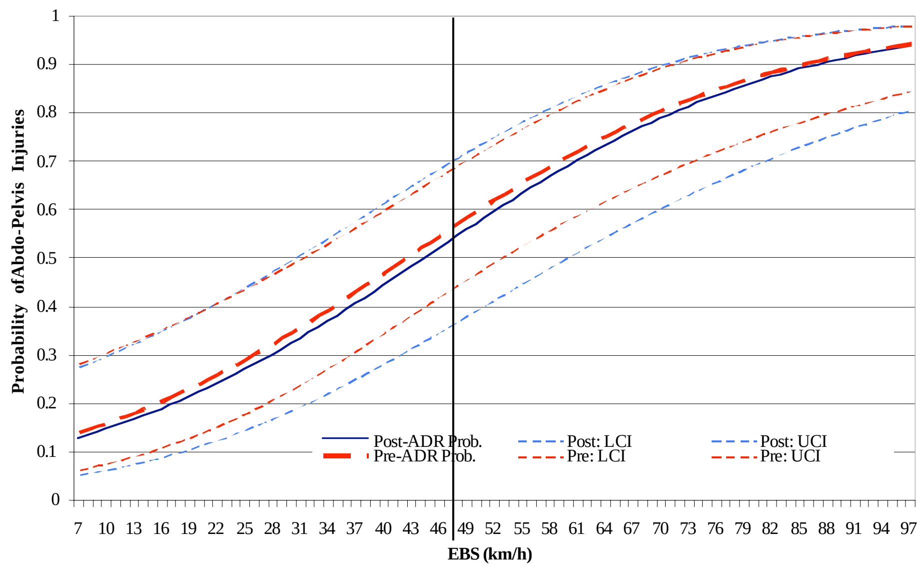


Table 39: Probability estimates for AIS 1+ abdomen-pelvic content injuries for drivers of post-ADR 69 vehicles; ADR 69 test speed shown in bold

EBS (km/h)	Pre-ADR 69 cases			Post-ADR 69 cases		
	Probability	95th% CI		Probability	95th% CI	
		Lower	Upper		Lower	Upper
10	0.16	0.08	0.30	0.15	0.06	0.30
20	0.24	0.14	0.39	0.22	0.11	0.39
30	0.35	0.23	0.49	0.32	0.19	0.50
40	0.47	0.35	0.60	0.44	0.28	0.61
48	**0.57**	**0.44**	**0.69**	**0.54**	**0.37**	**0.71**
50	0.60	0.47	0.71	0.57	0.39	0.73
60	0.71	0.58	0.82	0.69	0.50	0.83
70	0.81	0.67	0.89	0.79	0.60	0.90
80	0.87	0.75	0.94	0.86	0.69	0.94
90	0.92	0.81	0.97	0.91	0.76	0.97

Figure 20 and Table 40 presents the observed probability distribution for injuries of the abdomen-pelvic contents for drivers of vehicles with and without airbag deployment by EBS (km/h). As with the ADR 69 group comparison presented above, there is little difference in the probability of injury between the two airbag groups. Of concern however is the high probability of injury (approx. 70%) to the region at an EBS of 60 km/h.

Figure 20: Observed probability distribution for AIS 1+ injuries of the abdomen-pelvic contents for drivers with and without frontal airbag deployments

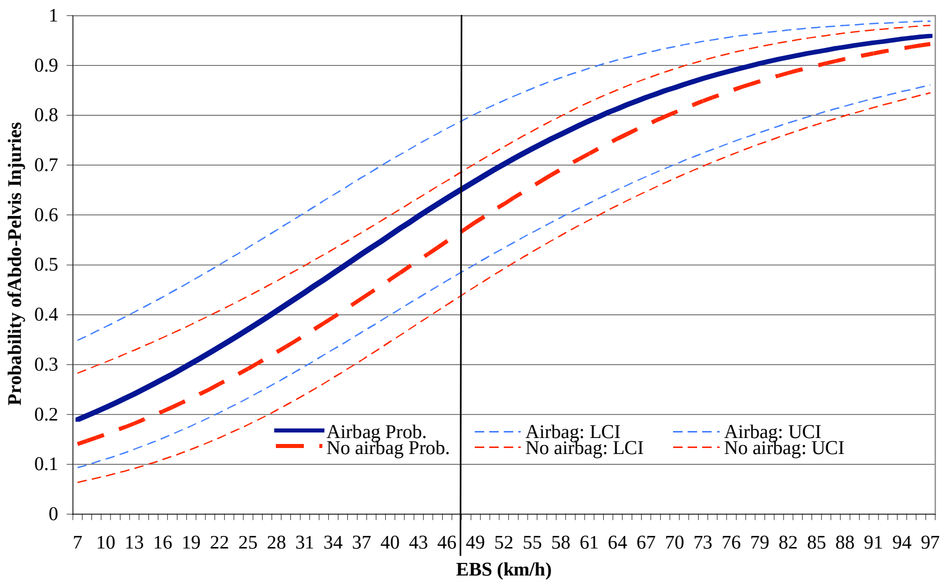


Table 40: Probability estimates for AIS 1+ abdomen-pelvic content injuries for drivers of vehicles with and without an airbag deployment

EBS (km/h)	Non-airbag deployed cases			Airbag deployed cases		
	Probability	95^{th}% CI		Probability	95^{th}% CI	
		Lower	Upper		Lower	Upper
10	0.16	0.08	0.30	0.21	0.11	0.38
20	0.24	0.14	0.39	0.31	0.19	0.48
30	0.35	0.23	0.49	0.43	0.29	0.59
40	0.47	0.35	0.60	0.56	0.40	0.71
48	**0.57**	**0.44**	**0.69**	**0.66**	**0.49**	**0.79**
50	0.60	0.47	0.71	0.68	0.51	0.81
60	0.71	0.58	0.82	0.78	0.61	0.89
70	0.81	0.67	0.89	0.86	0.70	0.94
80	0.87	0.75	0.94	0.91	0.77	0.97
90	0.92	0.81	0.97	0.94	0.83	0.98

AIS 2+ Abdomen / Pelvis Injury Risk

Approximately 4.5% of drivers of pre-ADR 69 vehicles sustained an AIS 2 (moderate) or higher injury of the abdomen and pelvic contents, compared to 6.2% of drivers of post-ADR 69 drivers. Table 38 (p.56) presents the odds ratios for AIS 2+ abdomen-pelvic content injury risk. Although not statistically significant, there was a trend toward drivers of post-ADR 69 manufactured vehicles being more likely to sustain this injury type than drivers of pre-ADR 69 vehicles (OR: 2.6, CI: 0.72-9.43, $p \geq 0.05$). Conversely, the relative odds of injury associated with a frontal airbag deployment were 0.17 (0.03-0.82, $p \leq 0.05$), translating to a statistically significant 83% reduction in injury risk. The combined benefit of ADR 69 vehicles plus airbag system deployment is indicated by the relative odds of injury being 56% lower (OR: 0.44, 0.10-2.01, $p \geq 0.05$) than for drivers of pre-ADR 69 vehicles without a frontal airbag system being activated. The latter two findings are indicative of benefits attributable to airbag system deployment, including seat belt technology (for instance, pretension systems and load limiters) in reducing the injury risk to the abdomen and pelvic contents.

In the calculation of odds ratios, EBS was seen to hold a non-linear relationship with the risk of AIS 2+ injuries, such that injury risk was higher for lower and higher EBS speeds ($p \leq 0.001$). The probability of AIS 2+ injury was low at the ADR 69 test speed of 48 km/h, with the estimate being 3% (CI: 0.01-0.08) among the drivers of pre-ADR 69 cars compared to 8% (CI: 0.02-0.24). for drivers of post-ADR 69 passenger cars. Similarly, the probability of AIS 2+ neck injuries among drivers of without an airbag deployment was 3% (CI: 0.01-0.08) compared to 1% (CI: 0.001-0.03) among drivers exposed to an airbag deployment. The equations in Equation Box 7, Section 7.1.7 were used to calculate the probability estimates

Finally, driver body weight was also an important predictor ($p \leq 0.05$) with the risk being higher for drivers of lighter body weight ($p \leq 0.05$).

3.3.6 Spine Injury Risk

ADR 69/00 did not directly specify performance criteria for the cervical spine with the exception of instances where no head contact was apparent. In cases of no head contact, ADR 69 sought to restrict the forces the Hybrid III dummy would experience, such that neck injury measurements shall not exceed 3300 N of tension force in the inferior-superior direction. Benefits might also be expected due to ADR 69's thorax and femur load specifications, which may act to limit forces applied to the thoraco-lumbar region of the vertebral column. This section will examine in detail AIS 1+ injuries due to 'whiplash' injuries being coded as AIS 1 (minor).

Table 41 gives examples of spinal injuries by AIS severity and these involve fractures of the vertebral column and spinal cord injuries at all levels, while Table 42 shows the proportion of drivers in the pre-ADR 69 group and post-ADR 69 group with each injury severity. Of importance is the observation that the proportion of drivers with spine injuries among the sample is low.

Table 41: Examples of spine injuries by AIS severity (AAAM, 1998)

AIS severity	Spine injury example
Minor (1)	Strain, acute with no fracture or dislocation (Cervical spine known as 'whiplash'); interspinous ligament disruption/laceration
Moderate (2)	Incomplete brachial plexus injury – contusion/laceration; Intervertebral disc injury without nerve root damage; disc subluxation without fracture or spinal cord contusion; contusion/laceration of nerve root; Vertebral fracture without cord involvement; fracture of vertebrae spinous process, transverse process, and minor compression (<25%) of vertebral body ('Burst fracture')
Serious (3)	Spinal cord contusion; major compression (>25%) of vertebral body ('Burst fracture'); fracture of vertebral lamina, pedicle
Severe (4)	Incomplete cord syndrome with *some* preservation of sensation/motor function
Critical (5)	Complete spinal cord syndrome - quadriplegia or paraplegia with no sensation. C4-C7; spinal cord laceration C4 or lower; Thoracic & Lumbar spine cord laceration & complete cord syndrome
Maximum (6)	Complete spinal cord syndrome - quadriplegia or paraplegia with no sensation. C1-C3; spinal cord laceration C3 or higher

Table 42: Distribution of AIS severity spine injuries for pre-& post-ADR 69 drivers

AIS	Pre-ADR 69		Post-ADR 69	
	Freq.	% of drivers	Freq.	% of drivers
Minor (1)	4	2.5	4	3.1
Moderate (2)	4	2.5	8	6.2
Serious (3)	1	0.6	2	1.5
Severe (4)	Nil	Nil	Nil	Nil
Critical (5)	Nil	Nil	Nil	Nil

Spine Injury Risk

Table 43 shows that 4.5% of drivers of pre-ADR 69 vehicles sustained an injury to the spine compared to 9.3% of drivers of post-ADR 69 vehicles. The direct ADR 69 comparison once controlled, or adjusted, for the effect of airbag deployment and impact EBS (km/h) shows that there was a significant increased risk for drivers of post-ADR 69 vehicles (OR: 6.62, 2.06-21.2, $p \leq 0.001$). This result is cause for some concern, and points to the need for future vehicle safety improvements, perhaps in improved seat design and seat belt systems. The analysis does however indicate a significant injury mitigation effect of the airbag, with the risk of spine injury being 81% lower where an airbag deployed (OR: 0.19, CI: 0.05-0.68, $p \leq 0.01$). There was, however, no benefit to drivers of post-ADR 69 vehicles where an airbag deployed, relative to drivers of pre-ADR 69 non-airbag deployed vehicles ($p \geq 0.05$). These results may be reflective of the influence of stiff front end structures in injury risk being compensated by airbag deployment, especially of the cervical spine.

In the analysis presented, it is important to note that variables such as vehicle market class, collision partner, and driver characteristics were not related to spine injury risk. Initial analysis indicated that weight was a significant predictor, however once a single outlier was removed from the analysis, occupant weight no longer held predictive value; hence the analysis presented excludes a single 66 year old with body weight 35 kg. While EBS was included in the model, there was no direct relationship with spine injury risk ($p \geq 0.05$). The statistical model itself displayed 'acceptable' discrimination, with Area under the ROC curve being 0.72.

Table 43: Percent of drivers sustaining an injury to the spine and AIS 2+ spine injuries, & the adjusted relative odds ratios for drivers of post-ADR 69 vehicles compared to pre-ADR 69 vehicles, airbag deployments, and the dual effect

Body region	Pre-ADR 69 (n=156)	Post-ADR 69 (n=129)	95% CI (L-U)	P
Injured / AIS 1+	4.5%	9.3%		
Post-ADR 69	OR: 6.62		2.06-21.2	≤0.001
Airbag deployment	OR: 0.19		0.05-0.68	≤0.01
ADR 69+Airbag	OR: 1.27		0.35-4.56	p≥0.05
AIS 2+ injury	2.5%	6.9%		
Post-ADR 69	OR: 9.95		2.29-43.1	≤0.01
Airbag deployment	OR: 0.18		0.04-0.81	≤0.05
ADR 69+Airbag	OR: 1.81		0.35-9.41	≥0.05

Figure 21 and Table 44 presents the probability of sustaining injuries to the spine for drivers of pre-ADR 69 and post-ADR 69 vehicles; the formulae in Equation Box 8, Section 7.1.8, were used in the calculation of these probability estimates. The ADR 69 test speed of 48 km/h is indicated by a vertical line in Figure 21 and by bold text in Table 44. As indicated by the odds ratio presented above, the probability estimates show the consistently higher risk of spine injury for drivers of post-ADR 69 vehicles. For instance, at an EBS of 48 km/h, the injury risk for drivers of post-ADR 69 vehicles was seen to be 0.27 (CI: 0.13-0.47) while the risk for drivers of pre-ADR 69 drivers was 0.05 (CI: 0.02-0.11); similar comparisons may be drawn across the entire EBS range.

Figure 21: Observed probability distribution for AIS 1+ spine injuries for drivers of pre-ADR 69 and post-ADR 69 vehicles; vertical line indicates 48 km/h; ADR 69 test speed

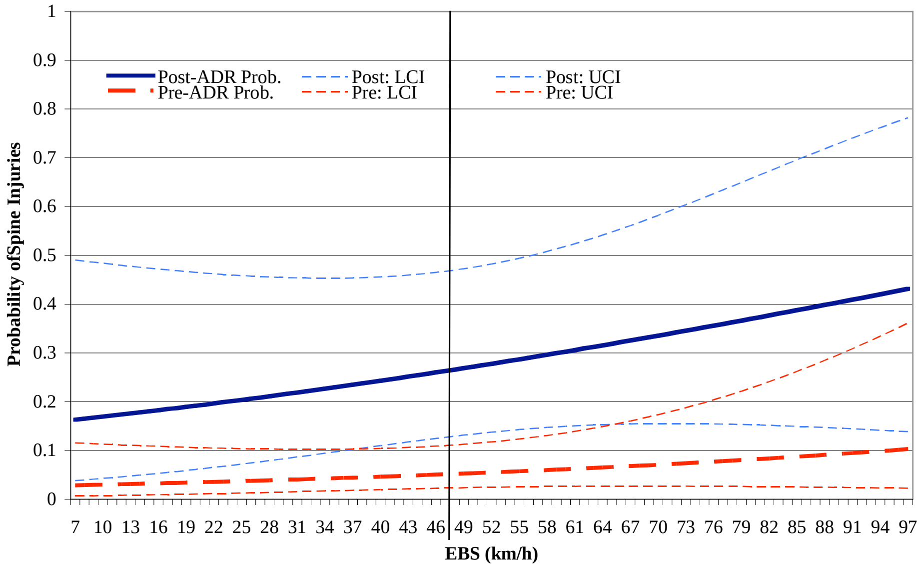


Table 44: Probability estimates for AIS 1+ spine injuries for drivers of pre-ADR 69 and post-ADR 69 vehicles

EBS (km/h)	Pre-ADR 69 cases			Post-ADR 69 cases		
	Probability	95th% CI		Probability	95th% CI	
		Lower	Upper		Lower	Upper
20	0.03	0.01	0.11	0.19	0.06	0.47
30	0.04	0.02	0.10	0.22	0.08	0.45
40	0.05	0.02	0.10	0.24	0.11	0.46
48	**0.05**	**0.02**	**0.11**	**0.27**	**0.13**	**0.47**
50	0.05	0.02	0.11	0.27	0.13	0.48
60	0.06	0.03	0.14	0.30	0.15	0.52
70	0.07	0.03	0.17	0.34	0.16	0.58
80	0.08	0.03	0.23	0.37	0.15	0.66
90	0.09	0.02	0.30	0.41	0.15	0.73

The injury mitigation effect of airbag fitment and deployment is seen expressed by the probability estimates presented in Figure 22 and Table 45. The odds ratio indicates a highly statistically significant 81% reduction in the risk of spine injury for those exposed to an airbag deployment relative to those without an airbag fitted / deployed (OR: 0.19, CI: 0.05-0.68, p≤0.01). While the airbag is highly beneficial in mitigating injuries to the spine, it is also important to note that the overall risk, or probability, of injury is small.

