MONASH University
Accident Research Centre

A centre within the Monash University Injury Research Institute

Assessment of the need for, and the likely benefits of, enhanced side impact protection in the form of a Pole Side Impact Global Technical Regulation

Dr Michael Fitzharris
Ms Karen Stephan

Accident Research Centre
Monash University

October 2013

ABSTRACT

Publication date	No. of pages
31 October 2013	219 (including appendices)

Publication title
Assessment of the need for, and the likely benefits of, enhanced side impact protection in the form of a pole side impact global technical regulation

Author(s)
Fitzharris Michael; Stephan Karen

Organisation that prepared this document
Accident Research Centre, a centre within the Monash Injury Research Institute, Monash University

Sponsoring organisation
Australian Department of Infrastructure and Regional Development

Abstract

Side impact crashes represent a significant component of the number of people killed and seriously injured. Narrow object impacts, such as trees and poles, carry an especially high risk of fatality. It is estimated that 225 000 drivers and passengers of category M1 and N1 vehicles are killed each year in side impact crashes globally. Fatalities due to side impact crashes range from 5.6% (Japan) to 24.8% (Germany) of all road users killed. Moreover, high numbers of people are seriously injured and admitted to hospital due to side impact crashes. At the same time, evidence now points to a 32% reduction in fatalities and a 34% reduction in serious injuries associated with side curtain and thorax airbags.

Notwithstanding the United States Federal Motor Vehicle Safety Standard 214, at present there is no internationally accepted narrow object side impact regulatory test. It is recognised that curtain and thorax airbags, among other structural modifications to the vehicle, would be required for a vehicle to pass a performance-based pole side impact test. It is expected that these additions and modifications would translate to reductions in the number of occupants killed and injured in side impact crashes.

Within this context, the Australian Government sponsored the development of a United Nations *Global Technical Regulation (UN GTR) on Pole Side Impact (PSI)* under the 1998 United Nations *Agreement concerning the establishing of global technical regulations for wheeled vehicles, equipment and parts which can be fitted and/or be used on wheeled vehicles.* A key step in ensuring the acceptance of the proposed PSI GTR is the establishment of the 'safety need'. That is: Is the current number of side impact crashes and their associated injury severity sufficient to warrant the development of a new global standard? This report addresses this question.

Analysis of police-reported data from the UK and Australia demonstrates the high injury severity associated with side impact crashes, including vehicle-to-vehicle side impact crashes and impacts with fixed objects. In particular, pole side impact crashes are seen to be associated with higher rates of injury as well as higher rates of serious injury. Analysis of in-depth crash data from Australia, the UK and Germany supports this finding.

The incremental benefit of the proposed PSI GTR for Australia was modelled. After considering the likely crash reduction benefits associated with electronic stability control, considerable fatality and serious injury reductions would be realised through the implementation of the PSI GTR. Throughout the first 30 years, the improved side impact safety requirements demanded by the PSI GTR will translate to 761 fewer passenger car (M1) and light commercial vehicle (N1) occupant fatalities (of which 675 were front row occupants), and a substantial reduction in the number of severe head injuries and other serious injuries. The combined economic saving is approximately $AU 3.47 billion for an outlay of $AU 0.726 billion for a BCR of 4.77:1 for vehicles designed to protect the front and rear seating positions. The bulk of these savings are driven by the front row occupant. Also, the introduction of the PSI GTR is highly cost effective for both the M1 and N1 vehicle segments individually, and sensitivity analysis highlights the robust nature of the benefits across a range of benefit scenarios and cost structures in meeting the PSI GTR.

This report highlights the injurious nature of side impact crashes and demonstrates the urgent need for improved side impact protection. It is concluded that the adoption of a requirement for vehicles to pass an oblique narrow object side impact performance-based standard will deliver significant benefit to the community.

Keywords: Crash, Pole Side Impact, Global Technical Regulation, Benefits, Cost

CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS USED

Abbreviation	Full name
ADR	Australian Design Rule
AIS	Abbreviated Injury Scale
AIS 2+	Abbreviated Injury Severity 2 or higher (moderate)
AIS 3+	Abbreviated Injury Severity 3 or higher (serious)
ATD	Anthropomorphic Test Device
BAU	Business-as-usual
BCR	Benefit Cost Ratio
BTE	Bureau of Transport Economics (Australia)
CAB	Curtain airbag (side)
CCIS	Co-operative Crash Injury Study (UK)
DfT	Department for Transport (UK)
E/A	Energy absorption
EBS	Equivalent Barrier Speed
EEVC	European Enhanced Vehicle-Safety Committee
ESC	Electronic Stability Control
ETS	Equivalent Test Speed
FMVSS	Federal Motor Vehicle Safety Standard (USA)
FRCD	Fatal Road Crash Database
GCS	Glasgow Coma Score
GTR	Global Technical Regulation
ISS	Injury Severity Score
km/h	Kilometres per hour
NCAP	New Car Assessment Program

NHTSA	National Highway Traffic Safety Administration
OBPR	Office of Best Practice Regulation
OR	Odds Ratio
PSI	Pole side impact
RR	Risk Ratio
SAB	Side airbag
SCA	Side curtain airbag
SCI	Spinal Cord Injury
TAC	Transport Accident Commission
TBI	Traumatic Brain Injury
TRL	Transport Research Laboratory (UK)
UNECE	United Nations Economic Commission for Europe
V2V	Vehicle-to-vehicle (side impact crash)
WP.29	Working Party 29

ACKNOWLEDGEMENTS

Dr Michael Fitzharris acknowledges the funding received from the Australian Department of Infrastructure and Regional Development that facilitated the undertaking of this work. Particular mention and thanks is extended to Mr Robert Hogan (General Manager, Vehicle Safety Standards), Mr Thomas Belcher (Research Engineer) and Mr Mark Terrell (Senior Research Engineer) for their engagement throughout this research.

A large number of individuals either assisted with various elements of the research, facilitated access to data, provided background materials, and intellectual and logistic support. These individuals and their organisations are duly noted below.

It is important at the outset to note the input of the WP. 29 Informal Group on a Pole Side Impact GTR (PSI Informal Group) for providing direction through comment on a number of early presentations of findings given by Dr Fitzharris at a number of meetings. The insights provided by these comments and additionally through the sharing of information in the form of presentations, access to data and technical documents proved immensely helpful in the performance of the analysis contained herein. We are grateful to the support from all members of the PSI Informal Group.

For the conduct of the literature review of side airbag effectiveness presented in Chapter 2

- Dr Fitzharris wishes to acknowledge and thank Ms Karen Stephan for playing a lead role in the literature review.

For the UK STATS19 data presented in Chapter 3:

- Dr Fitzharris wishes to acknowledge and thank Mr Bernie Frost and the DfT for supplying the STATS19 data.