Figure 22: Observed probability distribution for AIS 1+ spine injuries for drivers of vehicles with and without airbag deployment

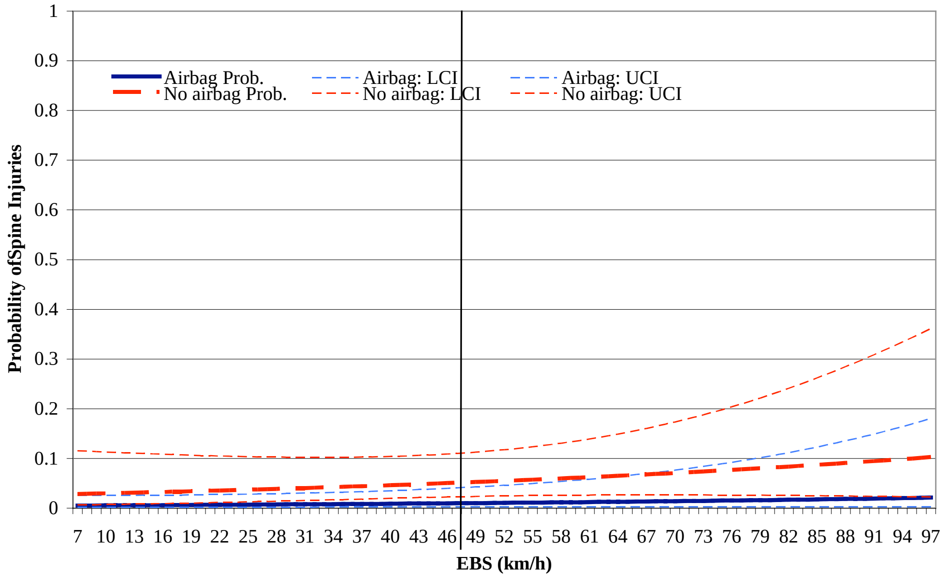


Table 45: Observed probability estimates for AIS 1+ injuries of the spine for drivers of vehicles with and without an airbag deployment; ADR 69 test speed shown in bold

EBS (km/h)	Non-airbag deployed cases			Airbag deployed cases		
	Probability	95th% CI		Probability	95th% CI	
		Lower	Upper		Lower	Upper
20	0.03	0.01	0.11	0.01	0.00	0.03
30	0.04	0.02	0.10	0.01	0.00	0.03
40	0.05	0.02	0.10	0.01	0.00	0.04
48	**0.05**	**0.02**	**0.11**	**0.01**	**0.00**	**0.04**
50	0.05	0.02	0.11	0.01	0.00	0.04
60	0.06	0.03	0.14	0.01	0.00	0.06
70	0.07	0.03	0.17	0.01	0.00	0.08
80	0.08	0.03	0.23	0.02	0.00	0.10
90	0.09	0.02	0.30	0.02	0.00	0.14

AIS 2+ Spine Injury Risk

Table 43 also shows that approximately 2.5% of drivers of pre-ADR 69 vehicles sustained an AIS 2 (moderate) or higher injury of the spine, compared to 6.9% of drivers of ADR 69 compliant vehicles. That the results mirror those seen for AIS 1+ injuries is unsurprising given the small numbers of drivers with AIS 2+ injuries, and consequently will not be elaborated upon. For purposes of completeness, it is noted that the probability of AIS 2+ injury was low at the ADR 69 test speed of 48 km/h, with the estimate being 3% (CI: 0.01-0.08) among the drivers of pre-ADR 69 cars compared to 21% (CI: 0.02-0.24). for drivers of post-ADR 69 passenger cars. Finally, the probability of AIS 2+ neck injuries among drivers of without an airbag deployment was 3% (CI: 0.01-0.08) compared to 0.5% (CI: 0.001-0.03) among drivers exposed to an airbag deployment. These probability estimates reflect the odds ratios presented in Table 43. The formulae in Equation Box 9, Section 7.1.9, were used in the calculation of these probability estimates.

3.3.7 Upper Extremity Injury Risk

Upper extremity injuries do not present the same degree of threat-to-life potential as injuries in other regions assuming appropriate and timely medical treatment is received, as evidenced by the highest possible AIS severity score being AIS 3 'Serious' for the region. Examples of upper extremity injuries are provided in Table 46.

Table 46: Examples of upper extremity injuries by AIS severity (AAAM, 1998)

AIS severity	Upper extremity injury example
Minor (1)	Superficial lacerations, contusions & penetrating injuries; minor lacerations of arterial/venous system; nerve contusions; joint sprains (elbow, shoulder, wrist) and bones of hand dislocation ; fracture of finger
Moderate (2)	Penetrating injury with tissue loss; major (size/depth) skin, muscle, subcutaneous laceration / avulsion; degloving injury of arm/forearm; minor lacerations of arterial and venous system; Dislocation of shoulder, sterno-clavicular joint; dislocation of wrist; fracture of clavicle; simple closed fracture of humerus, radius, scapula and ulna
Serious (3)	Amputation at any point of extremity except finger; penetrating injury with major (>20%) blood loss; major artery/vein lacerations; crush injury of wrist; open, displaced or comminuted fracture of humerus, radius or ulna

Table 47 shows the percentage of drivers in the two ADR 69 groups sustaining upper extremity injuries. A higher proportion of drivers of post-ADR 69 vehicles sustained AIS 1 'minor' injuries (64.3%) compared to drivers of pre-ADR 69 vehicles (53.8%). There were slightly fewer drivers of post-ADR 69 vehicles with 'moderate' (AIS 2) upper extremity injuries than their pre-ADR 69 counterparts, while a similar proportion sustained AIS 3 upper extremity injuries.

Table 47: Distribution of AIS severity upper extremity injuries for pre-& post-ADR 69 drivers

AIS	Pre-ADR 69		Post-ADR 69	
	Freq.	% of drivers	Freq.	% of drivers
Minor (1)	84	53.8	83	64.3
Moderate (2)	21	13.4	13	10.1
Serious (3)	5	3.2	5	3.9

Upper Extremity Injury Risk

As previous research has identified an increased injury risk associated with airbag deployments (Huelke, Moore, Compton, Samuels, & Levine, 1995), AIS 1 injuries were considered important to examine. Table 48 shows that a total of 70% of drivers of post-ADR 69 vehicles sustained an upper extremity injury, compared to 57% of drivers of pre-ADR 69 vehicles.

The statistical model building process indicated that the variables of EBS, driver height, object struck and vehicle market class required inclusion into the model due to either being a significant predictor of injury, or due to differences between the principal comparison groups, those being drivers of pre/post-ADR 69 vehicles and those with/without airbag deployments. The model itself displayed 'borderline acceptable' discrimination (0.635 Area under the ROC curve) indicating difficulty in obtaining a precise array of predictor variables. Interestingly, driver characteristics of age and gender were of no predictive value.

The analysis indicated a strong trend toward drivers of post-ADR 69 vehicles having a higher risk of sustaining upper extremity injuries than drivers of pre-ADR 69 vehicles (OR: 1.77, CI: 0.95-3.28, $p=0.07$), while there was no difference between those with and without an airbag deployment (OR: 1.20, CI: 0.64-2.26, $p \geq 0.05$). Of concern was the finding that the relative odds of sustaining minor (AIS 1) upper extremity injury was two times more likely for drivers of post-ADR 69 vehicles with an airbag deployment than for drivers of pre-ADR 69 vehicles without an airbag (OR: 2.13, 1.14-4.01, $p \geq 0.05$).

As noted above, EBS was found to be a significant predictor of upper extremity injuries, with the relationship being that for every 1 km/h increase in EBS, there was a 1.8% increase in injury risk (OR: 1.02, CI: 1.00-1.04, $p \leq 0.05$). Similarly, driver height was related to injury risk, such that for every 1 cm increase in height, there was a 3% increase in upper extremity injury risk (OR: 1.03, CI: 1.00-1.06, $p \leq 0.05$). The variables of object struck and vehicle market class were included in the statistical model for reasons of adjusting for different proportions between the ADR and airbag comparison groups, and neither was statistically related at the $p=0.05$ level to upper extremity injury risk.

Table 48: Percent of drivers sustaining an injury to the upper extremity and AIS 2+ upper extremity injuries, & the adjusted relative odds ratios for drivers of post-ADR 69 vehicles compared to pre-ADR 69 vehicles, airbag deployments, and the dual effect

Body region	Pre-ADR 69 (n=156)	Post-ADR 69 (n=129)	95% CI (L-U)	P
Injured / AIS 1+	57.1%	70.5%		
Post-ADR 69	OR: 1.77		0.95-3.28	0.07
Airbag deployment	OR: 1.20		0.64-2.26	p≥0.05
ADR 69+Airbag	OR: 2.13		1.14-4.01	p≤0.05
AIS 2+ injury	14.7%	13.9%		
Post-ADR 69	OR: 0.84		0.35-1.99	p≥0.05
Airbag deployment	OR: 0.95		0.40-2.28	p≥0.05
ADR 69+Airbag	OR: 0.81		0.33-1.95	p≥0.05

The probability estimates for upper extremity injuries are presented for drivers of pre-ADR 69 drivers and post-ADR 69 drivers in Figure 23, and are replicated in Table 49 in 10 km/h EBS increments. The ADR 69 test speed of 48 km/h is highlighted in Figure 23 by a vertical line and by bold typeface in Table 49. The formulae in Equation Box 10, Section 7.1.10, were used to calculate the probability estimates associated with the ADR 69 and airbag comparisons.

It is evident from Figure 23 and Table 49 that the risk of sustaining any AIS 1+ injury of the upper extremity is high, but higher for drivers of post-ADR 69 vehicles. At the ADR 69 test speed, the risk of injury was found to be 77% for drivers of post-ADR 69 vehicles and 66% for drivers of pre-ADR 69 vehicles. It does however remain important to note that AIS 1 injuries include superficial contusions but also joint sprains, fractured fingers and joint dislocations, and while these injuries may not present as a significant threat-to-life, they can represent significant morbidity in performing activities of daily living.

Figure 23: Observed probability distribution for AIS 1+ upper extremity injuries for drivers of pre-ADR 69 and post-ADR 69 vehicles

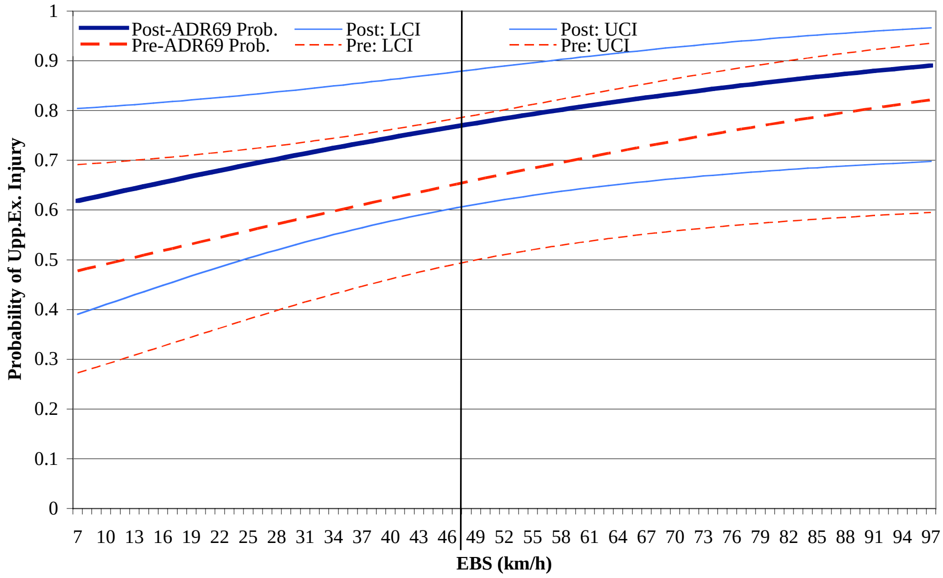


Table 49: Observed probability distribution for AIS 1+ upper extremity injuries for drivers of pre-ADR 69 and post-ADR 69 vehicles; ADR 69 test speed shown in bold

EBS (km/h)	Pre-ADR 69 cases			Post-ADR 69 cases		
	Probability	95th% CI		Probability	95th% CI	
		Lower	Upper		Lower	Upper
20	0.54	0.35	0.71	0.67	0.47	0.82
30	0.58	0.41	0.73	0.71	0.53	0.84
40	0.62	0.46	0.76	0.75	0.58	0.86
48	**0.66**	**0.50**	**0.79**	**0.77**	**0.61**	**0.88**
50	0.66	0.50	0.79	0.78	0.61	0.89
60	0.70	0.53	0.83	0.81	0.64	0.91
70	0.74	0.56	0.86	0.83	0.66	0.93
80	0.77	0.57	0.89	0.86	0.68	0.94
90	0.80	0.59	0.92	0.88	0.69	0.96

The probability estimates for sustaining upper extremity injuries by airbag deployment status is presented in Figure 24 and Table 50 below. Similar to the probability estimates presented above, the risk of upper extremity injury is high irrespective of airbag deployment group, however there is little difference in risk between the airbag deployed and no airbag group.

Figure 24: Observed probability distribution for AIS 1+ upper extremity injuries for drivers of vehicles with and without airbag deployment

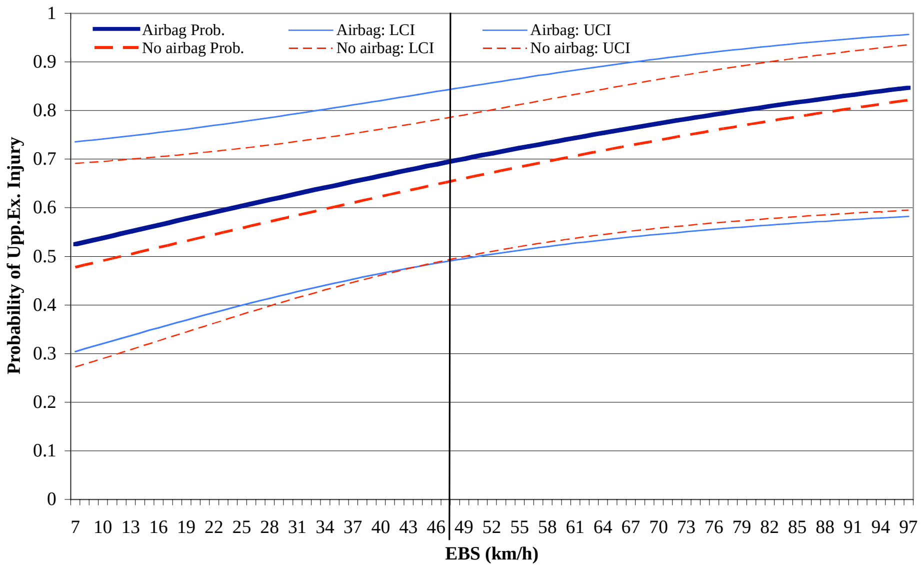


Table 50: Observed probability distribution for AIS 1+ upper extremity injuries for drivers of vehicles with and without an airbag deployment; ADR 69 test speed shown in bold

EBS (km/h)	Non-airbag deployed cases			Airbag deployed cases		
	Probability	95th% CI		Probability	95th% CI	
		Lower	Upper		Lower	Upper
20	0.54	0.35	0.71	0.58	0.37	0.76
30	0.58	0.41	0.73	0.63	0.42	0.79
40	0.62	0.46	0.76	0.67	0.47	0.82
48	**0.66**	**0.50**	**0.79**	**0.70**	**0.49**	**0.85**
50	0.66	0.50	0.79	0.70	0.50	0.85
60	0.70	0.53	0.83	0.74	0.53	0.88
70	0.74	0.56	0.86	0.77	0.55	0.91
80	0.77	0.57	0.89	0.80	0.56	0.93
90	0.80	0.59	0.92	0.83	0.57	0.95

AIS 2+ Upper Extremity Injury Risk

Table 48 (p.66) shows that approximately 15% of drivers of pre-ADR 69 vehicles sustained an AIS 2 (moderate) or higher injury of the upper extremity, compared to 14% of drivers of post-ADR 69 vehicles. AIS 2 injuries include dislocations of the shoulder and wrist, clavicle fractures and simple fractures of bones of the arm, while AIS 3 injuries include amputation, penetrating injuries with >20% blood loss, and open, displaced or comminuted fractures of the bones of the arm (refer Table 46).