For the CCIS data presented in Chapter 4:

- Dr Fitzharris wishes to acknowledge and thank Mr Richard Cuerdon and Ms Brenda Watterson at TRL for their assistance, for facilitating access to the CCIS dataset and for their gracious welcome. Thanks to Mr Bernie Frost (DfT), for facilitating access to CCIS.
- This report used accident data from the United Kingdom Co-operative Crash Injury Study (CCIS) collected during the period 2000-2010. CCIS was managed by TRL (Transport Research Laboratory), on behalf of the Department for Transport (Transport Technology and Standards Division, DfT) who funded the project along with Autoliv, Ford Motor Company, Nissan Motor Company, and Toyota Motor Europe. Previous sponsors of CCIS have included Daimler Chrysler, LAB, Rover Group Ltd, Visteon, Volvo Car Corporation, Daewoo Motor Company Ltd and Honda R&D Europe (UK) Ltd. Data were collected by teams from the Birmingham Automotive Safety Centre of the University of Birmingham; the Transport Safety Research Centre at Loughborough University; TRL and the Vehicle & Operator Services Agency of the Department for Transport.

For the Australian Fatal Road Crash Data presented in Chapter 5:

- Dr Fitzharris wishes to acknowledge and thank Ms Joanna Cotsanis, Victorian Institute of Forensic Medicine (Melbourne, Australia) for assistance in making the Fatal Road Crash Database (FRCD) available for analysis.
- Dr Fitzharris acknowledges the assistance and advice from Dr Lyndal Bujega, Coroners Court of Victoria and Monash University with cause of death coding.
- The FRCD is maintained by the VIFM on behalf of the Australian Department of Infrastructure and Regional Development.

For the Victorian and Queensland Police Reported Casualty Data presented in Chapter 5:

- Dr Fitzharris gratefully acknowledges VicRoads for providing MUARC with crash data.

- Dr Fitzharris gratefully acknowledges Queensland Transport for providing MUARC with crash data.
- Dr Fitzharris acknowledges Mr Angelo D'Elia for providing the casualty data for Queensland and Victoria.

For the Transport Accident Commission Claims Data presented in Chapter 6:

- Dr Fitzharris wishes to acknowledge and thank Mr Michael Nieuwesteeg and Ms Renee Shuster for assistance with the TAC Claims data; both are employees of the *Transport Accident Commission, Victoria.*
- Dr Fitzharris acknowledges the contribution of Ms Angela Clapperton, Monash University, for assistance with the early analysis of the Claims Data that was presented at the Washington, DC, Informal Group meeting.

For assistance with the NCAP test data noted in Chapter 6:

- Dr Fitzharris wishes to acknowledge and thank Mr Michael Paine (ANCAP) for providing test details, and to Miss Amy Allen for research assistance.

For assistance with reference to the analysis of the German GIDAS dataset referenced in Chapter 7:

- Dr Fitzharris wishes to expresses his thanks and gratitude to Mr Claus Pastor, GIDAS, BASt, Germany, for assistance in supplying the analysis of GIDAS data as part of the WP.29 Informal Document for Meeting 5 in London – and referenced here. Dr Fitzharris especially notes Claus' time and gracious hospitality whilst visiting BASt in May 2012.

With reference to the Australian National Crash In-depth Study used for analysis in Chapter 7:

- Monash University gratefully acknowledges the contribution of the ANCIS partners. Current partners of ANCIS are: the Australian Department of Infrastructure and Regional Development; Roads & Traffic Authority (NSW); Motor Accidents Authority of NSW; Transport Accident Commission (TAC) (Victoria), and VicRoads.
- Past sponsors and observers of ANCIS were: Autoliv Australia; Department of Infrastructure, Energy and Resources (Tasmania); Ford Motor Company Australia Ltd; GM Holden Ltd; Insurance Australia Group (IAG); Mitsubishi Motors Australia Ltd;; National Roads and Motorists' Association Ltd (trading as NRMA Motoring & Services); Royal Automobile Club of Victoria Ltd; Toyota Motor Corporation Ltd; and the Australian Automobile Association (AAA) and the Federal Chamber of Automotive Industries.
- Dr Fitzharris acknowledges the ANCIS Research Team and the contribution of the medical, nursing and allied health staff at the participating hospitals for their generous assistance in facilitating the ANCIS program. The current ANCIS team consists of Ms Kim Woolley (Research Nurse), Mr Ron Laemmle (Technical Officer), Mrs Deb Judd (Data Manager), and Associate Professor Stuart Newstead (Co-Chief Investigator).

For provision of new vehicle sales side airbag and ESC fitment rates used in Chapter 8:

- Dr Fitzharris wishes to acknowledge and thank Mr Michael Nieuwesteeg, Ms Renee Shuster, and Ms Jodi Page-Smith for assistance with the TAC Claims data, and for supplying the vehicle sales data; all are employees of the Transport Accident Commission, Victoria.

For the provision of information relating to vehicle age used in Chapter 8:

- Dr Fitzharris wishes to acknowledge and thank Ms Linda Watson for her assistance in supplying the vehicle age data for Class M1 and N1 vehicles.

Finally, Dr Fitzharris wishes to thank his colleagues at the Monash University Accident Research Centre including Dr Stuart Newstead for general advice in the early stages of the project, Ms Maatje Scheepers for proof-reading and Mrs Vanessa Fleming-Baillie-for proof-reading and administrative assistance.

EXECUTIVE SUMMARY

Side impact crashes are associated with high fatality and serious injury rates and represent a significant component of the road toll. Improved side impact protection has been a goal of governments and manufacturers for a number of years, as evidenced by the adoption of a vehicle-to-vehicle performance based standard and the push by the New Car Assessment Program (NCAP) in encouraging the fitment of side curtain airbags and rewarding vehicles that do so; however it is important that not all vehicles are subjected to NCAP tests nor do all NCAP protocols require a side impact pole test.

The potential value of a narrow object side impact test is generally recognised, however notwithstanding the United States (US) Federal Motor Vehicle Safety Standard (FMVSS) 214, there is currently no internationally accepted narrow object side impact regulatory test. It is recognised that curtain and thorax airbags would be required for a vehicle to pass a performance-based pole side impact test.

Within this context, the Australian Government sponsored the development of a United Nations Global Technical Regulation (UN GTR) on Pole Side Impact (PSI) under the 1998 United Nations *Agreement concerning the establishing of global technical regulations for wheeled vehicles, equipment and parts which can be fitted and/or be used on wheeled vehicles*. A key step in ensuring the acceptance of the proposed PSI GTR is the establishment of the 'safety need'. That is: Is the current number of side impact crashes and their associated injury severity sufficient to warrant the development of a new global standard? This report addresses this question and related issues.

PROJECT SPECIFICATION

The present project was undertaken to support the assessment of safety need, benefits and cost-effectiveness for case for the establishment of a PSI GTR. A number of key tasks were undertaken, these being:

1. Providing a global context to side impact crashes by reporting fatalities and injuries from among the WP. 29 Contracting Parties;
2. Examining evidence for the effectiveness of side airbag systems through the conduct of a literature review;
3. Documenting the number of side impact crashes in the UK using STATS19, the UK reported casualty data;
4. An assessment of the differential injury risk in narrow object side impact crashes relative to vehicle-to-vehicle side impact crashes, using the UK Co-operative Crash In-depth System;
5. Documenting trends in the number of side impact fatalities and their associated injuries using the Australian Fatality data (2001-2006);
6. An assessment of the differential injury risk in narrow object side impact crashes relative to vehicle-to-vehicle side impact crashes, using the Transport Accident Commission Claims data;
7. An assessment of the differential injury risk in narrow object side impact crashes relative to vehicle-to-vehicle side impact crashes, using the Australian National Crash In-depth Study (ANCIS);
8. Determining the incremental benefits associated with the implementation of a PSI GTR, given the fitment of ESC, for the Australian context, by:
    a. establishing the effectiveness of side impact airbags (SAB) (real-world and NCAP) and fitment rates of SAB through vehicle sales data;
    b. examining patterns of injury in NCAP 5* vehicles vs. 'the rest', and
    c. estimating the likely cost of injury estimates and incremental benefits of a PSI GTR, accounting for ESC fitment into the fleet, for occupants involved in both narrow object impact crashes and vehicle-to-vehicle side impact crashes.