The findings of the logistic regression model were such that there was no difference in risk of AIS 2+ injuries between the ADR 69 groups (OR: 0.84, CI: 0.35-1.99, $p \geq 0.05$) or the airbag deployed / non-deployed groups (OR: 0.95, CI: 0.40-2.28, $p \geq 0.05$). Similarly, there was no difference in injury risk of drivers of post-ADR 69 vehicles with an airbag deployed relative to drivers of pre-ADR 69 vehicles without an airbag (OR: 0.81, CI: 0.33-1.95, $p \geq 0.05$).

AIS 2+ upper extremity risk was influenced, and hence adjusted for EBS (km/h), vehicle market class, collision partner, and occupant height. Driver age and gender were not useful predictors of upper extremity injuries. Injury risk was seen to increase by 3.5% for every 1 km/h increase in EBS (OR: 1.03, CI: 1.01-1.06, $p \leq 0.05$), while drivers of large vehicles were 76.5% less likely to sustain AIS 2+ upper extremity injuries than occupants of small and medium sized vehicles (OR: 0.23, CI: 0.10-0.54, $p \leq 0.05$). While there was no difference between drivers involved in collisions with larger vehicles such as 4WD, trucks, and buses (as a single grouping) compared to those involved in collisions with sedans (OR: 1.24, CI: 0.41-3.68, $p \geq 0.05$), those impacting poles and trees were found to be over two times more likely to sustain AIS 2+ injuries of the upper extremity relative to those involved in collisions with sedans and derivatives such as station-wagons (OR: 2.27, CI: 1.05-4.90, $p \leq 0.05$). Driver height was also included in the logistic regression model and, whilst not statistically significant, the point estimate suggests an increase of 3.5% in risk for every 1 cm increase in height (OR: 1.035, CI: 0.99-1.08, $p \geq 0.05$); the probability for a driver of 165 cm in height was found to be 19% (CI: 9-35%) while for a driver of 180 cm in height the probability of an AIS 2+ injury was found to be 28% (CI: 13-49%).

Figure 25 shows the observed probability distribution for AIS 2+ upper extremity injuries for drivers of pre-ADR 69 and post-ADR 69 vehicles, while Table 51 shows the same estimates though in 10 km/h increments. The formulae in Equation Box 11, Section 7.1.11, were used to calculate the probability estimates associated with the ADR 69 and airbag comparisons. As noted above, the risk of sustaining an AIS 2+ upper extremity injury is seen to increase with increasing crash severity. At the mandated ADR 69 test speed of 48 km/h, the observed probability of sustaining an AIS 2+ upper extremity injury is 26% (CI: 12-46%) for drivers of post-ADR 69 vehicles compared to 29% (CI: 15-48%) for drivers of pre-ADR 69 vehicles. As indicated by the odds ratio, there was little difference in the risk of injury between drivers in the pre- and post-ADR 69 driver groups.

Figure 25: Observed probability distribution for AIS 2+ upper extremity injuries for drivers of post-ADR 69 vehicles

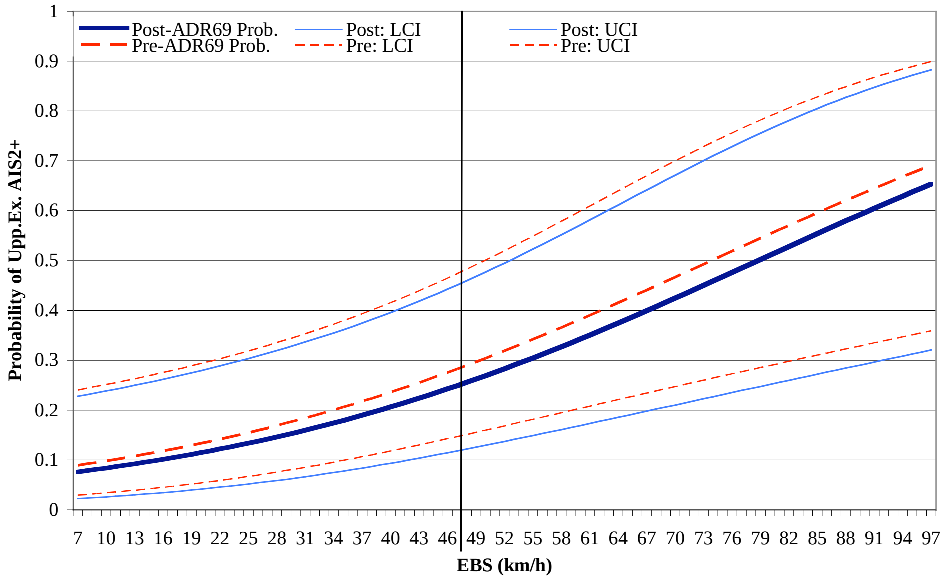


Table 51: Observed probability distribution for AIS 2+ upper extremity injuries for drivers of pre-ADR 69 and post-ADR 69 vehicles; ADR 69 test speed shown in bold

EBS (km/h)	Pre-ADR 69 cases			Post-ADR 69 cases		
	Probability	95th% CI		Probability	95th% CI	
		Lower	Upper		Lower	Upper
20	0.13	0.05	0.29	0.12	0.04	0.28
30	0.18	0.08	0.35	0.16	0.06	0.33
40	0.24	0.12	0.42	0.21	0.09	0.40
48	**0.29**	**0.15**	**0.48**	**0.26**	**0.12**	**0.46**
50	0.30	0.16	0.50	0.27	0.13	0.48
60	0.38	0.20	0.60	0.34	0.17	0.57
70	0.47	0.25	0.70	0.42	0.21	0.67
80	0.55	0.29	0.79	0.51	0.25	0.76
90	0.64	0.33	0.86	0.60	0.29	0.84

Figure 26 presents the observed probability distribution for AIS 2+ upper extremity injuries for drivers of vehicles with and without airbag deployments, while Table 52 presents the probability estimates in 10 km/h EBS increments. The lack of difference in injury risk between the airbag deployed and non-airbag groups is evident, with the curves closely tracking one another throughout the EBS range. While the probability of injury at EBS impact speeds of less than 48 km/h is relatively low at 25%, the probability of injury increases such that at 80 km/h the risk of injury in approximately 50% for both driver groups.

Figure 26: Observed probability distribution for AIS 2+ upper extremity injuries for drivers of vehicles with and without airbag deployment

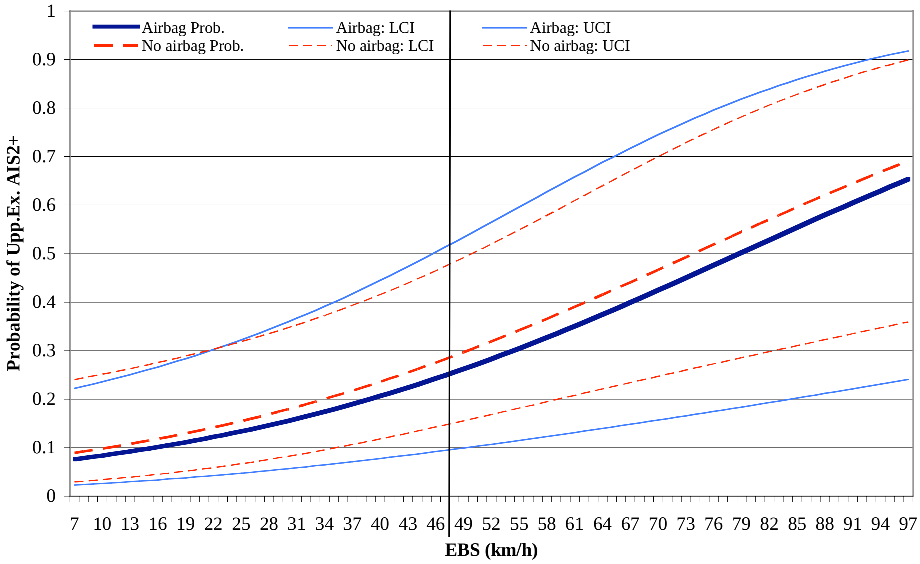


Table 52: Observed probability distribution for AIS 2+ upper extremity injuries for drivers of vehicles with and without an airbag deployment

EBS (km/h)	Non-airbag deployed cases			Airbag deployed cases		
	Probability	95th% CI		Probability	95th% CI	
		Lower	Upper		Lower	Upper
20	0.13	0.05	0.29	0.12	0.04	0.29
30	0.18	0.08	0.35	0.16	0.06	0.36
40	0.24	0.12	0.42	0.21	0.08	0.45
48	**0.29**	**0.15**	**0.48**	**0.26**	**0.10**	**0.52**
50	0.30	0.16	0.50	0.27	0.10	0.54
60	0.38	0.20	0.60	0.34	0.13	0.65
70	0.47	0.25	0.70	0.42	0.16	0.75
80	0.55	0.29	0.79	0.51	0.19	0.83
90	0.64	0.33	0.86	0.60	0.22	0.89

3.3.8 Lower Extremity Injury Risk

For the lower extremity, ADR 69 specified a maximum axial force through each femur not exceeding 10 kN. Examples of lower extremity injuries are presented in Table 53, while Figure 29 shows an x-ray of a fractured right fibula as a consequence of a frontal collision. Fractures of the lower extremity are of a minimum AIS 2 severity, and include simple fractures of the patella, pelvis, tibia, fibula and bones of the foot as examples, while the AIS severity increases with the increasingly serious nature of the fracture, and usually involves blood loss.

Table 53: Examples of lower extremity injuries by AIS severity (AAAM, 1998)

AIS severity	Lower extremity injury example
Minor (1)	Superficial lacerations, contusions & penetrating injuries; muscle strain/contusion, ankle, hip, knee, foot bones, fibula & tibia contusion/sprain; fractured toe
Moderate (2)	Penetrating injury with tissue loss; major (size/depth) skin, muscle, subcutaneous laceration / avulsion; minor disruption to arterial and venous structures (except femoral artery); nerve contusions/lacerations; ligament disruption; Dislocation of knee and ankle; calcaneus fracture; patella fracture; fracture of pelvis – closed, with or without dislocation; tibia/fibula fracture; crush injury / amputation of toe
Serious (3)	large blood loss due to injury to skin, muscle, subcutaneous laceration / avulsion; traumatic amputation below knee; major disruption to arterial and venous structures (except femoral artery); sciatic nerve laceration; Fractures of the tibia, fibula, pelvis, open, displaced or comminuted; fracture of the femur
Severe (4)	Traumatic amputation – above knee; major disruption to femoral artery; fracture of pelvis with substantial deformation, or ‘open book’, blood loss<20%
Critical (5)	Fracture of pelvis with substantial deformation, or ‘open book’ with blood loss>20%

Table 54 indicates that approximately half of all drivers in the two ADR 69 groups sustained a AIS 1 ‘Minor’ lower extremity injury. A sizeable proportion of drivers also sustained AIS 2 and AIS 3 injuries, while there was one driver in the post-ADR 69 group with an AIS 4 ‘Severe’ injury.

Table 54: Distribution of lower extremity injuries by AIS for pre-& post-ADR 69 drivers

AIS	Pre-ADR 69		Post-ADR 69	
	Freq.	**% of drivers**	**Freq.**	**% of drivers**
Minor (1)	83	53.2	62	48.1
Moderate (2)	28	17.9	19	14.8
Serious (3)	11	7.1	11	8.5
Severe (4)	Nil	Nil	1	0.8
Critical (5)	Nil	Nil	Nil	Nil

Lower Extremity Injury Risk

Table 55 shows that a slightly higher proportion of drivers of pre-ADR 69 vehicles sustained an injury of the lower extremity (55%) compared to drivers of post-ADR 69 vehicles (52%). In calculating the difference in injury risk between the ADR 69 and airbag driver groups, lower extremity risk was influenced by, and hence adjusted for, EBS (km/h) and driver gender; no other variables held any influence on the risk of injury. The logistic regression model displayed ‘acceptable’ discrimination, with the Area under the ROC curve being 0.72. The odds ratio for EBS indicated a statistically significant 4.6% increase in risk for every 1 km/h increase in EBS (OR: 1.05, CI: 1.02-1.06, $p \leq 0.001$), while males were 61% less likely to sustain lower extremity injuries than females (OR: 0.39, CI: 0.22-0.67, $p \leq 0.001$).

The injury risk estimates indicate a statistically significant greater risk of injury for drivers of post-ADR 69 vehicles relative to drivers of pre-ADR 69 vehicles (OR: 1.93, CI: 1.03-3.62, $p \leq 0.05$) once gender and EBS were taken into consideration. The odds ratio for the airbag group comparison suggests benefits (although borderline statistically significant) for drivers with an airbag deployment (OR: 0.53, CI: 0.29-1.00, $p \leq 0.05$), potentially due to the effect of seat belt pretension systems which act to minimise movement of the pelvis and / or the airbag preventing contact with the base of the steering wheel, and hence reducing the number of ‘bruise’ type injuries. There was, however, no difference in risk between drivers of pre-ADR 69 non-airbag equipped vehicles and drivers of post-ADR 69 vehicles with an airbag deployment.

Table 55: Percent of drivers sustaining an injury to the lower extremity and AIS 2+ lower extremity injuries & the adjusted relative odds ratios for drivers of post-ADR 69 vehicles compared to pre-ADR 69 vehicles, airbag deployments, and the dual effect

Body region	**Pre-ADR 69 (n=156)**	**Post-ADR 69 (n=129)**	**95% CI (L-U)**	**P**
Injured / AIS 1+	55.1%	51.9%		
Post-ADR 69	OR: 1.93		1.03-3.62	p≤0.05
Airbag deployment	OR: 0.53		0.29-1.00	p≤0.05
ADR 69+Airbag	OR: 1.03		0.55-1.94	p≥0.05
AIS 2+ injury	19.9%	17.0%		
Post-ADR 69	OR: 1.50		0.64-3.51	p≥0.05
Airbag deployment	OR: 0.60		0.25-1.39	p≥0.05
ADR 69+Airbag	OR: 0.90		0.39-2.10	p≥0.05

AIS 2+ Lower Extremity Injury Risk

Table 55 also presents the proportion of drivers with AIS 2+ lower extremity injuries and relevant odds ratio comparisons. Approximately 20% of drivers of pre-ADR 69 vehicles sustained an AIS 2 (moderate) or higher injury of the lower extremity, compared to 17% of drivers of post-ADR 69 vehicles, indicating little difference in the likelihood of injury.

Once the influence of EBS, vehicle market class and object struck were considered within the logistic regression model, there was no statistically significant difference among the three principal comparisons. The statistical model displayed borderline ‘acceptable’ discrimination with the Area under the ROC curve being 0.79, and correctly classified 84.2% of cases.

The analysis indicates no difference in injury risk between the drivers of pre- and post-ADR 69 vehicles (OR: 1.50, CI: 0.64-3.51, $p \geq 0.05$). Similarly, these was no difference in injury risk between drivers exposed to an airbag deployment relative to those not exposed to an airbag deployment (OR: 0.60, CI: 0.39-2.10, $p \geq 0.05$), or drivers of post-ADR 69 vehicles with an airbag relative to drivers of pre-ADR 69 vehicle without an airbag deployment (OR: 0.90, CI: 0.39-2.10, $p \geq 0.05$).

As noted above, AIS 2+ lower extremity risk was influenced by, and hence adjusted for, EBS (km/h), vehicle market class, and collision partner. Injury risk was seen to increase by a statistically significant 6.3% for every 1 km/h increase in EBS (OR: 1.06, CI: 1.04-1.09, $p \leq 0.001$), while drivers of ‘large’ vehicles were 59% less likely to sustain AIS 2+ lower extremity injuries compared to those in ‘small’ vehicles (OR: 0.41, CI: 0.17-0.97, $p \leq 0.05$). There was, however, no difference in injury risk for those in ‘medium’ sized vehicles compared to drivers of small vehicles, while the risk across an array of objects struck was similar; however it was important to include this variable due to differences in object struck between the principal comparison groups ($p=0.5$).

The probability of sustaining AIS 2+ injuries was derived using the formulae in Equation Box 12, Section 7.1.12. Figure 27 and Table 56 presents the observed probability distribution for AIS 2+ lower extremity injuries for drivers of pre-ADR 69 and post-ADR 69 vehicles, and the slightly higher risk to drivers of post-ADR 69 vehicles is evident. At the mandated ADR 69 test speed of 48 km/h, the observed probability of an AIS 2+ lower extremity injury is 46% (CI: 24-70%) compared to 36% for drivers of pre-ADR 69 vehicles (CI: 19-57%). The EBS result indicates that the risk of injury increases by 6% for every 1 km/h EBS increase and this is equal across both groups of drivers.