THE GLOBAL CONTEXT – ROAD DEATHS, REGULATIONS AND RESEARCH INTO THE EFFECTIVENESS OF SIDE IMPACT AIRBAG SYSTEMS

Safer vehicles represent a key plank of achieving the UN Decade of Action for Road Safety and consequently the UN W.P.29 defined key activities within the scope of their work program. It is clear then that the goal of improved side impact protection falls within this broader ambit.

Side impact crashes represent a significant component of the number of people killed and seriously injured. Narrow object impacts, such as trees and poles, carry an especially high risk of fatality. It is estimated that 225 000 drivers and passenger of category M1 and N1 vehicles are killed in side impact crashes globally. Fatalities due to side impact crashes range from 5.6% (USA) to 24.8% (Germany) of all road users killed. Moreover, high numbers of people are seriously injured and admitted to hospital due to side impact crashes.

Estimates from Australia suggest that 11,673 occupants of 4-wheeled passenger vehicles sustained an AIS 3+ (serious) injury in the period 2000 to 2009, equating to 1167 persons per annum. Analysis of AIS 3+ injuries by body region highlights the large number of occupants sustaining thorax, head and lower extremity injuries in particular. Despite representing a small proportion of the total number of crash involved occupants, serious head injuries cost the Australia community between $AU 9.68 billion to $AU 19.36 billion in the 10-year period 2000-2009, depending on the economic value of traumatic brain injury assumed at the AIS 3+ level.

Notwithstanding the US FMVSS-214, at present there is no internationally accepted narrow object side impact regulatory test. It is recognised that curtain and thorax airbags would be required for a vehicle to pass a performance-based pole side impact test. Evidence points to a 32% reduction in fatalities associated with head and thorax side airbag systems, and similar reductions in serious injury. Hence, significant reductions in the number of occupants killed and seriously injured would be expected once vehicles are fitted with side airbag systems.

It is clear on the basis of global crash trends that there is a pressing need to address side impact protection standards globally. With evidence of the effectiveness of side impact airbags in mitigating injury growing, there is an opportunity to address vehicle safety standards that would lead to the universal adoption of side impact airbag systems.

INCIDENCE AND BURDEN OF SIDE IMPACT CRASHES IN THE UK

The analysis of STATS19 data highlights the high cost associated with side impact crashes, and in particular the severe nature of pole side impact crashes. In the period 2000 to 2009, side impact crashes cost the UK community £18.73 billion, and accounted for 40% of occupants of M1 vehicles killed and 35% of M1 occupants seriously injured. In numeric terms, 4890 people were killed and 44,237 seriously injured in vehicle-to-vehicle and other object side impact crashes, while 1369 were killed and 5190 were seriously injured in pole side impact crashes. The increased risk associated with pole side impact crashes is evidenced by 20% of occupants involved in PSI killed compared to 10% overall and 70% of financial costs to the community being associated with fatalities.

On a population basis, PSI fatalities have not reduced over the last decade, despite reductions being observed in all other impact configurations (up to 6.5%). On a per-vehicle basis, there has been a 2% per annum reduction in PSI fatalities, compared to an 8% and 6% reduction in frontal / rear and other side impact crashes. While over the past 10 years PSI fatalities represent approximately 20% of side impact fatalities and 10% of fatalities in all M1 vehicles, their importance as part of the fatality burden is growing in proportional terms.

INJURY RISK IN SIDE IMPACT CRASHES: ANALYSIS OF UK CCIS IN-DEPTH CRASH DATA

The primary objective of the analysis of the CCIS in-depth data was to determine the nature of injuries sustained in side impact crashes and the extent of differences, if any, in the injury outcomes of occupants involved in pole side impact crashes compared to those involved in vehicle-to-vehicle (V2V) side impact crashes. The analysis highlighted a number of key points:

- Of the side impact crashes within the case selection criteria in the UK CCIS database, 88% were vehicle-to-vehicle crashes and 12% PSI crashes;

- For occupants involved in PSI crashes, approximately 28% of occupants sustained an AIS 3+ injury of the head (cf. 5% V2V) and also the thorax (cf. 8% V2V), with AIS 3+ injuries of the lower extremity (19%; cf. 3% V2V) and abdomen-pelvis (~11%; cf. 5% V2V) being prominent;
- Pole side impact crashes are associated with significantly higher likelihood of injury and death than vehicle-to-vehicle side impacts, specifically:
  - Involvement in pole side impact crashes was associated with higher odds (and probability of injury) of serious head, thorax, upper extremity and lower extremity injuries (defined as AIS 3+ injuries);
  - Pole side impact crashes were associated with a four times higher odds of death and major trauma (ISS > 15);
  - The probability of sustaining a serious (AIS 3+) injury was as high as 0.46 (i.e., 46%) in PSI (cf. 12% for V2V) in the case of the thorax, and
  - The observed probability of sustaining a serious head injury was 0.34 (i.e., 34%) in PSI crashes compared to 0.07 (7%) for vehicle-to-vehicle side impact crashes.

Based on the analysis of UK CCIS in-depth data, it is clear then that PSI carry a significantly higher burden of injury than vehicle-to-vehicle side impact crashes. While the number of available occupant cases available for analysis was relatively small (PSI, n = 36; V2V, n = 263), the magnitude of the difference between the two crash impact groups is significant.

It must be noted that the inclusion criteria were highly focussed and these results are applicable to recent vehicles (MY 2000+) where side impact standards are applicable (i.e., ECE R95) and EuroNCAP side impact crash tests are performed. That occupants of vehicles involved in side impact crashes, and PSI crashes in particular, are exposed to considerably higher risk of severe and costly injuries means that further countermeasure development work is required to mitigate this risk.

INCIDENCE AND BURDEN OF SIDE IMPACT CRASHES IN AUSTRALIA

Pole side impact fatality crashes - Fatalities associated with PSI crashes account for 43% of all side impact fatalities, 15% of passenger vehicle fatalities and approximately 9% of all road fatalities in Australia. This translates in numeric terms to 898 individuals being killed, costing the Australian community an estimated $AU 4.4 billion over the period 2001-2006, or an average 150 people killed and $AU 0.7 bn. per annum. Trend analysis indicates reductions in the fatality rate have been achieved, although the reductions in PSI fatalities hit a plateau from 2003 to 2006.