Figure 27: Observed probability distribution for AIS 2+ lower extremity injuries for drivers of post-ADR 69 vehicles

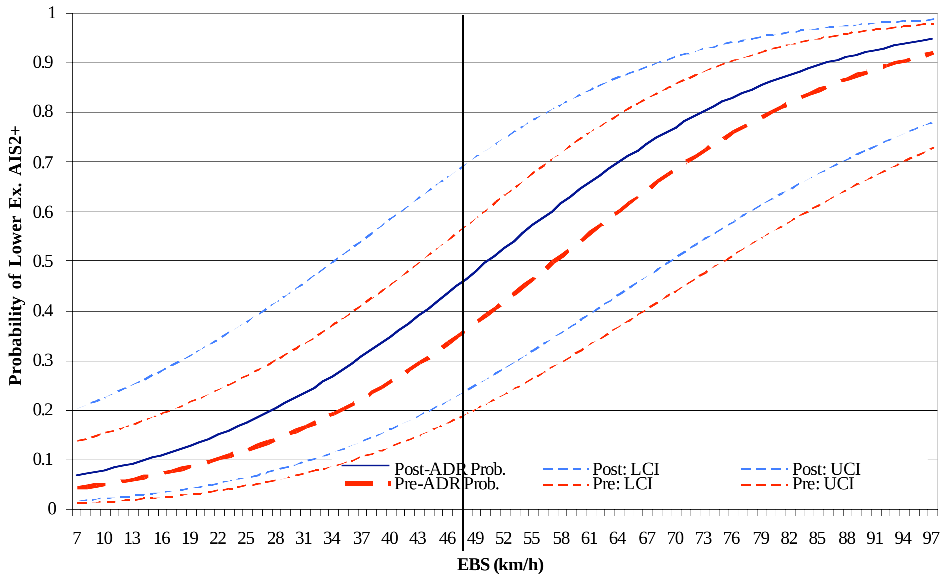


Table 56: Observed probability distribution for AIS 2+ lower extremity injuries for drivers of pre-ADR 69 and post-ADR 69 vehicles

EBS (km/h)	Pre-ADR 69 cases			Post-ADR 69 cases		
	Probability	95th% CI		Probability	95th% CI	
		Lower	Upper		Lower	Upper
20	0.09	0.03	0.23	0.13	0.05	0.32
30	0.16	0.07	0.33	0.22	0.09	0.45
40	0.26	0.13	0.46	0.35	0.16	0.59
48	**0.36**	**0.19**	**0.57**	**0.46**	**0.24**	**0.70**
50	0.39	0.21	0.61	0.49	0.26	0.73
60	0.54	0.32	0.75	0.64	0.38	0.84
70	0.69	0.44	0.86	0.77	0.51	0.91
80	0.80	0.56	0.93	0.86	0.63	0.96
90	0.88	0.67	0.97	0.92	0.73	0.98

Figure 28 presents the observed probability distribution for AIS 2+ lower extremity injuries for drivers of vehicles with and without airbag deployments, while Table 57 presents the probability estimates in 10 km/h EBS increments. The lack of difference in injury risk between the airbag deployed and non-airbag group is evident, with the curves closely tracking one another throughout the EBS range. While the probability of injury at EBS impact speeds of less than 48 km/h is relatively low at between 25%-36%, the probability of injury increases such that at 80 km/h the risk of injury in approximately 70% for the airbag deployed group and 80% for the non-airbag group, with both reaching a maximum probability of approximately 90% at the highest EBS of 97 km/h.

Figure 28: Observed probability distribution for AIS 2+ lower extremity injuries for drivers of vehicles with and without airbag deployment

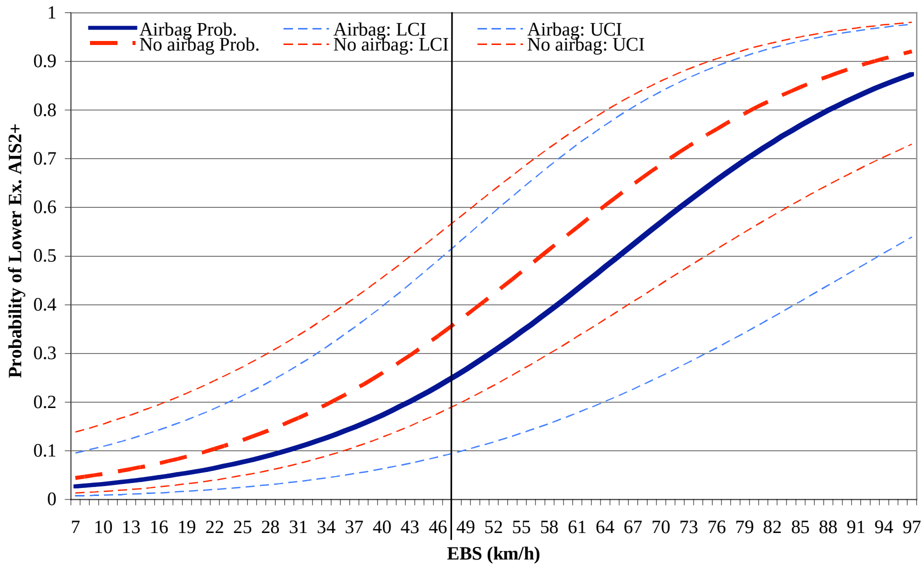


Table 57: Observed probability distribution for AIS 2+ lower extremity injuries for drivers of vehicles with and without an airbag deployment; ADR 69 test speed shown in bold

EBS (km/h)	Non-airbag deployed cases			Airbag deployed cases		
	Probability	95th% CI		Probability	95th% CI	
		Lower	Upper		Lower	Upper
20	0.09	0.03	0.23	0.06	0.02	0.17
30	0.16	0.07	0.33	0.10	0.03	0.26
40	0.26	0.13	0.46	0.17	0.06	0.40
48	**0.36**	**0.19**	**0.57**	**0.26**	**0.10**	**0.52**
50	0.39	0.21	0.61	0.28	0.11	0.56
60	0.54	0.32	0.75	0.42	0.17	0.71
70	0.69	0.44	0.86	0.57	0.25	0.84
80	0.80	0.56	0.93	0.71	0.35	0.92
90	0.88	0.67	0.97	0.82	0.46	0.96

Figure 29 shows an oblique view of a right ankle indicating a fractured fibula, resulting from a frontal collision. Such injuries were found to be common, and as with all lower extremity fractures are extremely debilitating. Indeed, the average return to work time for those with serious fractures of the lower extremity is over 6-months (see Kufera, Read, Dischinger et al., 2004).

Figure 29: Oblique view of right lower leg indicating a fractured fibula, resulting from a frontal collision

3.4 Injury cost (harm) analysis: Harm associated with ADR 69 status

As discussed in the method, HARM is a technique for costing injuries of varying severity for each body region. HARM analysis has the advantage of reflecting total injury outcome (and associated cost).

Table 58 shows the mean HARM for each body region for drivers of pre-ADR 69 and post-ADR 69 manufactured vehicles, expressed in Australian dollars. Table 58 also provides the relative mean HARM estimate and the estimated cost of injury difference expressed as reduction (-) or increase (+) for drivers of post-ADR 69 vehicles relative to pre-ADR 69 manufactured vehicles. The regression model adjusts for EBS and vehicle market class. Due to the structure of the Poisson regression model it is not appropriate to sum the cost savings of individual body regions in Table 58 to derive an additive ADR 69 benefit; for instance summing Head and Face will provide an incorrect monetary estimate. A series of cost of injury comparisons across a number of body regions combined are presented in Table 59.

3.4.1 Cost of Head Injuries

The mean cost of injury (HARM) associated with injuries of the head for drivers in the pre-ADR 69 vehicle group was approximately AUD$31,110 compared to AUD$10,650 for drivers of post-ADR 69 manufactured vehicles. Adjusting for EBS and vehicle market class differences between the ADR 69 groups, the head HARM in the post-ADR 69 group was 0.39 times (RR: 0.39, CI: 0.19-0.78, $p \leq 0.001$) that of drivers in the pre-ADR 69 group, equating to a 61% lower HARM. By using the point estimate and the mean HARM associated with the pre-ADR 69 group, these results translate to an average per case saving of AUD$18,970, with the confidence intervals suggesting this saving might range from as high as AUD$25,100 to as low as AUD$6,800 per case.

3.4.2 Cost of Face Injuries

The mean cost of injury (HARM) associated with injuries of the face for drivers in the pre-ADR 69 vehicle group was approximately AUD$10,320 compared to AUD$3,200 for drivers of post-ADR 69 manufactured vehicles. Adjusting for EBS and vehicle market class differences between the ADR 69 groups, the face HARM in the post-ADR 69 group was 0.35 (RR: 0.35, CI: 0.21-0.58, $p \leq 0.001$) that of drivers in the pre-ADR 69 group, equating to a 65% lower cost of facial injury. By using the point estimate and the mean HARM associated with the pre-ADR 69 group, these results translate to an average per case saving of AUD$6,730, with the confidence intervals suggesting that the savings might be as low as AUD$4,400 or as high as AUD$8,100 on average per case.

Table 58: Mean HARM (AUD'000) & adjusted cost estimates by body regions for drivers of post-ADR 69 vehicles relative to drivers of pre-ADR 69 vehicles, adjusted for EBS and vehicle market class

Body Region	Pre-ADR 69 Mean ('000)	Post- ADR 69 Mean ('000)	Estimate Post-ADR vs. Pre-ADR	Estimate 95% CI (L/U)	P	Benefit (-) / Cost (+) $ Estimate ('000)	95% CI (L-U) $ Estimate ('000)
Head	31.11	10.65	0.39	0.19-0.78	≤0.01	-18.97	-25.1, -6.8
Face	10.32	3.20	0.35	0.21-0.58	≤0.001	-6.73	-8.1, -4.4
Neck	4.00	1.48	0.33	0.20-0.57	≤0.001	-2.66	-3.2, -1.7
Chest	12.85	12.46	0.98	0.69-1.41	≥0.05	-0.23	-4.0, -5.2
Abdomen / pelvis	4.64	5.94	1.15	0.75-1.75	≥0.05	+0.68	-1.1,3.5
Spine	1.65	4.31	1.78	0.99-3.20	=0.05	+1.29	-.02, -3.6
Upper Extremity	14.60	13.80	0.98	0.70-1.39	≥0.05	-0.26	-4.4, 5.6
Lower Extremity	25.91	33.38	1.42	0.98-2.05	=0.06	+10.84	-.04, 27.1

3.4.3 Cost of Neck Injuries

The mean cost of neck injury (HARM) for drivers of pre-ADR 69 vehicles was AUD$4,000 compared to AUD$1,480 for drivers of post-ADR 69 manufactured vehicles, translating to an estimated average per case saving of AUD$2,660 (CI: AUD$1,700 saving to AUD$3,200 saving). The neck injury HARM associated with drivers of post-ADR 69 vehicles was one-third that of drivers of pre-ADR 69 vehicles (RR: 0.33, CI: 0.20-0.57, $p \leq 0.001$)

3.4.4 Cost of Chest Injuries

Table 58 indicates that there was no difference ($p \geq 0.05$) in the cost of chest injury between drivers of pre-ADR 69 and post-ADR 69 vehicles, with the average per case cost being AUD$12,850 and AUD$12,850 respectively.

3.4.5 Cost of Abdomen / Pelvic content Injuries

The cost of injury sustained to the abdomen and pelvic contents was, on average per case, approximately AUD$4,640 and AUD$5,940 for drivers of pre- and post-ADR 69 vehicles respectively. Poisson analysis indicates that the cost of injuries sustained by drivers of pre-ADR 69 and post-ADR 69 vehicles was not statistically different, although the point estimate suggests an added 15% cost of injury for drivers of post-ADR 69 vehicles (RR: 1.15, 0.75-1.75, $p \geq 0.05$). The cost difference was seen to be AUD$680 on average higher for drivers of post-ADR 69 vehicles compared to drivers of pre-ADR 69 vehicles, however the 95th percentile confidence intervals indicate that the benefit/disbenefit might range from a saving of AUD$1,100 to an increased cost of AUD$3,500 per case, on average.

3.4.6 Cost of Spine Injuries

The analysis indicates that following adjustment for crash severity and occupant vehicle market class, there was a 78% higher cost of spine injuries for drivers of post-ADR 69 vehicles relative to drivers of pre-ADR 69 vehicles (RR: 1.78, CI: 0.99-3.2, $p \leq 0.05$). The cost increase for drivers of post-ADR 69 vehicles is AUD$1,200 per case on average, with the estimate ranging from a benefit of $AUD200 to a disbenefit of AUD$3,600. The increase in cost was of borderline statistical significance.

3.4.7 Cost of Upper Extremity Injuries

Table 58 indicates that there was no difference ($p \geq 0.05$) in the cost of upper extremity injury between drivers of pre-ADR 69 and post-ADR 69 vehicles with the average per case cost being AUD$14,600 and AUD$13,800 respectively. These results are interesting when linked to those of the Injury Risk Analysis that showed that there was no difference in risk of higher severity (AIS 2+) upper extremity injuries between drivers of pre-ADR 69 vehicle and post-ADR 69 vehicles; notably though a statistically borderline increase in sustaining an AIS 1+ injury was observed.

3.4.8 Cost of Lower Extremity Injuries

The cost of lower extremity injuries for drivers of pre-ADR 69 vehicles was, on average, AUD$25,910 compared to AUD$33,380, on average, for drivers of post-ADR 69 drivers. Following adjustment for EBS and vehicle market class, the cost of injury was 42% higher for drivers of post-ADR 69 vehicles, compared to drivers of pre-ADR 69 vehicles, although this was seen to be of borderline statistical significance ($p=0.06$). This cost increase is seen in the Injury Risk Analysis as being driven by a higher proportion of drivers in the post-ADR 69 group with the more severe, and costly, AIS 3 and AIS 4 lower extremity injuries (see Table 54, p.72).

3.4.9 Cost of Injuries Associated With Multiple Body Regions

Table 59 presents the mean cost for each of the two ADR 69 groups, as well as the regression estimate of the difference in the mean injury costs for various combinations of body regions. As noted above, it not statistically valid to simply add or subtract the cost differences of any number of the individual body regions in Table 59 to arrive at a injury cost value; rather, separate models have been calculated where the cost of injuries for multiple body regions are assessed and compared in the Poisson cost model. As an example, for the first comparison presented in Table 59 summed the cost of injuries to the head, face, neck, and chest. The cost of injury for drivers of post-ADR 69 vehicles (Mean: AUD$27,790) was 47% lower (0.53, 0.34-0.83, $p \leq 0.01$) than for drivers of pre-ADR 69 vehicles (Mean: AUD$58,280).

Table 59 also presents a number of injury combinations and it can be seen that all comparisons find a cost saving associated with ADR 69 vehicles with the exception of the 'Whole-of-Body' comparison. Notably, the 'whole-of-body' comparison indicates that adding lower extremity injuries to the cost comparison reduces the overall benefit of introducing ADR 69, indicating room for design improvements.

3.4.10 Summary of Injury Costs By Body Region

The HARM, or average cost of injury, sustained by drivers of post-ADR 69 manufactured vehicles was lower for the head, face and neck, and higher [although borderline statistically significant] for the spine and lower extremity than for drivers of pre-ADR 69 manufactured vehicles. While the results are suggestive of an increased abdomen / pelvic content injury cost associated with drivers of post-ADR 69 vehicles, the result is ambiguous. The results indicate no difference in the cost of chest and upper extremity injuries between the groups. The cost of injury analysis also indicates significant benefits for combined body regions; however the addition of lower extremity injuries reduces the overall benefit of introducing ADR 69 and indicates room for design improvement.

Table 59: Mean HARM (AUD'000) & adjusted cost estimates for combined body regions for drivers of post-ADR 69 vehicles relative to drivers of pre-ADR 69 vehicles, adjusted for EBS and vehicle market class

Body Regions	Pre-ADR 69 Mean ('000)	Post- ADR 69 Mean ('000)	Estimate Post-ADR vs. Pre-ADR	Estimate 95% CI (L/U)	P	Benefit (-) / Cost (+) $ Estimate ('000)	95% CI (L-U) $ Estimate ('000)
Head, Face, Neck, Chest	58.28	27.79	0.53	0.34, 0.83	≤0.01	-27.60	-38.7, -10.1
Head, Face, Neck, Chest, Abdomen-Pelvis, Spine	64.57	38.03	0.63	0.42, 0.94	≤0.05	-24.19	-37.7, -3.9
Head, Face, Neck, Chest, Abdomen-Pelvis, Spine, Upper Extremity	79.18	51.84	0.70	0.49, 0.99	≤0.05	-24.00	-40.4, -0.5
Head, Face, Neck, Chest, Upper Extremity	72.88	41.59	0.63	0.43, 0.92	≤0.01	-27.11	-41.6, -5.8
Whole-of-body	105.09	85.22	0.87	0.64-1.20	≥0.4	-13.24	-38.2, 20.9

4 DISCUSSION

4.1 Principal study outcomes

The findings of this study demonstrate significant reductions in injury risk, injury severity and reduced cost of injury for particular body regions for drivers of post-ADR 69 vehicles relative to drivers of pre-ADR 69 vehicles involved in frontal impact tow-away and hospitalised crashes. In addition, significant improvements in safety were associated with driver airbag deployment, regardless of ADR 69 build date. Moreover, the combined effect of post-ADR 69 vehicles with an airbag indicated benefits over and above the benefits associated with airbags or post-ADR 69 status alone. These results indicate that the presence and deployment of the frontal airbag has driven much of the injury reduction benefits observed for the head, face and chest. It remains the case for this sample though, that neither ADR 69 compliance nor airbag deployment held any clear injury reduction benefits for the neck, abdomen-pelvic contents, spine, upper extremity or the lower extremity. The implications of these findings are discussed below and, consistent with earlier sections of this report, each body region is considered briefly.