Side airbags were known to be available and have deployed in only 0.3% of side impact fatalities (n=5) and 13 cases overall, with the status of airbags unknown for 49% of cases as the data was not collected. It is the case though that airbag penetration rates in the 2001 – 2006 period were extremely low. The data is useful then in presenting a 'base case' against which the effects of improved safety can be assessed. Analysis of the Coroner ruled cause of death data indicated that head injuries were the most common cause of death, with 55% of PSI deaths sustaining a 'fatal' head injury, and this was higher than for occupants killed in frontal impacts (44%) and other side impact crashes (49%). Injuries to multiple body regions were also noted to be a common cause of death, and this frequently includes injuries to the head and one or more body region. The pattern of injuries was similar in Class M1 and Class N1 vehicles, with head injuries being the most common cause of death in PSI for both vehicle types (~55% of occupants).

The findings clearly highlight the need for enhanced head protection for M1 and N1 vehicle occupants in PSI, and for N1 occupants in side impact crashes generally. It is clear then that any enhanced protection focussed on PSI would also address a more generalised side impact protection need.

Estimates of side impact fatalities and injuries in Australia – It was estimated that 155 occupants of M1 / N1 vehicles were killed in pole side impact crashes and 152 were killed in vehicle-to-vehicle and other object side impact crashes and 6830 were seriously injured (PSI: n = 1640, 24%; Other: n = 5190, 76%) in Australia in 2009.

INJURY RISK IN SIDE IMPACT CRASHES: ANALYSIS OF VICTORIAN MASS DATA

The analysis of the Victorian TAC Claims Data demonstrates the severe nature of side impact crashes, and in particular pole side impact crashes. For occupants of Model Year 2000 Class MA passenger vehicles involved in pole side impact crashes, there was a significantly higher risk of serious head, thorax, abdominal-pelvic injuries, and lower extremity injuries. Across these body regions, the odds of serious injury was at least twice that for occupants involved in vehicle-to-vehicle side impact crashes. Specifically, occupants involved in pole side impact crashes had a 54% increased probability of sustaining a serious head injury, 62% increased probability of a serious thorax injury and an 87% higher probability of sustaining a serious lower extremity injury. While occupants exposed in pole side impact crashes had a higher risk of serious injury than those struck by vehicles, approximately 5% of these occupants sustained an AIS 3+ head injury and approximately 9% sustained an AIS 3+ (serious) thorax injury.

Among the occupants involved in side impact crashes and seriously injured, a similar proportion of occupants struck by a vehicle and those striking a narrow object sustained serious head (~35%) and thorax injuries (~55%).

A key finding was the injury reduction benefits of head protecting side impact airbags. Specifically, the probability of occupants sustaining an AIS 3+ head injuries was 71.4% lower for occupants exposed to a deployed side airbag system than occupants without side airbags.

The injuries patterns and risk profile highlight by this analysis is particularly concerning as the vehicles examined are those that would meet the requirements of UN ECE R95 / ADR 72. As such, these findings highlight the need for improved countermeasure requirements to mitigate injury from side impact crashes, and narrow object impact side impact crashes in particular.

INJURY RISK IN SIDE IMPACT CRASHES: ANALYSIS OF IN-DEPTH AUSTRALIAN CRASH DATA

The objective in conducting an analysis of the Australian in-depth dataset was to determine the pattern of injuries sustained by occupants of Model Year 2000 and new vehicles involved in vehicle-to-vehicle and pole side impact crashes. In doing so, there was interest in determining the nature of injury differences, if any, in the injury outcomes of occupants involved in pole side impact crashes compared to those involved in vehicle-to-vehicle side impact crashes.

At the outset it is essential to state that the small number of occupants (42 vehicle-to-vehicle and 16 PSI) constrains the analysis. Nonetheless, the analysis of the ANCIS dataset was useful for a number of reasons, including as a point of comparison with the analysis of the UK CCIS dataset and the GIDAS in-depth dataset where similar results were obtained with respect to AIS 3+ injuries of the head, thorax, abdomen-pelvis and lower extremity.

The overall injury probability among the occupants examined was high, with those involved in vehicle-to-vehicle impacts having a 0.39 probability of having an ISS > 15 (i.e., classified as major trauma) while those involved in pole side crashes had a probability of 0.53 of being classified as a 'major trauma case'.

In comparing injury risk between those involved in pole side impact crashes and vehicle-to-vehicle impact crashes, there were some differences evident in the percent of occupants sustaining AIS 1+ and AIS 3+ injuries in particular. The head and the thorax were most at risk of serious injury. Among those struck by vehicles, the probability of sustaining an AIS 3+ head injury was 0.14 and an AIS 3+ chest injury was 0.37; in comparison, among those involved in pole side impact crashes, the AIS 3+ head injury probability was 0.18 and the chest injury probability was 0.52.

While crash severity as indexed as Equivalent Barrier Speed (EBS) (km/h) was consistently – but not always, associated with injury outcomes, increased age was associated with a higher likelihood of multiple serious injuries and thus classification of the occupant as a major trauma case, and also serious thorax injuries. Similarly, the injury risk for females was significantly greater for AIS 1+ injuries of the abdomen-pelvis and AIS 1+ lower extremity injuries.

ESTABLISHMENT OF THE INCREMENTAL BENEFITS AND BCR CASE FOR A PSI GTR

A central aim was to estimate the likely benefits and costs associated with the introduction of improved side impact protection in the form proposed by the PSI GTR. Of primary interest were the benefits to front seat occupants of M1 and N1 vehicles, and of secondary interest was the likely benefit of the PSI GTR across all seating positions. It is recognised that the costs of meeting the PSI GTR will differ according to whether the front and / or rear row is afforded protection, and this is factored into the analyses.

A series of successive analytical steps were required to arrive at the final estimates of the incremental benefit of a PSI GTR. A key step was the estimation of the future number of crashes, accounting for the present fitment rate and benefits associated with ESC, and also the safety benefits afforded by current curtain and thorax side impact airbags and their associated technologies such as seatbelt pretensioners and vehicle structures. The GTR was estimated to improve the safety performance of current side impact airbags (and associated side impact structures) by 30%. Comprehensive sensitivity analysis was also performed, both on device increment cost and likely effectiveness over and above current side curtain airbag systems.

Incremental benefits associated with a PSI GTR for front row occupants of M1 vehicles for Australia

Table E.1a presents the expected benefits generated by the PSI GTR for front seat occupants assuming a 30% additional safety benefit over the 30 year period, 2016 to 2045, while Table E.1b presents the savings and costs on an average per annum basis. A per unit cost of $AU 30.47 in Year 1 was used (2012 dollars), with this accounting for the need to fit complete side impact systems in 3.3% of M1 vehicles in year 1 due to incomplete levels of standard fitment by manufacturers in certain segments (cost of $AU 164.38), and $AU 25.90 (2012 dollars) for subsequent years. A 7% discount rate was used on all costs (and also benefits).

The financial benefits to Australia are significant, at $AU 2.6 billion over the 30 year period for an incremental cost of $AU 0.27 billion, for an overall BCR of 9.5:1. Across the period, 608 lives will be saved through the enhanced safety requirements demanded by a GTR, with 421 fewer cases of severe traumatic brain injury (TBI), 254 fewer moderate TBI, and 23 cases of paraplegia avoided. In addition, 4868 serious injuries and 13,679 minor injuries will be saved.