Table 60 presents in summary form the change in AIS 2+ injury risk associated with post-ADR 69 vehicles relative to pre-ADR 69 vehicles, airbag deployment, and the combined effect (see Section 7.2 for all injuries). In interpreting these findings, it is important to also consider the probability of injury, as while there might be large differences in terms of injury reductions, or increased likelihood of injury in the instance of the spine and to a lesser degree the abdomen-pelvic contents in the post-ADR 69 versus pre-ADR 69 drivers, the probability of injury might be low. Table 61 and Table 62 present the probability of sustaining AIS 2+ injuries at an EBS of 48 km/h for post-ADR 69 drivers and pre-ADR 69 drivers, and airbag deployment groups respectively.

Table 60: Change in injury risk for AIS 2+ injuries associated with ADR 69 status, airbag deployment and the combined effect

Body region	Post-ADR 69 drivers[(a)]	Airbag exposed drivers[(b)]	Post-ADR 69 + Airbag exposed [(c)]
Head	78% reduction†	82% reduction‡	96% reduction‡
Face	88% reduction†	91% reduction‡	99% reduction‡
Neck	N.S.D	N.S.D	Indicative 80% reduction*
Chest	N.S.D	79% reduction‡	74% reduction‡
Abdomen – Pelvic contents	N.S.D	83% reduction†	N.S.D
Spine	895% increase‡	82% reduction‡	N.S.D
Upper Extremity	N.S.D	N.S.D	N.S.D
Lower Extremity	N.S.D	N.S.D	N.S.D

[(a)] Relative to pre-ADR 69 drivers; [(b)] Relative to driver's without an airbag deployment; [(c)] Relative to pre-ADR 69 drivers without an airbag deployment; * p≤0.1, †≤0.05, ‡≤0.01; N.S.D – No statistical difference

Table 61: AIS 2+ probability estimates for drivers of pre-ADR 69 and post-ADR 69 passenger cars by body region at an EBS of 48 km/h

Body region	Pre-ADR 69 cases			Post-ADR 69 cases		
	Probability	95th% CI		Probability	95th% CI	
		Lower	Upper		Lower	Upper
Head	0.44	0.23	0.67	0.15	0.05	0.37
Face	0.12	0.03	0.35	0.02	0.002	0.12
Neck	0.09	0.02	0.29	0.04	0.01	0.22
Chest	0.62	0.41	0.79	0.67	0.43	0.84
Abdomen-Pelvis	0.03	0.01	0.08	0.08	0.02	0.24
Spine	0.03	0.01	0.08	0.21	0.09	0.42
Upper Extremity	0.29	0.15	0.48	0.26	0.12	0.46
Lower Extremity	0.36	0.19	0.57	0.46	0.24	0.70

Table 62: Injury probability estimates for drivers without a frontal airbag deployment and drivers of passenger cars with an airbag deployment by body region at an EBS of 48 km/h

Body region	Non-airbag deployed cases			Airbag deployed cases		
	Probability	95th% CI		Probability	95th% CI	
		Lower	Upper		Lower	Upper
Head	0.44	0.23	0.67	0.12	0.03	
Face	0.12	0.03	0.35	0.01	0.001	0.17
Neck	0.09	0.02	0.29	0.04	0.004	0.31
Chest	0.62	0.41	0.79	0.26	0.09	0.54
Abdomen-Pelvis	0.03	0.01	0.08	0.01	0.001	0.03
Spine	0.03	0.01	0.08	0.005	0.001	0.03
Upper Extremity	0.29	0.15	0.48	0.26	0.10	0.52
Lower Extremity	0.36	0.19	0.57	0.26	0.10	0.52

4.1.1 Discussion of Injuries to the Head

As presented in Table 60, the implementation of ADR 69 was associated with a 78% reduction in the risk of AIS 2+ injuries of the head. These injuries range from loss of consciousness and concussion through to large haematomas within the brain at the most critical end of the injury spectrum. Similarly, the injury reduction effect attributable to the airbag, given the average effect of ADR 69 vehicle status, EBS, vehicle market class and driver weight, was seen to be an 82% reduction in risk, while the combined effect was seen to result in a 96% reduction in AIS 2+ head injury risk. These reductions can also be seen in the shift downwards of the probability of injury at any given impact speed, such that the EBS at which a driver of a pre-ADR 69 vehicle was seen to have a 50% chance of sustaining an AIS 2+ head injury is 52 km/h compared to 76.5 km/h for drivers of post-ADR 69 vehicles. The reduction in injury risk was similar for the airbag comparison pointing to strong airbag benefits. These reductions in injury risk translate in broad terms to a reduction in head injury cost to the community, measured using the HARM metric, of approximately AUD$18,970 on average. These results indicate that ADR 69 was of significant benefit in reducing head injury risk for Australian passenger car drivers.

In conducting the analysis, drivers of large and medium vehicles were seen to have a marginally lower injury risk than drivers of small vehicles; further countermeasure work focussing on reducing the risk of injury to drivers of small vehicles, particularly with the polarisation of the Australian market to either small or large vehicles might be warranted. It also proved to be the case that EBS was significantly related to injury risk, such that a 1 km/h increase translated to a 6% increase in the risk of sustaining an AIS 2+ head injury. As noted in Section 3.3.1, the risk increased substantially for speeds above 48 km/h. Given this finding, consideration could be given to lifting the test speed with the goal of driving down the high end speed injury risk; this recommendation is common to other body regions but particularly the chest and lower extremity where the risk of injury remains high beyond 48 km/h. In doing so, consideration of potential disbenefits of higher test speeds with respect to vehicle aggressivity must be made. The reader is referred to the Introduction (pp. 7-10) for a brief discussion of the potential implications of increases in crash test impact speeds on front end stiffness in the context of lower extremity injuries and frontal offset standards.

<u>Recommendation 1:</u> Explore the feasibility and likely benefits of increasing the ADR 69 test speed with the goal of further reducing the probability of injury at higher impact speeds. In doing so, consideration of potential disbenefits of higher test speeds with respect to vehicle aggressivity must be made.

4.1.2 Discussion of Injuries to the Face

The injury reduction benefits associated with the face were equally impressive as those observed for the head. The implementation of ADR 69 was associated with an 88% reduction in the risk of AIS 2+ injuries of the face, while airbag deployment resulted in a 91% reduction in risk, and the combined effect was a 99% reduction in risk. Common injuries of this region are fractures of the mandible and LeForte Type I, II, III fractures. Importantly, the probability of AIS 2+ face injuries is lower among drivers of post-ADR 69 vehicles compared to drivers of pre-ADR 69 vehicles, such that at the ADR 69 test speed of 48 km/h the risk of injury was 1.6% compared to 12%. These reductions in injury risk translate in broad terms to a reduction in head injury cost to the community, measured using the HARM metric, of approximately AUD$6,730 on average. As with the head, these results indicate that ADR 69 was beneficial in reducing face injury risk, and the airbag appears to have played a major role in this result. Impact severity was again related to injury risk such that a 1 km/h increase in EBS resulted in an 8% increase in injury risk.

In conducting the analysis, drivers of large and medium vehicles were seen to have a marginally lower injury risk than drivers of small vehicles, while impacts with trees/poles resulted in a risk seven times higher of sustaining a face injury than if the collision partner was a similar passenger car. The result pertaining to the increased risk associated with pole/tree impacts is of concern given the high exposure to poles and trees on the roadside.

4.1.3 Discussion of Injuries to the Neck

Injuries to the neck region include penetrating injuries, lacerations and contusions, injuries of the pharynx and larynx and blood vessel disruption; 'whiplash' type injures are coded to the AIS spine region. As presented in Table 60 there was no statistical difference in AIS 2+ injury risk associated with either ADR 69 vehicle status, or airbag status alone, however the combined effect was seen to produce a trend toward an 80% reduction in AIS 2+ neck injury risk, although the confidence intervals are very wide (CI: 0.03-1.40, $p \geq 0.05$). Notably, the estimated probability of AIS 2+ injuries was 3% for drivers of post-ADR 69 vehicles compared to 9% for drivers of pre-ADR 69 vehicles at an EBS of 48 km/h, indicating potentially some benefit.

Given the small numbers of drivers sustaining AIS 2+ neck injuries in the sample (9 in total), emphasis was placed on AIS 1+ injuries, where the airbag and post-ADR 69 plus airbag combination demonstrated statistically significant 53% and 65% reductions in injury risk respectively; the ADR 69 comparison indicated no difference in injury risk. These reductions in injury risk translate in broad terms to a reduction in head injury cost to the community, measured using the HARM metric, of approximately AUD$2,660 on average. These results indicate that ADR 69 was beneficial in reducing neck injury risk, particularly lower severity injuries.

In contrast to every other AIS body region presented, the risk of AIS 1+ neck injuries decreased with increasing EBS, such that injury risk fell by 3% for every 1 km/h increase in EBS. A possible reason for this result is related to injury biomechanics associated with the neck region. Evidence has consistently shown that 'whiplash' type injuries occur at lower impact speeds, as forces are applied to the neck tissues in the forward motion and rebound (flexion-extension) common to frontal impact crashes (McElhaney, Nightingale, Winkelstein et al., 2002). While ligamentous disruption (whiplash) is coded to the AIS Spine region, it might also be the case that contusions and lacerations are associated with lower speeds for similar biomechanical reasons; the interaction with the seatbelt and seat, particularly the head rest, at lower speeds might also be a factor.

Finally, injury risk was modified by age but not gender. Interestingly, injury risk increased rapidly from 17 years-mid-30's, and then decreased somewhat in a linear manner. This might be the result of different musculature of those in the mid-30's, or may reflect the parameters not included in the statistical model such as driver height, vehicle market class (hence size) and object struck, though none of which were seen to hold any predictive value in the calculation of injury risk.

4.1.4 Discussion of Injuries to the Chest

AIS 2+ chest injuries include disruption to the vessels of the chest (aorta, pulmonary vein etc…), fractures of two or more ribs, hemothorax, and pneumothorax, with the most common injury source generally being seat-belt loading. The results indicate that the ADR 69 regulation produced no observable injury reduction benefit for the chest (controlling for the average airbag / non-airbag injury effect), and this was reflected in the difference in the cost of injury between the two ADR 69 groups. The probability of AIS 2+ injuries for drivers of post-ADR 69 vehicles at an impact speed of 48 km/h (EBS) remains high at 67%, while increasing to a reported maximum of 86% at 90 km/h. Important factors in the calculation of injury risk based on ADR 69 status were the presence or otherwise of a frontal airbag, impact speed (EBS, km/h), driver age and height and vehicle market class; gender was not related to chest injury outcome in this sample.

In contrast to the ADR 69 group comparison, the injury reduction benefit associated with the frontal airbag was 79% (see Table 60). The observed probability of injury for airbag exposed drivers was 26% at 48 km/h, while for those without an airbag the probability was 62%. The role of the airbag was such that drivers of post-ADR 69 vehicles with an airbag deployment were 74% less likely to sustain an AIS 2+ chest injury than drivers in a pre-ADR 69 car without an airbag deployment.

As ADR 69 provided the impetus for manufacturers to install frontal airbag systems (including optimised seat-belt systems), ADR 69 as a performance-based regulation can be considered to be beneficial in driving reductions in chest injury risk. It must be noted though that airbags are not mandatory in Australia and some vehicles in the Australian market, particularly those in the small vehicle market group, continue to only offer frontal airbags as optional equipment for the passenger side. While this report does not examine the injury reduction effect of airbags on the front left passenger, similar protection experienced by the driver could be expected. Given the strong evidence for airbag effectiveness and the high risk of injury in their absence, particularly with respect to the chest, this report recommends that an assessment be made of the necessity and likely benefits of mandating dual frontal airbags as standard equipment in all passenger cars. The role of ADR 73 in making this recommendation is discussed below.

<u>Recommendation 2:</u> That an assessment be made of the necessity and likely benefits of mandating dual frontal airbags as standard equipment in all passenger vehicles.

Driver height also proved to be a significant predictor of chest injuries, such that short-statured drivers were found to be at greater risk of sustaining such injuries. Inclusion of the 5th percentile female Hybrid III dummy to the ADR 69 test regime may be beneficial in reducing chest injury risk to short vehicle occupants. Given these findings, this report recommends that consideration be given to modifications in the ADR 69 test protocol that would capture the differential injury risk for short statured drivers.

<u>Recommendation 3:</u> Explore the feasibility and likely benefits of inclusion of the 5th percentile female into the ADR 69 test regime as a means of addressing the increased risk of chest injury for short-statured drivers.

The analysis of chest injuries also demonstrated that the risk of AIS 2+ chest injuries was higher for older drivers than for younger drivers, and the risk curve was not linear; the risk to a driver aged 60 years was seen to be 77% (CI: 56-91%)

compared to 9% (3-10%) for a driver aged 20 years, adjusting for all other factors noted above including the airbag effect. This finding of increased risk of chest injuries with aging is consistent with previous research (Foret-Bruno, Trossielle, Le Coz et al., 1998; Zhou, Rouhana, & Melvin, 1996). Chest injuries carry a high degree of morbidity and mortality for older adults in particular, such that older patients with rib fractures have twice the mortality and morbidity of younger patients with similar injuries, and for every additional rib fracture mortality increases by 19% and the risk of pneumonia increases by 27% (Bulger, Arneson, Mock, Jurkovich, 2000).

A variety of indices of chest injury risk have been developed, and it may prove that revising the ADR 69 (sternal) deflection threshold to less than the present 76.2 mm might have value in reducing the risk of chest injury; indeed Mertz, Horsch, & Horn (1991) demonstrated that a Hybrid III sternal deflection of 76 mm correlated to an approximately 95% risk of AIS 3+ chest injury while the lower value of 50 mm correlated to a 50% risk; similarly Stalnaker and Mohan (1974, cited in Cavanaugh, 2002) presented evidence of no rib fractures using a chest deflection measure of 58 mm. Importantly though, similar or higher reductions might also be obtained by using alternative injury tolerance measures, such as the sternal rate of compression measure (Mertz, 2002), the viscous criterion (Vianno and Lau, 1985, cited in cited in Cavanaugh, 2002), and the Combined Thoracic Index proposed by NHTSA for use in FMVSS 208 (Kleinberger et al., 1998), which in its proposed form translates to an injury risk of 50% of AIS 3+ injuries (in cadavers). Alternatively, age modifiers could also be used in the assessment of chest injury risk as a means of assessing crashworthiness across a range of age categories.

4.1.5 Discussion of Injuries to the Abdomen-Pelvic contents

ADR 69/00 did not specify injury risk performance criteria for the abdomen and pelvis, however some benefit could be expected in reducing abdominal and pelvic injuries from the introduction of the thorax injury criteria noted above, and the 10 kN axial load limit on the femur. Injuries to this region include contusions, penetrating injuries, and injuries to the internal organs such as kidney, pancreas, liver and spleen.

Emphasis in the analysis was placed on AIS 1+ injuries due to the small number of AIS 2+ injuries in the sample (approx. 5%). The injury risk comparison of pre-ADR 69 drivers vs. post-ADR 69 drivers indicated no difference in risk for AIS 1+ or AIS 2+ injuries. This finding was also reflected in the statistically non-significant AUD$680, on average, increase in HARM.

The analysis of all injuries to the region revealed that males were 58% less likely than females to sustain injuries to this region. These results suggest that the seat-belt system may be optimised for males at the expense of females given that only the 50th percentile Hybrid III male is used in the test protocol. Similarly, being of light weight was associated with significantly increased risk of AIS 2+ injuries. This data also supports Recommendation 3 noted above in the context of chest injuries.

It is noteworthy that the observed probability of AIS 1+ injuries at 48 km/h was high, being 57% and 54% for drivers of pre-ADR 69 and post-ADR 69 vehicles, but that the observed probability for AIS 2+ injuries was low at 3% and 8% respectively, and even lower for drivers exposed to an airbag (1%). Analysis of this body region highlighted the limitations of the sample and the need for nationally representative data, a point discussed below.

As with the chest, it could be considered that ADR 69 as a regulation has been beneficial in reducing injuries to the abdomen-pelvis as ADR 69 provided the impetus for manufacturers to install optimised frontal airbag systems including optimised seat-belt systems. It is likely that the airbag has its injury reduction effect in preventing impact by preventing loading of the abdomen from the steering wheel, while the reduction in rib fractures might also affect secondary organ damage (see Rouhana, 2002 for an excellent discussion of biomechanics of abdominal trauma).

4.1.6 Discussion of Injuries to the Spine

ADR 69 did not specify performance criteria for the spine except for instances where no head contact was made. In cases of no head contact, ADR 69 sought to restrict the forces the Hybrid III dummy would experience, such that neck injury measurements not exceed 3300 N of tension force in the inferior-superior direction. Benefits might also be anticipated to this body due to ADR 69's thorax and femur load specifications which may act to limit forces applied to the thoraco-lumbar region of the vertebral column.

Injuries included with the AIS Spine body region are strains ('whiplash') and interspinous ligament disruptions thru to major burst fractures of vertebral bodies thru to complete spinal cord syndrome (quadriplegia, paraplegia). Anterior wedge fractures are an example of a vertebral column fracture resulting from dynamic flexion and compression as the driver moves forward where the anterior (or front) portion of the vertebral body fractures, and are most common at C5-C7 where the neck joins with the largely immobile thoracic cage (King, 2002).

Of note was the finding of the large statistically significant increase in the risk of AIS 2+ 'spine' injuries for drivers of post-ADR 69 vehicles relative to drivers of pre-ADR 69 vehicles. Table 60 indicates this increase to be of the magnitude of 895% (OR: 9.95, 2.3 43.1). This result is also replicated when considering all injuries of the spine (AIS 1+), with odds ratio being 6.62 (CI: 2.06-21.2, $p \leq 0.001$). This increase is also seen in the statistically significant increase in HARM, that being AUD$1290 on average per driver. EBS was however not statistically related to the risk of spine injuries ($p \geq 0.05$), however EBS was important in adjusting for differences in crash severity between the two groups. The probability of AIS 2+ spine injuries at 48 km/h for drivers of post-ADR 69 vehicles was 21% (CI: 9-42%) in contrast to 3% (1-8%) for drivers of pre-ADR 69 vehicles.

In contrast, exposure to the frontal airbag resulted in statistically significant 82% reduction in AIS 2+ neck injury risk, rendering the actual probability of spine AIS 2+ injury at an EBS of 48 km/h to be less than 1%. It appears though that the airbag was not sufficiently able to compensate for the increased risk associated with post-ADR 69 status as the combined ADR 69 plus airbag effect did not result in lower risk of injury for either AIS 1+ or AIS 2+ injuries; this latter finding possibly due to increased frontal stiffness or difficulties in optimising restraint systems and seat design for the full height-weight range of drivers.

The results of the AIS Spine body region raise a number of substantive issues. As with the AIS Chest and AIS Abdomen-Pelvic contents body regions, the airbag is associated with statistically significant reductions in injury risk. The reduction in abdomen-pelvis injuries associated with airbag deployments must be noted, as clinically fractures of the lumbar spine are often associated with abdominal organ damage, and is associated with ‘submarining’ or misplacement of the seat belt (Rouhana, 2002). It appears that the airbag and restraint system is of benefit to both the AIS regions of the Spine and Abdomen-pelvic contents, although the clinically important seat belt sign (i.e., significant bruising across the shoulder, diagonally across the thorax and across the abdomen) appears, anecdotally at least, to be common among those seriously injured.

Of concern though is the large increase in risk associated with post-ADR 69 vehicles in the absence of an airbag. It may prove that the use of an alternative neck injury criterion, such as Nij as proposed by Kleinberger et al. (1998), might provide a means to reduce injuries to the cervical spine, and possibly drive reductions in injury risk to this region.

On two final points, future analysis would be better served to combine vertebral column and spine injuries to their matched AIS body region rather than the AIS body region categories per se. Ideally, injuries of the cervical spine would be analysed with all neck injuries, injuries to the thoracic spine fall within the AIS chest region, and the lumbar spine within the AIS region of the Abdomen-Pelvis. This division might result in improved injury risk estimates by capturing the total risk to each specific region, whilst highlighting benefits of vehicle countermeasures and areas requiring further improvements. The analysis conducted in this Report followed the convention of the AIS coding manual (AAAM, 1998).

Finally, improvements in the quality of diagnostic imaging in the hospital setting have led to the development of detailed cervical spine clearance protocols designed to determine the presence of cervical spine injuries in the conscious and unconscious patient (Ackland, 2005). The improved resolution of magnetic resonance imaging (MRI) and multi-slice fine-cut CT imaging means that soft tissue injuries of the neck ligaments and subtle fractures that may have been difficult to visualise in the past, and consequently under-diagnosed, are now plainly visible. Such advances offer new opportunities to identify mechanisms of injury and assess relevant countermeasures, but might also mean a reported increase in injuries to the vertebral column, particularly of the cervical spine, in future epidemiological studies.

4.1.7 Discussion of Injuries to the Upper Extremity

Injuries of the upper extremity are by definition not particularly life-threatening if appropriately treated, as the highest possible AIS code is 3 (‘Serious’) (AAAM, 1998). These injures can, however, prove to be extremely debilitating (Nash, Mickan, Del Mar et al., 2004). AIS 1 injuries include lacerations and contusions, joint sprains (i.e., wrist, elbow, shoulder), and dislocations of bones of the hand. AIS 2 injuries include deep penetrating wounds and simple closed fractures of the clavicle and bones of the arm (humerus, radius, & ulna), while AIS 3 injuries can be either open or displaced fractures, and may or may not involve significant blood loss. There is currently no injury criteria associated with upper extremity injuries.

Upper extremity injuries were sustained by 57% of drivers of pre-ADR 69 vehicles compared to 70.5% of drivers of post-ADR 69 vehicles, and there was no difference in the cost of injury between the two groups. Once AIS 2+ injuries are considered, these percentages decrease to 14.7% and 13.9% of drivers of pre-ADR 69 and post-

ADR 69 vehicles. The results indicate no difference in risk of AIS 2+ injuries for any of the three comparisons, with the probability of AIS 2+ injuries at an EBS of 48 km/h was 29% and 26% respectively. For AIS 2+ injuries drivers of large vehicles were nearly 60% less likely to sustain such injuries compared to drivers of small vehicles, while drivers colliding with poles and trees were more than twice as likely as those colliding with other passenger cars to sustain these injuries. For both AIS 1+ and AIS 2+ injuries, EBS and driver height were related to the risk of injury, such that increases in both resulted in increased risk of upper extremity injuries.

AIS 1+ injuries were considered in detail due to the reported interactions between the upper extremity and airbags (Huelke et al., 1995). The analysis indicated that, once the impact of airbag deployment, EBS, driver height, object struck and vehicle market class were controlled for, there was a strong trend toward ($p=0.07$) a 77% increased risk of upper extremity injuries for drivers of post-ADR 69 vehicles, while the airbag comparison indicated no difference in risk (OR: 1.20, 0.64-2.26, $p \geq 0.05$). However, drivers of post-ADR 69 vehicles with an airbag deployment were twice as likely to sustain an injury of the upper extremity relative to drivers of pre-ADR 69 vehicles without an airbag. The probability of injury at an EBS of 48 km/h was high at 77% and 66% for drivers of post-ADR 69 and pre-ADR 69 vehicles respectively.

Upper extremity injuries remain a challenge for manufacturers and improved interior padding and trim and modified glazing may be some of the few available countermeasures to address these injuries.

4.1.8 Discussion of Injuries of the Lower Extremity

ADR 69 specified a performance requirement of the maximum allowable femur axial force not exceeding 10 kN. This criteria emphasised protection for the femur, bony pelvis and the knee. As noted in the Introduction, there was no performance specification for the lower leg, namely the tibia, fibula, ankle and the foot in ADR 69. It is also important to bear in mind the difficulties of measuring lower extremity injury risk using the Hybrid III, and the stated need for a comprehensive set of lower limb injury criteria given the high frequency of lower leg injuries in Australian passenger vehicles at the time of the early Standards Development Program, as discussed in the Introduction (Fildes et al., 1994; Seyer, 1993). This report paid particular attention to AIS 2+ injuries as they are both common and often extremely debilitating (ATSB, 2004b; NHTSA, 2004; Read, Kufera, Dischenger et al., 2004).

The results indicated that approximately 20% of drivers of pre-ADR 69 vehicles sustained AIS 2+ injuries, compared to 17% of drivers of post-ADR 69 vehicles. The analysis indicated that there was no difference in injury risk between the groups after controlling for differences and the effect of impact speed, collision partner and vehicle market class. Injury risk increased with increasing impact speed by a factor of 6% for every 1 km/h increase in impact speed, while drivers of larger vehicles were 59% less likely to sustain an AIS 2+ injury compared to drivers of small vehicles. The probability estimates also suggest the risk of injury remains high, with the risk at 60 km/h estimated to be 64% and 54% for drivers of post-ADR 69 and pre-ADR 69 vehicles respectively. The HARM estimates demonstrate a borderline statistically significant ($p=0.06$) AUD$10,840 average increase per driver in the cost of injury to the lower extremity (AIS 1+) injuries; this reinforces the statistically significant increase in risk of AIS 1+ injuries for drivers of post-ADR 69 vehicles relative to drivers of pre-ADR 69 passenger cars.

These results are cause for some concern, particularly the increase in average total cost of injury associated with drivers of post-ADR 69 vehicles. Arguably shifting the test speed upward and revising the axial femur load downward from 10 kN to a lower value could potentially result in significant injury reductions. Similarly, adoption of alternative lower leg injury criteria, such as the current ADR 73 criteria, might also be expected to have a beneficial impact on reducing these debilitating injuries, a point noted by Seyer (1992, 1993) and Fildes et al. (1994) in the Standards Development Research Program. Prior to consideration of any revisions of the current ADR 69 lower extremity criteria, it is essential to examine the influence of ADR 73 on lower extremity injury risk.

<u>Recommendation 4:</u> Examine the risk of lower extremity injuries among occupants of ADR 73 compliant passenger cars involved in frontal crashes. In the event of continuing high risk of injury, as reported in this study, improved injury criteria and new dummy instrumentation might be an appropriate method of addressing the high risk of lower extremity injury as highlighted in this study.

Finally, the analysis conducted in this report considered the risk to lower extremity as a whole. While it is arguable that the upper leg and lower leg should have been considered separately, the intent of the femur axial load criteria is to provide some protection for the whole lower extremity. Any future analysis of ADR 73 must examine the risk to the lower extremity as a single unit, but also must assess the upper and lower leg separately due to the inclusion of the Tibia Index and the Tibia Compression Force Criteria. Similarly, future HARM analysis must also consider the upper and lower leg individually as the mean cost of injury for specified AIS levels are likely to differ.

4.1.9 Cost savings associated with ADR 69

Using HARM as the cost of injury metric, this report evaluates the mean difference in injury cost between drivers of pre- and post-ADR 69 vehicles, adjusting for differences in EBS and vehicle market class between the two groups. The analysis indicated significant injury savings to the head (AUD$18,970), the face (AUD$6,730), the neck (AUD$2,660), while an increase in the cost of injury of the spine (AUD$1,290) was observed. Of concern was the strong trend of an average AUD$10,840 increase in injury cost for the lower extremity for drivers of post-ADR 69 vehicles. Also of concern was finding of no cost of injury reduction for the chest, although a cost reduction benefit would be observed if the comparison was based on exposure to the airbag.

The cost savings for individual body regions are not additive, and so the cost of head, face, neck and chest injuries for post-ADR 69 drivers (mean: AUD$58,280) was compared to pre-ADR 69 drivers (Mean: AUD$27,790), with the regression analysis indicating an average per driver cost saving of AUD$27,600 ($p \leq 0.01$). The whole-of-body injury cost analysis suggests an AUD$13,240 benefit for drivers of post-ADR 69 vehicles, however this is not statistically significant and is substantially lower than the cost savings associated with the head, face, neck and chest, principally due to the high cost associated with lower extremity injuries.

These cost injury estimates demonstrate significant cost savings in regions most expected, while pointing to the need for further improvements in controlling lower extremity injury risk. Estimates such as these would also be useful in the conduct of future cost-benefit analysis of ADR 69. Given the age of the HARM values (1996 dollars), the cost savings reported here are conservative.

4.2 Relationship of ADR 69 to the current FMVSS 208 standard

At the time of introduction, ADR 69 was based on US FMVSS 208 with respect to the mandated injury performance criteria, with the difference being that the Australian procedures required that the Hybrid III dummies be restrained; the US on the other hand had extremely low levels of seatbelt use and a role of the airbag in the US market was to prevent occupant ejection. Recent amendments to the US FMVSS 208 Standard have meant that the injury tolerance criteria of ADR 69 are no longer directly comparable. It is critical to note that while the performance specifications of ADR 69 have been updated (see below), Australia also introduced ADR 73 to apply to all new passenger cars (Class MA) from 1 January 2000. Further discussion of ADR 73 is provided in Section 4.3.

The following discussion of FMVSS 208 is provided to highlight the complexities of vehicle safety regulation, and the fact that ADR 69 was originally based on the US Standard.

Since the US FMVSS 208 standard was introduced in January 1968, the standard has evolved to reflect improved vehicle safety knowledge and on-going problems with out-of-position occupants due to the continuing high proportion of unbelted occupants; notably, in 2005 55% of fatalities in the US were unbelted (NHTSA, 2006). Airbags were mandated for vehicles of model year 1997 and the Advanced Airbag Rule mandates new airbag technologies, made possible by the ‘Buckle-Up America’ campaign and the shift from non-seat belt wearing from a secondary offence in many states to be a primary penalty offence. A further instance of this evolution was the relatively recent change from HIC_{36}1000 to HIC_{15}700 as the head injury performance criterion, a change made possible largely due to the development of the neck injury standard, Nij.

It is important to note that the Australian ADR system also changed to reflect new knowledge, and this was seen in the issuing of a number of Determinations. Arguably the most important Determination was the addition of a revised head injury criterion for instances of no head contact, where either the forces to the neck were not to exceed 3.3 kN of tension force in the inferior-superior direction or a HIC_{15} value of 700 was not to be exceeded (DoTARS, 2004).

In 2000, NHTSA shifted to a more rigorous FMVSS 208 test battery which involves the testing of vehicles with 50th percentile male Hybrid III dummies, 5th percentile female dummies as well as a number of test requirements for the 1-year old dummy in the child safety seat, the 3 year old and the 6-year old; there has also been some discussion of the need for inclusion of the 95th percentile male in the test protocols. The phase-in requirements commenced 1 September 2003 and will continue until light vehicles manufactured on or after September 1 2010 enter production. The requirements concerning the adults are shown in Table 63 with ADR 69 included for comparison.

Table 63. Test requirements for the revised FMVSS 208 and ADR 69

Dummy / test criteria	**FMVSS 208** **(NHTSA, 2000)**	**ADR 69**
50th percentile adult male (Rigid barrier, full frontal)	Belted (perpendicular): 1st stage of phase-in†: 48 km/h 2nd stage of phase-in†: 56 km/h Unbelted (perpendicular & up to 30°oblique): 40 km/h (increase to 48 km/h likely 2010)	Belted (perpendicular): 48 km/h Unbelted not tested due to high belt wearing in Australia
5th percentile female (Rigid barrier, full frontal)	Belted (perpendicular): 48 km/h, with increase to 56 km/h in future Unbelted (perpendicular): 40 km/h (likely 48 km/h 2010)	5th percentile female not in test regime Unbelted not tested due to high belt wearing in Australia
5th percentile female (40% offset deformable barrier)	Belted (offset / left side impact – driver side): 40 km/h	5th percentile female not in test regime ADR 73 56 km/h offset test uses 50th percentile male only
Injury criteria		
Head	$HIC_{15}700$	$HIC_{36}1000$ For instances of no head contact: $HIC_{15}700$, or neck force not to exceed 3300 N of tension force in the inferior-superior direction
Neck	Nij not > 1.0 (22% AIS 3+) Peak tension not >4.17 kN for male and not >2.62 kN for female Peak compression not >4.0 kN for males and not >2.52 kN for female	None specified
Sternum	50th percentile male: 63 mm 5th percentile female: 52 mm For both, acceleration not > 60g, except intervals not >3 ms	50th percentile male: 76.2 mm & acceleration not > 60g, except intervals not >3 ms
Femur	50th percentile male: 10 kN 5th percentile female: 6.8 kN	50th percentile male: 10 kN

†1st stage of phase-in: Sept 2003-31/8/2006, for MY2007; 2nd stage phase in: 1/9/2007-31/8/2010, MY2008

The revisions to FMVSS 208 aim to capture more fully the range of sizes of vehicle occupants as well as ensuring optimisation of airbag-restraint system performance for belted occupants. The inclusion of the 5th percentile female was to improve protection to belted persons sitting in the full forward seat position, including female drivers and those of short-stature. In addition, injury criteria were also made more stringent than the previous incarnation of FMVSS 208. Notably though, the revised Standard did not adopt any lower leg criteria.