On a per annum basis, a GTR would be expected to save the Australian community approximately $AU 87.5 million per annum for an outlay of $AU 9.2 million per annum. This is the result of an on average per annum saving of 20 additional lives will be saved through the enhanced safety requirements demanded by a GTR, with 14 cases of severe TBI, 8 moderate TBI and 1 case of paraplegia per annum also avoided. In addition, 162 serious injuries and 456 minor injuries would be avoided. It is worth noting that injury shifts from fatality and serious injury to minor injuries were accounted for, both in number and in cost implications.

Table E.1a Incremental benefits of a GTR for M1 vehicles, over and above Business-as-Usual (BAU) of side airbag (SAB) installation for Australia, 2016-2045

Incremental benefits	**Pole impacts**	**Vehicle-to-Vehicle**	**Other fixed object**	**Total**
Additional Fatalities avoided	305	291	12	608
Additional TBI-severe avoided	132	274	14	421
Additional TBI-moderate avoided	38	212	4	254
Additional Paraplegia avoided	6	16	1	23
Additional Serious injuries avoided	1041	3717	111	4868
Additional Minor injuries avoided	1217	12215	246	13679
Financial benefits, 2016-2045	$797,111,037	$1,766,848,280	$61,822,030	$2,625,781,346
GTR requirement cost	$276,117,445	$276,117,445	$276,117,445	$276,117,445
BCR (30 year period)	**2.89**	**6.40**	**0.22**	**9.51**
BCR in Yr 30	5.03	11.23	0.39	16.65

Table E.1b Incremental <u>per annum</u> benefits of a GTR for M1 vehicles, over and above Business-as-Usual (SAB) of side airbag (SAB) installation for Australia, 2016-2045

Incremental benefits	Pole impacts	Vehicle-to-Vehicle	Other fixed object	Total
Additional Fatalities avoided	10	10	0.4	20
Additional TBI-severe avoided	4	9	0	14
Additional TBI-moderate avoided	1	7	0.13	8
Additional Paraplegia avoided	0.2	1	0.02	1
Additional Serious injuries avoided	35	124	4	162
Additional Minor injuries avoided	41	407	8	456
Financial benefits, 2016-2045	$26,570,368	$58,894,943	$2,060,734	$87,526,045
GTR requirement cost	$9,203,915	$9,203,915	$9,203,915	$9,203,915
BCR (30 year period)	**2.89**	**6.40**	**0.22**	**9.51**

Using the same method as above, sensitivity analysis was performed using a range of incremental costs, from $AU 40 through to $AU 200 (see Figure E.1). This analysis is useful as it provides an indication of the strength of the benefit across a range of increment values.

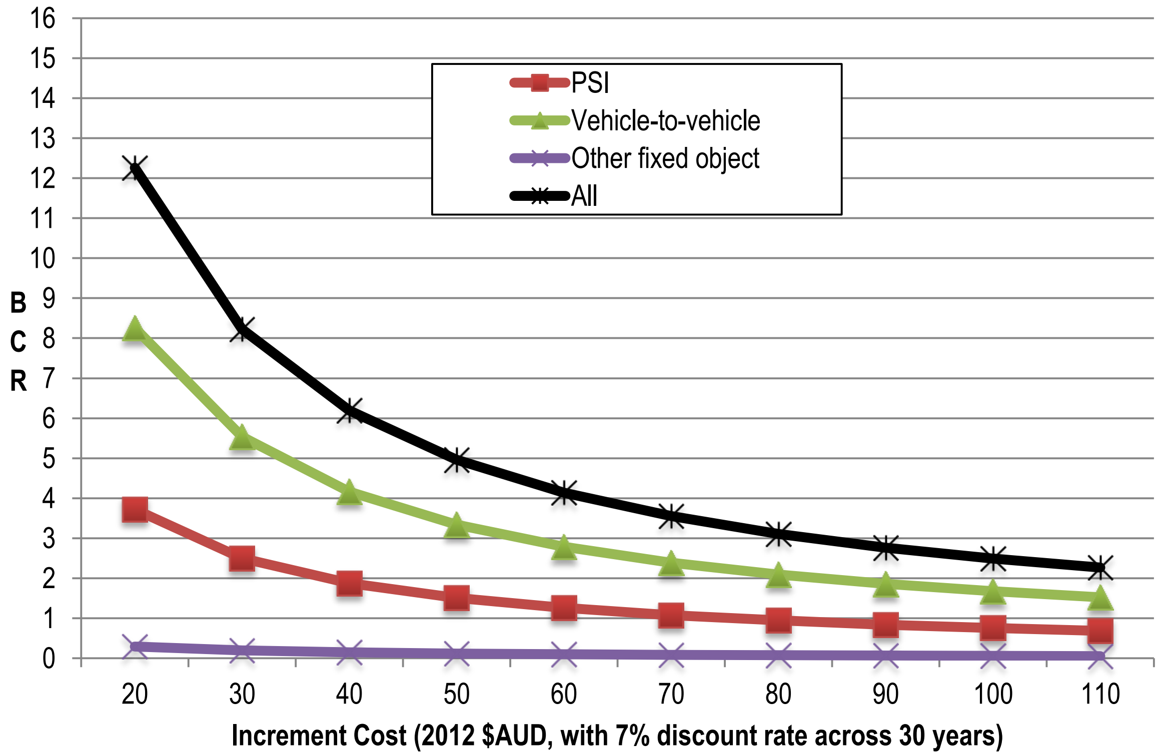


Figure E.1. BCR values across the range of increment costs for the PSI GTR, Class M1 vehicles

Incremental benefits associated with a PSI GTR for front row occupants of N1 vehicles

Table E.2a and Table E.2b presents the expected benefits generated by the PSI GTR assuming a 30% additional safety benefit over the 30 year period, 2016 to 2045 for Category N1 vehicles, and on a per annum basis respectively.

The costs of meeting the PSI GTR were as follows: for vehicles without SAB fitted, the cost was $AU 303.58 ($ 2012 dollars) and for vehicles with a side curtain airbag fitted as standard, the GTR increment cost of $AU 29.82 ($ 2012 dollars) was used. Given the low rate of fitment of side curtain airbags in the N1 category (i.e., vans, 4 x 2, 4 x 4) and the differences in sales volumes across N1 sub-types, the cost of meeting the PSI GTR was calculated for each year, 2016 to 2045. A 7% discount rate was applied to both costs and benefits.

Over the 30 year period, it is estimated that the GTR would result in 67 fewer fatalities avoided, 88 fewer severe TBI injuries and 34 moderate TBI injuries. A small number of instances of paraplegia are also estimated to be avoided (n = 22), while the number of occupants saved from serious and minor injuries is large. Translated into monetary values, the fatality and injury savings equate to $AU 0.407 billion over the period, for an implementation cost of $AU 0.157 billion; the overall BCR was 2.59:1. Sensitivity analysis presented in Figure E.2 shows the BCRs across a range of incremental cost values, ranging from $AU 20 through to $AU 70 per vehicle.