With respect to the addition of the offset test, it was noted that offset tests can result in designs with either low thresholds for airbag deployment or late deployments in the field, and consequently NHTSA (2000: 30708-30709) state that the main purpose of the offset test was to:

> …help ensure manufacturers upgrade their crash sensing and software systems, as necessary, to better address soft crash pulses. Improved sensing technology will be particularly important if manufacturers design vehicles with softer front ends to meet the 56 km/h (35 mph) belted rigid barrier test.

It must be noted that the revisions to the US FMVSS 208 Standard have been undertaken due to continuing concern in the US for risks associated with US-style airbags, particularly to small women and young children, and also with the intent of providing ‘improved frontal crash protection for all occupants’ (NHTSA, 2000: 30680). Given the phase-in requirements of the ‘updated’ FMVSS 208 Standard, it will be some time before any analysis can be made concerning the efficacy of these changes to the Standard. It must also be noted that FMVSS 208 is a Standard enforced only by the US Department of Transportation, and does not represent a global standard.

4.3 Importance of ADR 73, the 56 km/h offset frontal test for Australian passenger cars

As a treaty signatory to the United Nations Economic Commission for Europe (UNECE) 1958 Agreement, ‘Agreement Concerning The Adoption Of Uniform Technical Prescriptions For Wheeled Vehicles, Equipment And Parts Which Can Be Fitted And/Or Be Used On Wheeled Vehicles And The Conditions For Reciprocal Recognition Of Approvals Granted On The Basis Of These Prescriptions’, Australian Government policy is to harmonise, wherever possible, with UN ECE Vehicle regulations.

ADR 73, the Offset Frontal Impact Occupant Protection Standard, represents a completely harmonised standard under the Uniform Provisions Concerning the Approval of Vehicles with Regard to the Protection of the Occupants in the Event of a Frontal Collision. Under the Provisions of the Agreement, the standard is known as UN ECE Regulation No. 94/01.

ADR 73 applies only to Class MA vehicles (passenger cars), with the phase-in requirements being:

- From 1 January 2000 on all new model MA category vehicles; and with a Gross Vehicle Mass of less than 2.5 tonnes
- From 1 January 2004 on all MA category vehicles with a Gross Vehicle Mass of less than 2.5 tonnes

As noted in the Introduction, Amendments to ADR 69 by Determination No. 2 of 1998 (DoTARS, 2004: ii) rules that ‘vehicles complying with the new ADR 73 Offset Frontal Impact Protection, can be deemed to comply to this rule (i.e., ADR 69) provided they are fitted with dual airbags and the manufacturer can demonstrate by other means that the vehicles would comply with ADR 69’. As per Clause 12 of ADR 69, compliance with ADR 73/00 is to be demonstrated at the Conformity of Production Assessment.

ADR 73 assesses vehicle performance in a 56 km/h offset test against a deformable barrier, and has a number of differences in injury criteria in comparison to ADR 69. In particular, ADR 73 includes lower leg criteria (TI, TCFC), different neck and femur criteria, and a chest compression criterion of 50 mm plus inclusion of the viscous criterion as an index of chest injury risk.

Seyer (1993) noted the importance of global harmonisation but also noted that Standards should be consistent with themselves; for instance Seyer (1993) promoted the notion that lower leg injury criteria then under consideration by the EEVC for the frontal offset standard be incorporated into the Full Frontal Standard, ADR 69 if proved beneficial; whether the Hybrid III dummy and the Tibia Index and Tibia Compression Force Criteria are useful in predicting lower leg injury is still keenly debate as noted in the Introduction of this report. While the EEVC frontal offset standard was adopted for Australia to apply from 2000 as ADR 73, the injury performance criteria of ADR 69 were not revised to reflect the more stringent injury risk tolerance values across the body regions. For this reason, it remains important to evaluate ADR 73 prior to the assessment of Recommendations made in this report concerning ADR 69.

<u>Principal Recommendation:</u> That an evaluation of ADR 73 be undertaken using the same methods used in this report so as to assess both the need, and if necessary the order of priority, of Recommendations 1 - 4. This principal recommendation is made on the basis of ADR 73 representing an updated frontal crash occupant protection standard, recognition of the significant regulatory hurdles in adopting any changes to the provisions of ADRs, and the preference of the Australian Government to harmonise vehicle safety regulations in accordance with the provisions of the United Nations Economic Commission for Europe (UNECE) 1958 Agreement concerning the adoption of Uniform Technical Prescriptions for vehicles.

Following this Principal Recommendation, three points are noteworthy, and serve to highlight the complexity of vehicle safety standards:

1. Both NCAP and the US National Standard include a frontal offset test. NCAP (2004) uses a test speed of 64 km/h. Interestingly NHTSA (2004, 2005) use the offset test for the 5th percentile belted female at 40 km/h, and view the addition of an offset test as a supplement to the FMVSS 208 full frontal test. This was introduced as a protection against incompatibility problems stemming from design changes to accommodate the 56 km/h rigid barrier test. NHTSA (2005) have also flagged the addition of a high speed offset test due to its demanding nature on vehicle structure as seen by increased intrusion and a method to control lower leg injury risk.

2. The US Insurance Institute for Highway Safety state that full frontal tests remain an essential element of vehicle safety regimes, suggesting that the full frontal test and the offset test complement each other (IIHS, 1995, cited in NHTSA, 1997). The full frontal test is regarded to be a more demanding test of

restraint systems while the offset test represents a better test of intrusion (IIHS, 1995, cited in NHTSA, 1997). Consequently, future analysis of in-depth data would be best served by comparing the injury risk for three groups: occupants of pre-ADR 69 passenger cars, occupants of ADR 69 passenger cars, and occupants of ADR 73 compliant passenger cars.

3. The potential safety benefit of ADR 73 will not be seen in the Australian fleet for a considerable period as it applied to all new vehicle models from 2000 and all new vehicles from 2004. Furthermore, it will prove interesting if lower extremity injury risk reductions are seen in ADR 69 / ADR 73 compliant vehicles in the future given the instrumentation of lower leg and associated injury criteria in ADR 73.

4.4 Harmonisation and vehicle safety regulations

An important issue in vehicle safety is the harmonisation of safety vehicle standards. This is particularly pertinent in the era of Free Trade Agreements being signed between many nations, as well as Australia being a signatory to the provisions of the World Trade Organisation on ‘Technical Barriers to Trade’ (TBT), and a signatory to the United Nations Economic Commission for Europe (UNECE) 1958 Agreement, ‘Agreement Concerning The Adoption Of Uniform Technical Prescriptions For Wheeled Vehicles, Equipment And Parts Which Can Be Fitted And/Or Be Used On Wheeled Vehicles And The Conditions For Reciprocal Recognition Of Approvals Granted On The Basis Of These Prescriptions’.

It is recognised that Government regulators would realise an additional cost burden associated with changes to ADR 69, as would manufacturers. It is therefore imperative that any regulatory change and Regulatory Impact Statements be informed by results of evaluation studies using in-depth crash investigation data. In doing so, these additional regulatory costs must also be balanced against the total cost of injury resulting from frontal crashes, both to the individual and the community.

A final consideration is whether any new design rule, or modification of an existing rule, would breach Australia’s obligations under the World Trade Organisation Agreement (WTO) on ‘Technical Barriers to Trade’ (TBT). The principal goal of the TBT Agreement is to ensure a sovereign nation does not engage in protectionist behaviour through setting technical standards that present as obstacles to international trade (WTO, 1994). Implicit within this Agreement is the preference to harmonise standards insofar as possible, however it is noteworthy that Article 2 of the TBT Agreement gives provision for any sovereign nation to mandate regulations necessary to promote the health of citizens, and at the same time not breaching the Agreement by stating:

> …technical regulations shall not be more trade-restrictive than necessary to fulfil a legitimate objective, taking account of the risks non-fulfilment would create. Such legitimate objectives are, inter alia: national security … protection of human health or safety, …the environment. In assessing such risks, relevant elements of consideration are, inter alia: available scientific and technical information, related processing technology or intended end-uses of products.

While this Report makes a number of recommendations based on the sample of drivers available at the time for analysis, the Principal Recommendation that an assessment of ADR 73 be made prior to consideration of Recommendations 1 – 4 is critical. The results of such an evaluation would influence the need for Recommendations 1 – 4, and could also be used to inform the UN ECE regulatory agenda. Certainly any change in vehicle regulations in Australia is likely to be a complex and lengthy process, though this must be balanced against the need, and likely effectiveness, of such changes to reduce injury risk in the event of frontal crashes.

4.5 Study limitations

There were a number of limitations associated with the study. More generally, while the use of sophisticated regression models represents an advance from previous research examining the effectiveness of ADR 69 and frontal airbags in Australia a number of limitations remain. The sample of cases analysed is a product of focussed entry criteria and hence the results are applicable only to belted drivers of Australian passenger vehicles (sedans and derivatives; Class MA) in crashes where no occupant was fatally injured. The following limitations must be also considered.

4.5.1 The issue of separating the airbag effect and determining compliance with ADR 69

The inability to separate clearly the impact of airbags from the ADR 69 regulation is a limitation, but one explained by the overlap in their introduction to the vehicle fleet. It remains the case though that the analysis of ADR 69 and airbag effectiveness in this report was complicated by the fact that the ADR 69 regulation, while not mandating the fitment of frontal airbag systems, provided the impetus for many manufacturers to do so, with the effect of airbags coming to market both before ADR 69 standard was mandated and in a progressive manner afterwards. It was not possible in the context of this report, therefore, to specify the precise level of ADR 69 compliance and airbag effectiveness in mitigating injury risk absolutely; the results do however statistically adjust for the average effect of the presence and effect of frontal airbags for the ADR 69 comparison, and ADR 69 status for the airbag comparison. The results were however unequivocal in delineating the combined effectiveness of the ADR 69 regulation and airbags in reducing injury risk, particularly for the head, face and for airbags, the chest.

An important issue is whether vehicles manufactured prior to the introduction of the ADR 69 standard would have in fact met the ADR 69 standard if tested. Indeed, some manufacturers elected to fit frontal driver airbag systems some years before the standard, and this is further complicated by the phased introduction of ADR 69 from mid-1995. Precise information of the compliance status of these vehicles was not available; however it is noteworthy that some pre-ADR 69 vehicles would likely have met the standard, indicated by five of the seven vehicles tested in the Standards Development Program meeting the specified performance criteria [Seyer, 1992, 1993].

4.5.2 Selection and injury recall bias

The results of the study may have some degree of selection bias, as participation in each of the three in-depth crash research programs was voluntary, and the direction of this sampling bias is at this stage unclear. Similarly, the tow-away study relied on driver recall of injuries sustained and some recall bias might be anticipated among this subset of the sample. An attempt to ensure consistent responses was made by employing interviewers trained in the use of structured post-crash questionnaire; however the accuracy of self-reporting of injuries for drivers is unknown. For those hospitalised, reliance on the medical notes and diagnostic imaging may lead to an underestimation of soft tissue bruising as such injuries often appear a number of days post-crash, by which time the patient may have been discharged or the tertiary survey might have been conducted by hospital medical staff.

4.5.3 Potential sample bias and the need for sample weights

The present evaluation of ADR 69 relied upon 156 belted drivers of pre-ADR 69 (pre-1995) vehicles and 129 belted drivers of post-ADR 69 vehicles with at least one AIS 1 (minor injury), two-thirds of which were male. In addition, the majority of vehicles were in the 'large' market class with a smaller proportion of 'small' vehicles, and a nominal number of medium-sized vehicles. While the degree of statistical control exercised in this evaluation means that this report represents the most complete evaluation of ADR 69 yet, the results are best viewed as being sample-specific rather than representative of the entire Australian vehicle fleet, as at present the direction of any potential sample bias is unknown. However, it remains the case that the in-depth driver cases were collected over a period of many years and were drawn at random, either by notifications from the towing industry or selected at random as hospital in-patients.

Ideally, any evaluation of an Australian Design Rule would be seen to be representative of the entire Australian passenger car fleet, and this motivated a genuine attempt to devise sample weights for application in this report. The goal of weighting in-depth crash data is to ensure that any analysis is reflective of the total crash population. The task, then, is to formulate 'weights' to ensure that the sample of crashes are in the same proportion of crashes as the broader population, and also that when the weights are applied that they sum to the total number of crashes in the specified jurisdiction. The underlying basis of a weighting system formulated is the need for complete injury outcome information for all 'injury' crashes in Australia. This information would provide the basis for calculating the 'expected' number of occupants with particular crash characteristics and injury outcomes, and would permit the 'weighting' of in-depth cases. Section 7.3 outlines a proposed system of calculating weights.

The fundamental basis of the weighting system is detailed casualty crash information. While detailed information is available for all fatality crashes in Australia via the ATSB fatality file, no such information is available for serious injury crashes. The information in the report, Serious Injury due to Road Crashes in Australia, (ATSB, 2004b) supplied by State and Territory Departments of Health in 6-month summary table blocks does not lend itself to thorough analysis of serious injury outcomes by the various crash types or vehicles involved.

As a consequence of the unavailability of national crash injury data, it was not possible to use a weighting system in this report. This report strongly recommends the establishment of a national crash injury file, inspired by the impressive ATSB fatality file. This initiative could be made possible by linking hospital and police crash databases, and potentially the creation of a National Injury Crash Outcome Information Network. Such information would underpin all future ADR evaluations and be used to monitor current and emerging road safety concerns. An alternative would be to establish an in-depth sampling system, similar to the NHTSA NASS system, where sampling weights are applied to create national estimates based on appropriately selected representative crashes from pre-defined geographic regions, or ‘sampling units’.

<u>Recommendation 5:</u> Examine the feasibility and value of establishing a national injury crash database, using linked hospital and police crash data. Alternatively, the feasibility of establishing an on-going national in-depth crash sampling system could be examined. These initiatives would add value to future vehicle safety evaluations as well as permitting the monitoring of current and emerging road safety concerns.

4.6 Conclusion

This report set out to examine the effectiveness of ADR 69 in preventing injury among Australian passenger cars drivers. The results presented in this report demonstrate significant benefits associated with the introduction of ADR 69 as well as the voluntary parallel introduction of frontal airbags in Australia. The results of this evaluation are applicable only to Class MA passenger cars, as no consideration was given to the real-world crash performance of forward control passenger vehicles (Class MB), off-road passenger vehicles (Class MC), and light goods vehicles (Class NA, NA1).

This report demonstrated significant reductions in the risk of head, face, neck and chest injuries associated with the ADR 69 standard and airbag systems in particular. It is expected that the safety benefits associated with ADR 69 to these body regions will flow through the passenger car fleet over time, with the injury reduction benefits to be realised for generations to come. The findings do however point the way forward for improvements in design standards, with the aim of enhancing the protection of the abdomen and pelvic contents, the spine, and the lower extremity in particular, where the regulation has had little improvement in injury risk among this sample. This Report makes a number of recommendations for further study with the intent of examining methods to improve occupant protection standards, thereby reducing the number and severity of injuries for male and female passenger car occupants in Australia.

Future studies would be best placed to use a larger sample with a range of greater range of injury severities than was used here. Further, the benefit of sample weights based on complete Australian hospital presentation and admission data linked to Police reported casualty crashes in the evaluation of ADRs cannot be underestimated. The use of sample weights would ensure the results of future evaluations would be applicable to all Australian drivers and passengers. A series of Recommendations stemming from this work are noted throughout the report and summarised in Chapter 5.

5 RECOMMENDATIONS

Recommendations 1 – 4 are made on the basis of the findings of this report, while Recommendation 5 stems from methodological considerations in the conduct of this report. In framing Recommendations 1 - 4, the authors are cognisant of the role of ADR 73, Australia's Frontal Offset regulatory test in the current regulatory regime for passenger car occupants. It is recommended therefore that an evaluation of ADR 73 be undertaken using the same methods used in this report so as to assess both the need, and if necessary the order of priority, of Recommendations 1 - 4. This principal recommendation is made on the basis of the ADR 73 representing an updated frontal crash occupant protection standard, recognition of the significant regulatory hurdles in adopting any changes to the provisions of ADRs, and the preference of the Australian Government to harmonise vehicle safety regulations in accordance with the provisions of the United Nations Economic Commission for Europe (UNECE) 1958 Agreement concerning the adoption of Uniform Technical Prescriptions for vehicles.

TITLE	RECOMMENDATION NUMBER	RECOMMENDATION
Conduct an evaluation of ADR 3. Pg. 96	PRINCIPAL	The intent of this recommendation is to determine the effect of the frontal offset standard on injury risk, and to determine the need, and order, for Recommendations 1 – 4.
Explore the feasibility and likely benefits of increasing the ADR 69 test speed from 48 km/h to a higher speed. Pg 85	1	The aim is to further reduce the probability of injury at higher impact speeds, as beyond the current 48 km/h test speed the probability of injury remains high. In doing so, consideration of potential disbenefits of higher test speeds with respect to vehicle aggressivity must be made.
That an assessment be made of the necessity and likely benefits of mandating dual frontal airbags as standard equipment in all passenger vehicles. Pg 87	2	The frontal airbag is highly effective in reducing chest injuries; as such, manufacturers should be encouraged to ensure dual frontal airbag systems are fitted in all passenger vehicles as standard equipment.
Explore the feasibility and likely benefits of inclusion of the 5th percentile female into the ADR 69 test regime as a means of addressing the increased risk of chest injury for short-statured drivers. Pg 87	3	The risk of chest injury is higher for those of short stature, with the risk of injury increasing as height decreases. Inclusion of the 5th percentile female may mitigate this risk.

Examine the risk of lower extremity injuries among occupants of ADR 73 compliant passenger cars involved in frontal crashes. pg 92	4	The risk of lower extremity injuries remains high, despite inclusion of a femur force criterion in ADR 69. These injuries are seen to be frequent and debilitating. The performance criteria of ADR 73 may have acted to resolve this heightened risk.
Examine the feasibility and value of establishing an Australian National Injury Crash Database, or alternatively examine the establishment an on-going national in-depth crash sampling system. pg 100	5	The value of complete crash injury information cannot be understated; these initiatives would add value to future vehicle safety evaluations as well as permitting the monitoring of current and emerging road safety concerns.

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7 APPENDIXES

7.1 Formula for obtaining injury probability estimates

7.1.1 Equation Box 1. Formulae for the calculation of Head AIS 2+ injuries

logit [HEADAIS 2+ injury] = _constant + ADR 69 group + Airbag group + EBS + Vehicle Market Class1 + Vehicle Market Class2 + Occupant Weight

logit [HEADAIS 2+ injury] = -0.736731 + (ADR 69group*-1.53177) + (Airbag group* -1.723659) + (EBS*-2.014223) + (Vehicle MarketClass1* -2.014223) + (VehicleMarketClass2*-0.7571986) + (Occupant Weight*-0.0318917)

Where:

ADR 69 group: Pre-ADR 69 =0; Post-ADR 69 =1

Airbag group: No airbag deployment/fitted = 0; Airbag fitted=1

EBS (km/h): EBS-40 (centred using mean EBS)

Vehicle Market class: Small=0; Medium=1; Large=2

Occupant Weight (kg): Weight (kg) – 76.88

Probability [HeadAIS 2+ injury] = exp(logitHEADAIS 2+injury) / (1+exp(logitHEADAIS 2+injury)

7.1.2 Equation Box 2. Formulae for the calculation of Face AIS 2+ injuries

logit [FACEAIS 2+ injury] = _constant + ADR 69 group + Airbag group + EBS + Vehicle Market Class1 + Vehicle Market Class2 + Collision Partner1 + Collision Partner 2

logit [FACEAIS 2+ injury] = -2.62003 + (ADR 69group*-2.076757) + (Airbag group*-2.306527) + (EBS*-0.076407) + (Vehicle MarketClass1*-1.080084) + (VehicleMarketClass2*-0.9836135) + (CollisionPartner1*1.253546) + (CollisionPartner2*1.958332)

Where:

ADR 69 group: Pre-ADR 69 =0; Post-ADR 69 =1

Airbag group: No airbag deployment/fitted = 0; Airbag fitted=1

EBS (km/h): EBS-40 (centred using mean EBS)

Vehicle Market class: Small=0; Medium=1; Large=2

Collision Partner: Passenger vehicle=0; 4WD/Truck/Bus=1; Pole/Tree=2

Probability [FaceAIS 2+ injury] = exp(logitFACEAIS 2+injury) / (1+exp(logitFaceAIS 2+injury)

7.1.3 Equation Box 3. Formulae for the calculation of Neck AIS 1+ injuries

logit [NECKAIS 1+ injury] = _constant + ADR 69 group + Airbag group + EBS + Age_1 + Age_2

logit [NECKAIS 1+ injury] = -.3743646 + (ADR 69group*-0.3083719) + (Airbag group*-0.7465827) + (EBS*-0.0202943) (Age_1*-20.82653) + (Age_2*-32.92066)

Where:

ADR 69 group: Pre-ADR 69 =0; Post-ADR 69 =1

Airbag group: No airbag deployment/fitted = 0; Airbag fitted=1

EBS (km/h): EBS-40.0 (centred using mean EBS)

Age_1: X^-2-.0645, where X = age/10

Age_2: X^-2*ln(X)-.0884, where X = age/10

Probability [NeckAIS 1+ injury] = exp(logitNECKAIS 1+injury) / (1+exp(logitNECKAIS 1+injury)

7.1.4 Equation Box 4. Formulae for the calculation of Neck AIS 2+ injuries

logit [NECKAIS 2+ injury] = _constant + ADR 69 group + Airbag group + EBS

logit [NECKAIS 2+ injury] = -2.873494 + (ADR 69group*-0.4733402) + (Airbag group*-1.120829) + (EBS*0.0091115)

Where:

ADR 69 group: Pre-ADR 69 =0; Post-ADR 69 =1

Airbag group: No airbag deployment/fitted = 0; Airbag fitted=1

EBS (km/h): EBS-40.0 (centred using mean EBS)

Probability [NeckAIS 2+ injury] = exp(logitNECKAIS 2+injury) / (1+exp(logitNECKAIS 2+injury)

7.1.5 Equation Box 5. Formulae for the calculation of Chest AIS 2+ injuries

logit [CHESTAIS 2+ injury] = _constant + ADR 69 group + Airbag group + EBS + Vehicle Market Class1 + Vehicle Market Class2 + Age + Height_1 + Height_2

logit [CHESTAIS 2+ injury] = 0.2803183 + (ADR 69group*0.2211183) + (Airbag group*-1.546525) + (EBS*-0.0260038) + (Vehicle MarketClass1*-0.0866093) + (VehicleMarketClass2*-0.8803802) + (Age*-10.35632) + (Height_1*-83214.18) + (Height_2*35794.21)

Where:

ADR 69 group: Pre-ADR 69 =0; Post-ADR 69 =1

Airbag group: No airbag deployment/fitted = 0; Airbag fitted=1

EBS (km/h): EBS-40 (centred using mean EBS)

Vehicle Market class: Small=0; Medium=1; Large=2

Age: X^-1-.2541, where X = age/10

Height_1: X^-2-.0033, where X = height/10

Height_2: X^-2*ln(X)-.0095, where X =height/10

Probability [ChestAIS 2+ injury] = exp(logitCHESTAIS 2+injury) / (1+exp(logitCHESTAIS 2+injury)

7.1.6 Equation Box 6. Formulae for the calculation of Abdomen-pelvic contents injuries

logit [Ab_Pel_AIS1+ injury] = _constant + ADR 69 group + Airbag group + EBS + Gender

logit [Ab_Pel_AIS1+ injury] = -0.1176965 + (ADR 69group*-0.1160454) + (Airbag group*0.3601362) + (EBS*0.0513099) + (Gender*-0.8603729)

Where:

ADR 69 group: Pre-ADR 69 =0; Post-ADR 69 =1

Airbag group: No airbag deployment/fitted = 0; Airbag fitted=1

EBS (km/h): EBS-40 (centred using mean EBS)

Gender: Female=0; Male=1

Probability [Ab_Pel_ AIS1+ injury] = exp(logitAb_PelAIS1+injury) / (1+exp(logitAbpelAIS1+injury)

7.1.7 Equation Box 7. Formulae for the calculation of Abdomen-pelvic contents AIS 2+ injuries

logit [Ab_Pel_AIS 2+ injury] = _constant + ADR 69 group + Airbag group + EBS_1 + EBS_2

logit [Ab_Pel_AIS 2+ injury] = -3.599057 + (ADR 69group*0.9583166) + (Airbag group*-1.768962) + (EBS_1*-11.76417) + (EBS_2*3.00285) + (Weight*-0.0444557)

Where:

ADR 69 group: Pre-ADR 69 =0; Post-ADR 69 =1

Airbag group: No airbag deployment/fitted = 0; Airbag fitted=1

EBS_1 (km/h): X^.5-2.0, where X = EBS/10

EBS_2 (km/h): X-4.0, where X=EBS/10

Weight (kg): weight-76.88 (centred on mean)

Probability [Ab_Pel_ AIS 2+ injury] = exp(logitAb_PelAIS 2+injury) / (1+exp(logitAbpelAIS 2+injury)

7.1.8 Equation Box 8 Formulae for the calculation of Spine AIS 1+ injuries

logit [SPINEAIS1+ injury] = _constant + ADR 69 group + Airbag group + EBS + Gender

logit [SPINEAIS1+ injury] = -3.025938 + (ADR 69group*1.890673) + (Airbag group*-1.652161) + (EBS*0.015081)

Where:

ADR 69 group: Pre-ADR 69 =0; Post-ADR 69 =1

Airbag group: No airbag deployment/fitted = 0; Airbag fitted=1

EBS (km/h): EBS-40.01 (centred using mean EBS)

Probability [Spine_ AIS1+ injury] = exp(logitSPINEAIS1+injury) / (1+exp(logitSPINEAIS1+injury)

7.1.9 Equation Box 9 Formulae for the calculation of Spine AIS 2+ injuries

logit [SPINEAIS 2+ injury] = _constant + ADR 69 group + Airbag group + EBS

logit [SPINEAIS 2+ injury] = -3.768894 + (ADR 69group*2.298312) + (Airbag group*-1.701426) + (EBS*0.0180666)

Where:

ADR 69 group: Pre-ADR 69 =0; Post-ADR 69 =1

Airbag group: No airbag deployment/fitted = 0; Airbag fitted=1

EBS (km/h): EBS-40.01 (centred using mean EBS)

Probability [SpineAIS 2+ injury] = exp(logitSPINEAIS 2+injury) / (1+exp(logitSPINEAIS 2+injury)

7.1.10 Equation Box 10. Formulae for the calculation of Upper Extremity AIS 1+ injuries

logit [UPEX_AIS1+ injury] = _constant + ADR 69 group + Airbag group + EBS + Vehicle Market Class1 + Vehicle Market Class2 + Collision Partner 1 + Collision Partner 2 + Height

logit [UPPEXAIS1+ injury] = 0.5030415 + (ADR 69group*0.5719651) + (Airbag group*0.1877379) + (EBS*0.0179289) + (Vehicle Market Class*-0.3423234) + + (CollisionPartner1*-0.4785527) + (CollisionPartner2*0.0684416) + (Height*0.0314412)

Where:

ADR 69 group: Pre-ADR 69 =0; Post-ADR 69 =1

Airbag group: No airbag deployment/fitted = 0; Airbag fitted=1

EBS (km/h): EBS-40 (centred using mean EBS)

Vehicle Market class: Small/Medium=0; Large=1

Collision Partner: Passenger vehicle=0; 4WD/Truck/Bus=1; Pole/Tree=2

Height (cm): height-173.5

Probability [UpExAIS1+ injury] = exp(logitUPEX_AIS1+injury) / (1+exp(logitUPEX_AIS1+injury

7.1.11 Equation Box 11. Formulae for the calculation of Upper Extremity AIS 2+ injuries

logit [UPEX_AIS 2+ injury] = _constant + ADR 69 group + Airbag group + EBS + Vehicle Market Class1 + Vehicle Market Class2 + Collision Partner 1 + Collision Partner 2 + Height

logit [UPPEXAIS 2+ injury] = -1.176211 + (ADR 69group*-0.1688494) + (Airbag group*-0.0428528) + (EBS*0.0347353) + (Vehicle Market Class*-1.445196) + (CollisionPartner1*0.2152157) + (CollisionPartner2*0.8218623) + (Height*0.0341864)

Where:

ADR 69 group: Pre-ADR 69 =0; Post-ADR 69 =1

Airbag group: No airbag deployment/fitted = 0; Airbag fitted=1

EBS (km/h): EBS-40 (centred using mean EBS)

Vehicle Market class: Small/Medium=0; Large=1

Collision Partner: Passenger vehicle=0; 4WD/Truck/Bus=1; Pole/Tree=2

Height (cm): height-173.5

Probability [UpExAIS 2+ injury] = exp(logitUPEX_AIS 2+injury) / (1+exp(logitUPEX_AIS 2+injury)

7.1.12 Equation Box 12. Formulae for the calculation of Lower Extremity AIS 2+ injuries

logit [LOWEX_AIS 2+ injury] = _constant + ADR 69 group + Airbag group + EBS + Vehicle Market Class1 + Vehicle Market Class2 + Collision Partner 1 + Collision Partner 2

logit [LOWEX_AIS 2+ injury] = -1.050265 + (ADR 69group*0.4102755) + (Airbag group*-0.5089616) + (EBS*0.0613511) + (Vehicle MarketClass1*0.065812) + (VehicleMarketClass2*-0.8819173) + (CollisionPartner1*0.2860884) + (CollisionPartner2*-0.2294495)

Where:

ADR 69 group: Pre-ADR 69 =0; Post-ADR 69 =1

Airbag group: No airbag deployment/fitted = 0; Airbag fitted=1

EBS (km/h): EBS-40 (centred using mean EBS)

Vehicle Market class: Small=0; Medium=1; Large=2

Collision Partner: Passenger vehicle=0; 4WD/Truck/Bus=1; Pole/Tree=2

Probability [LowerEx_AIS 2+ injury] = exp(logit LOWEX_AIS 2+injury) / (1+ exp(logit LOWEX_AIS 2+injury)

7.2 Summary table of change in injury risk for all injuries

Table 64: Change in injury risk for AIS 1+ injuries

Body region	Post-ADR 69 drivers[(a)]	Airbag exposed drivers[(b)]	Post-ADR 69 + Airbag exposed [(c)]
Head	69% reduction‡	Indicative 54% reduction*	86% reduction‡
Face	N.S.D	Indicative 40% reduction*	58% reduction‡
Neck	N.S.D	53% reduction†	65% reduction‡
Chest	N.S.D	Indicative 42% reduction*	N.S.D
Abdomen – Pelvic contents	N.S.D	N.S.D	N.S.D
Spine	562% increase‡	81% reduction‡	N.S.D
Upper Extremity	Indicative 77% increase*	N.S.D	113% increase†
Lower Extremity	93% increase†	47% reduction†	N.S.D

[(a)] Relative to pre-ADR 69 drivers; [(b)] Relative to driver's without an airbag deployment; [(c)]Relative to pre-ADR 69 drivers without an airbag deployment; *$p \leq 0.1$, †$p \leq 0.05$, ‡$p \leq 0.01$; N.S.D – No Statistical Difference

7.3 Method for the construction of a crash-based weighting system for in-depth data

The approach in devising a weighting system was motivated broadly by the US National Automotive Sampling System (NASS) weights with some modification. We consider that there are 4 levels of crash severity: fatal; admitted to hospital, ‘tow-away crash –injured’, and finally, ‘tow-away crash-uninjured’. In the calculation of weights these groups are treated independently given the unique occupant, crash, and injury characteristics associated with each crash type. In this way, it is ensured that the sample crash data for each severity is correctly weighted for the population from which it was drawn.

The weighting system developed creates categories, or ‘bins’, into which each crash would fall based on the variables: year of vehicle manufacture; impact direction (front, left side of vehicle etc…); seating position of occupant; single vehicle crash or multiple vehicle crash; speed zone (reduced to categories: ≤60, 70-90, 100+ km/h); head injury AIS ≥ 3; chest or abdominal-pelvic injury AIS ≥ 3; and lower extremity AIS ≥3. As such, the weighting system results in 4032 possible covariate patterns for the 4 severity levels. The year of manufacture is important to include as advances in vehicle safety have progressed rapidly, and pre-/post-1995 serves as a cut-point for the evaluation of ADR 69 due to its commencement in mid-1995. The variable speed zone is used as a surrogate for crash severity, while in combination with single vehicle accident variable it serves as a partial control and identifier for rural/urban crashes. The AIS injury severity variables are included to ensure that overall severity of crashes among the four broad crash categories are met, and that particular high severity in-depth case do not bias the results; ICD injury codes would be converted to AIS codes using ICD mapping software (MacKenzie, Sacco, and Colleagues, 1997). This is especially pertinent when occupant HARM is calculated, and overall societal costs are being estimated.

After obtaining the expected proportion of crashes for each ‘bin’ for each crash severity, we multiply by the observed reported official numbers over a rolling three year period by the percent of cases in weight category, leaving the national expected number of crashes with specified characteristics in Australia per annum.

Finally, the frequency weight is simply expected number of crashes in each ‘bin’ in Australia divided by the number of matched (based on matching bins) in-depth cases. Application of the weight to the in-depth data would weight up or down the cases collected by MUARC and would result in a nationally representative database.