Table E.2a Incremental benefits of a GTR for N1 vehicles, over and above BAU of SAB installation for Australia, 2016-2045

Incremental benefits	Pole impacts	Vehicle-to-Vehicle	Other fixed object	Total
Additional Fatalities avoided	24	43	0	67
Additional TBI-severe avoided	18	64	7	88
Additional TBI-moderate avoided	13	16	5	34
Additional Paraplegia avoided	4	16	2	22
Additional Serious injuries avoided	138	382	53	574
Additional Minor injuries avoided	306	2199	27	2532
Financial benefits, 2016-2045	$102,677,223	$279,098,236	$25,948,052	$407,723,511
GTR requirement cost	$157,288,189	$157,288,189	$157,288,189	$157,288,189
BCR (30 year period)	**0.65**	**1.77**	**0.16**	**2.59**
BCR in Yr 30	1.23	3.44	0.31	4.97

Table E.2b Incremental per annum benefits of a GTR for N1 vehicles, over and above BAU of SAB installation for Australia

Incremental benefits	Pole impacts	Vehicle-to-Vehicle	Other fixed object	Total
Additional Fatalities avoided	1	1	0	2
Additional TBI-severe avoided	1	2	0.2	3
Additional TBI-moderate avoided	0.4	1	0.17	1
Additional Paraplegia avoided	0.1	1	0.06	1
Additional Serious injuries avoided	5	13	2	19
Additional Minor injuries avoided	10	73	1	84
Financial benefits, 2016-2045	$3,422,574	$9,303,275	$864,935	$13,590,784
GTR requirement cost	$5,242,940	$5,242,940	$5,242,940	$5,242,940
BCR (30 year period)	**0.65**	**1.77**	**0.16**	**2.59**

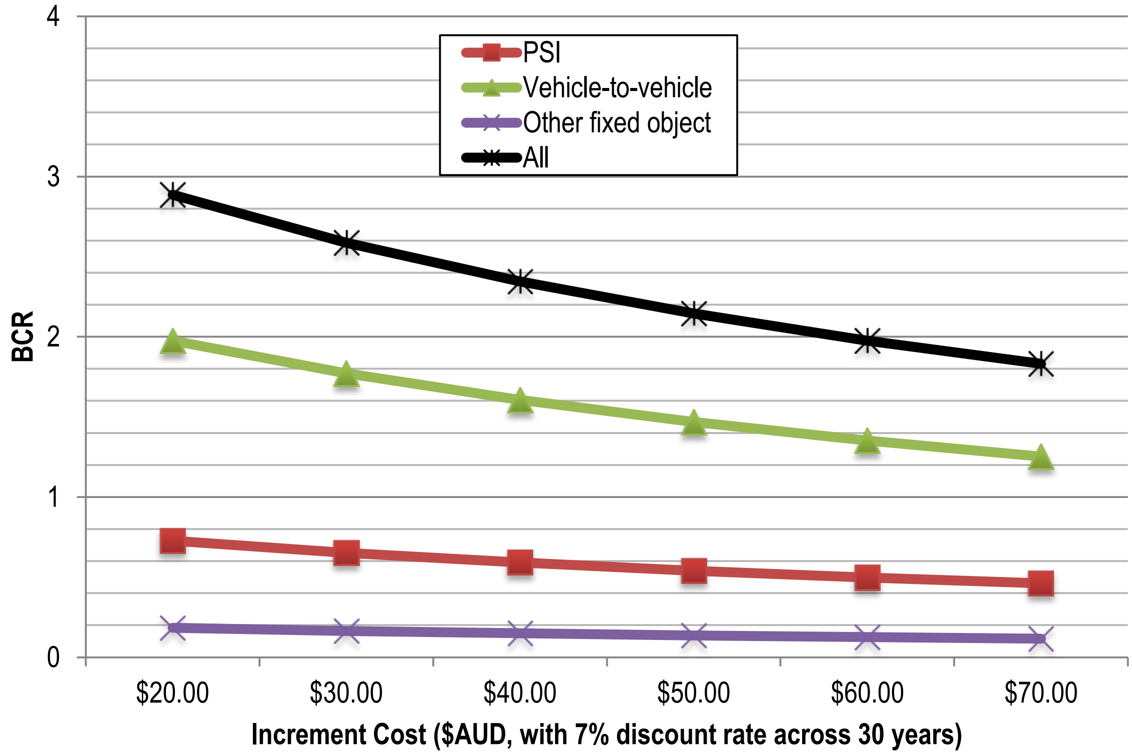


Figure E.2. BCR values across the range of increment costs for the PSI GTR, Class N1 vehicles

Sensitivity assessment of incremental benefits associated with a PSI GTR for M1 and N1 vehicles for front row and all vehicle occupants

The analysis demonstrates the proposed GTR is highly cost effective for front row occupants of both M1 and N1 vehicles. Given the performance requirements of the PSI GTR, the safety benefits to the occupants in the front row and the rear are likely to be similar, if not the same. While the notion that the GTR will have similar effects for non-struck side and rear occupants is contestable, it is especially important to note the comments made in the EEVC report that benefits of a pole test would be expected to accrue to the non-struck side occupant. Morover, with improvements in sensor technology and structural changes to the side airbag system itself (larger volume, broader reach forward and rearwards), the same level of protection would be afforded to rear seat occupants than for those in the front.

Following from above, the benefits analysis was extended to two additional scenarios, these being:

- front row occupants but where four sensor increment costs were used for M1 and weighted two / four sensor increment costs were used for N1 vehicles (to allow for twin vab N1 vehicles), and
- all occupants (front, rear) using four sensor increment costs for M1 vehicles and and weighted two / four sensor increment costs were used for N1 vehicles (to allow for twin cab N1 vehicles).

These additional analysis were performed as a sensitivty analysis in the case of front occupants where manufacturers may elect to cover all seating positions, and to be in line with the likely inclusion of the rear seating positions as part of phase-in requirements of the PSI GTR.

The sensitivity analysis was conducted modelling different GTR increment values, ranging from 20% to 40%. As evident in Table E.3, each of the BCRs were positive for M1 and N1 vehicles for front seat occupants only and for all occupants.

Table E.3 BCR values for M1 and N1 occupants, for front row struck side, all front row occupants and all occupants

GTR increment†	**Front occupants**		**Front occupants**		**All occupants‡**	
	BCR (30 yr. period)	**BCR (equilibrium, at 30th year)**	**BCR (30 yr. period)**	**BCR (equilibrium, at 30th year)**	**BCR (30 yr. period)**	**BCR (equilibrium, at 30th year)**
M1	*Weighted 2 / 4 sensor cost*		*4 sensor cost*		*4 sensor cost*	
20%	7.02	11.65	3.47	5.73	3.99	6.58
30%	***9.51***	***16.65***	***4.70***	***8.18***	***5.41***	***9.41***
40%	12.00	21.65	5.94	10.64	6.83	12.24
N1	*2 sensor cost*		*Weighted 2 / 4 sensor cost (single / dual cab)*		*Weighted 2 / 4 sensor cost (single / dual cab)*	
20%	2.01	3.74	1.88	3.40	2.07	3.75
30%	***2.59***	***4.97***	***2.42***	***4.53***	***2.67***	***5.00***
40%	3.17	6.21	2.96	5.66	3.27	6.24

† percent increment over and above current SAB effectiveness: fatality, 32%; injury, 34%
‡ all occupants means front and rear outboard seated occupants

Combined influence of the GTR on M1 and N1 vehicle side impact fatalities and injuries in Australia

The PSI GTR is aimed at Category M1 and N1 vehicles. It is useful then to present the combined benefits analysis. Table E4 presents the consolidated benefits and costs of the PSI GTR for front seat occupants of M1 and N1 vehicles, while Table E5 presents the same but for all (front and rear) occupants.

For occupants in the front row, the injury savings in person terms translate to considerable economic cost savings, at a value of $AU 3 billion over the first 30 years for an outlay of $AU 0.4 billion (BCR: 7.0:1).

Table E.4 Consolidation of benefits and costs of the PSI GTR for Australia for front row occupants, assuming an incremental safety benefit of 30%

M1 / N1	Pole impacts	Vehicle-to-Vehicle	Other fixed object	Total
Additional Fatalities avoided	329	334	12	675
Additional TBI-severe avoided	150	338	21	509
Additional TBI-moderate avoided	51	228	9	288
Additional Paraplegia avoided	11	32	2	45
Additional Serious injuries avoided	1179	4099	164	5442
Additional Minor injuries avoided	1524	14414	273	16210
Financial benefits, 2016-2045	$899,788,259	$2,045,946,515	$87,770,082	$3,033,504,857
GTR requirement cost	$433,405,635	$433,405,635	$433,405,635	$433,405,635
BCR (30 year period)	**2.08**	**4.72**	**0.20**	**7.00**

In addition to the analysis above where it was assumed manufacturers would seek to install SAB systems to protect only the front row, a supplementary assessment of the economic benefits was performed for front row occupants using different cost structures. Specifically, for M1 vehicles 4 sensor SAB costs were used while for N1 vehicles a weighted combination of two and four sensor SAB systems was used. While the person savings is as above, the BCR was lower due to higher implementation costs; at a installation cost of $AU 0.72 billion the BCR was 4.17:1.

The BCR also remained high at 4.77:1 when the analysis was extended to include benefits for all M1 and N1 front and rear outboard occupants, while using the same increased implementation costs (as outlined in the paragraph above). As stated above, this higher implementation cost is due to the additional sensors likely to be required to achieve the same enhanced SAB effectiveness for front and rear outboard seat positions.

Table E.5 Consolidation of benefits and costs of the PSI GTR for Australia for all outboard occupants, assuming an incremental safety benefit of 30%

M1 / N1	Pole impacts	Vehicle-to-Vehicle	Other fixed object	Total
Additional Fatalities avoided	353	396	12	761
Additional TBI-severe avoided	173	392	21	586
Additional TBI-moderate avoided	60	266	9	335
Additional Paraplegia avoided	13	36	2	51
Additional Serious injuries avoided	1354	4784	164	6302
Additional Minor injuries avoided	1745	15907	325	17978
Financial benefits, 2016-2045	$1,005,078,212	$2,376,484,294	$88,546,262	$3,470,108,769
GTR requirement cost	$726,927,417	$726,927,417	$726,927,417	$726,927,417
BCR (30 year period)	**1.38**	**3.27**	**0.12**	**4.77**

The total savings in person terms and also in economic terms of the PSI GTR are significant. Over the first 30 years, a total of 761 fatalities would be avoided (Table E5), with 675 being front seat occupants (Table E4). There are also significant injury reduction benefits of the GTR, including reductions in serious and moderate traumatic brain injury which in economic terms carry a high economic cost, not to mention the impact on the injured individual and their family.

KEY DISCUSSION POINTS AND CONCLUSION

This report set out to determine the 'safety need' for the establishment of a PSI GTR. The proposed regulation, sponsored by the Australian Government, seeks to develop and implement a side impact crash test specific to narrow object impacts, such as trees and poles.

Based on the series of analyses conducted here, it can be stated that there is a clear need for the enhanced protection of occupants involved in side impact crashes. It is important to note that vehicle-to-vehicle side impact crashes represent a substantial proportion of side impact crashes overall, and the analysis reported here demonstrates a continued high incidence levels of serious head and thorax injuries despite current test protocols.

Further, the analysis of the in-depth data from Australia, the UK and Germany[1] reveals a higher risk of injury to the head, thorax, abdomen-pelvis and lower extremities in narrow object impacts than in vehicle-to-vehicle side impact crashes. These findings are reinforced by the analysis of the Transport Accident Commission Claims Data, which represents a census of all persons injured and making a claim due to their involvement in a traffic crash. This data showed a significantly elevated risk of injury in pole side impact crashes relative to vehicle-to-vehicle side impact crashes, with the head and thorax being up to three times more likely to sustain a 'serious' injury.

Finally, an assessment was made of the likely savings associated with the implementation of a PSI GTR, given certain assumptions. The two key assumptions related to the likely injury reduction benefit associated with the PSI GTR itself given the current implementation of curtain airbags and the expected benefits of ESC. The cost-effectiveness analysis for M1 (passenger vehicles) and N1 vehicles (light commercial) vehicles accounted for the fact that ESC will prevent a number of crashes in the future, whilst also recognising the current fitment rates of head protecting side curtain airbags and thorax protecting side impact airbags.

Throughout the first 30 years, the improved side impact safety requirements demanded by the PSI GTR will translate to 608 fewer passenger car (M1) and 67 fewer light commercial vehicle (N1) front row occupant fatalities. There is also a substantial reduction in the number of severe head injuries and other serious injuries. The combined economic saving is approximately $AU 3 billion for an outlay of $AU 0.43 billion; the requirement is highly cost-effective (BCR: 7.0:1). The introduction of a PSI GTR is highly cost effective for both the M1 and N1 vehicle segments individually, and where higher costs are used assuming all seat positions are afforded improved side impact protection. Sensitivity analysis highlights the robust nature of the benefits across a range of benefit scenarios.

The analysis also highlights the significant positive benefits of the GTR when considering all M1 and N1 vehicle occupants, for a combined saving of 761 lives and a large number of injuries. In monetary terms, the total savings was estimated $AU 3.47 billion (2012 dollar values) for an outlay of $AU 0.726 billion (2012 dollar values) spread over the 30-year period 2016 to 2045, for a BCR of 4.77:1.

In sum, the findings of this report highlight the injurious nature of side impact crashes, and especially pole side impact crashes. These findings alone demonstrate the need for enhanced side impact protection. The position for the development and introduction of a pole side impact test that would demand an on average 30% improvement in side impact protection over and above current practice by focussing on the head and thorax is supported by the cost-effectiveness analysis reported here. The sensitivity analysis gives further confidence in the findings. In short, the evidence in support of a proposed pole side impact regulatory test is overwhelming.

1 Refer**: PSI-05-04** - (BASt) Pole Side Impact Accidents in Germany, http://www.unece.org/trans/main/wp29/wp29wgs/wp29grsp/psimpact_5.html

1 INTRODUCTION

1.1 Background

Side impact crashes are associated with high rates of serious injury, particularly those where the collision partner is a narrow object such as a tree or a pole. At present, while the United States of America (USA) requires a pole side impact test as part of the Federal Motor Vehicle Safety Standards (FMVSS), there is no pole side impact test requirement in the international regulatory regime. Rather, the international test regime includes a test that emulates a vehicle-to-vehicle side impact crash only. The potential value of a narrow object side impact test, and its relevance to side impact crashes generally, is widely recognised. The inclusion of a pole side impact test in the *New Car Assessment Program* (NCAP) regime is evidence of the acceptance and perceived importance of the test. It is however critical to note that not all regional NCAP regimes include a pole side impact test requirement, not all vehicles are subject to the NCAP regime, and those that are tested are not automatically subjected to the pole side impact test.

Within the context of continued high injury severity of narrow object side impact crashes, the Australian Government has sponsored the development of a United Nations *Global Technical Regulation (UN GTR) on Pole Side Impact (PSI)* under the 1998 Global Agreement concerning the establishment of GTRs. A key step in the acceptance of the PSI GTR is the establishment of the 'safety need'. That is, whether the current number of side impact crashes and their associated injury severity is sufficient to warrant the development of a new global standard. This report, commissioned by the Australian Department of Infrastructure and Regional Development, addresses this question.

1.2 Project specification and report structure

The present project aims to provide the basis for determining the case as to the establishment and implementation of a pole side impact GTR. To this end, it was necessary to determine a range of key inputs so as to arrive at the final estimate values, these being:

1. Documenting the number of side impact crashes in the UK using STATS19, the UK reported casualty data;
2. An assessment of the differential injury risk in narrow object side impact crashes relative to vehicle-to-vehicle side impact crashes, using the UK Co-operative Crash In-depth System;
3. Documenting trends in the number of side impact fatalities and their associated injuries using the Australian Fatality data (2001-2006);
4. An assessment of the differential injury risk in narrow object side impact crashes relative to vehicle-to-vehicle side impact crashes, using the Transport Accident Commission Claims data;
5. An assessment of the differential injury risk in narrow object side impact crashes relative to vehicle-to-vehicle side impact crashes, using the Australian National Crash In-depth Study (ANCIS);
6. Determining the incremental benefits associated with the implementation of a PSI GTR, given the fitment of ESC, for the Australian context, by:
    a. establishing the effectiveness of SAB (real-world and NCAP) and fitment rates of SAB vehicle sales data;
    b. examining patterns of injury in NCAP 5* vehicles vs. 'the rest', and
    c. estimating the likely cost of injury estimates and incremental benefits of a PSI GTR, accounting for ESC fitment into the fleet.

The report is structured into eight substantive Chapters in order to address the specifications of the project sponsor.

1.3 Use of the report

This report provides the basis for assessing the safety need and the likely cost-effectiveness of a Pole Side Impact Global Technical Regulation (PSI GTR). In doing so, the report provides detailed information concerning the safety benefits and associated costs of enhanced side impact protection for all side impact crashes where the occupant compartment is directly engaged, including fixed narrow object impacts and vehicle-to-vehicle side impact crashes. This report will permit evidenced-based decisions to be taken concerning the implementation of a new side impact GTR.

The report has been commissioned by the Australian Department of Infrastructure and Regional Development in support of their role as Technical Sponsor for the proposal to develop a GTR concerning PSI crashes within UN ECE WP.29.

2 SIDE IMPACT CRASHES: A CORE COMPONENT OF THE GLOBAL ROAD TOLL

2.1 The global road safety context

Road crashes and associated deaths and injuries are a recognised global prevention priority. This is evidenced by the decade 2011-2020 being declared the Decade of Action for Road Safety by the United Nations General Assembly.[1] This resolution stemmed from the fact that annually 1.3 million people are killed on our roads, with further estimates suggesting that between 20 – 30 million people are injured.[2] As part of the United Nations *Decade of Action for Road Safety,* a global plan that recognises the safe systems approach and the central role of human tolerance to physical injury was formulated (see Figure 2.1).[3] Safer vehicles are recognised to be one of the three key mechanisms of achieving sustained reductions in the number of people killed and injured, along with safe speeds and safe roads and roadsides.

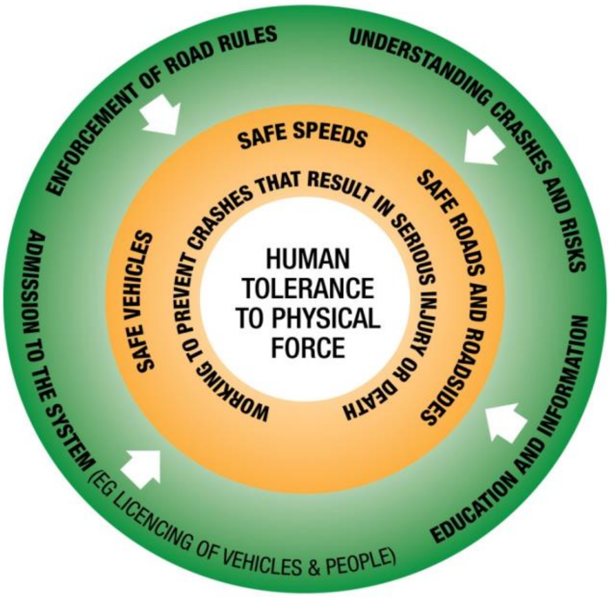


Figure 2.1 The Safe Systems Approach to Road Safety (Source: WHO, 2009)[2]

The *Action Plan*[3] for the Decade of Action specifically notes the role of passive and active safety technologies, such that it seeks to promote the...

> ...Global deployment of improved vehicle safety technologies for both passive and active safety through a combination of harmonization of relevant global standards, consumer information schemes and incentives to accelerate the uptake of new technologies...

...and first among its six activities is:

> Activity 1: Adherence by Member States to motor vehicle safety standards as developed by the UN World Forum for the Harmonization of Vehicle Regulations (WP.29) so that they conform at least to minimum international standards.

This call for activity has been recognised by the UN ECE in the 154th WP.29 session (21-24 June 2011, agenda item 8.9.),[4] whereby activities under Pillar 3 that fall under the responsibility of WP.29 were to be defined. This culminated in the development of the UN ECE Decade of Action for Road Safety - UNECE Plan 2011–2020 which outlines a number of innovations in the arena of active and passive safety systems.[5] The development of Global Technical Regulations (GTRs) that improve the safety of vehicles falls within the scope of the global road safety framework. It is within this context that consideration is being given to the development of a GTR specifically focussed on mitigating the injury risk associated with narrow object side impact crashes, such as poles and trees. It is also recognised that the GTR would produce vehicle safety countermeasures that will also deliver significant benefits for other side impact crashes, including vehicle to vehicle crashes.

2.2 The incidence and burden of side impact crashes

In establishing the need for a GTR focussed on improving side impact protection, consideration must be given to the number of PSI crashes and the proportion of the overall crash problem that they represent. Crash data was supplied to the *Informal Group on Pole Side Impact GTR* by a number of the contracting parties *(*https://www2.unece.org/wiki/download/attachments/3179173/PSI-06-06e.pdf *).*

2.2.1 Number of people killed in side impact crashes

Side impact crashes represent a sizeable proportion of the number of people killed in road crashes. Based on the data supplied to the *Informal Group* by the *Contracting Parties* (see Table 2.1, Table 2.2, Appendix A2 for definitions of 'injury'), side impact crashes account for between 5.6% (Japan) to as high as 24.8% (Germany) of the national road deaths. Impacts with narrow objects, such as poles, accounted for between 11.4% (Japan) to 50.4% (Australia) of all side impact deaths across the nine *Contracting Parties* which provided data.

It can also be stated that deaths due to pole side impact crashes account for between 0.6% of the national road fatality toll (i.e., Japan) to as high as 10.3% in the case of Australia of all persons killed, and between 2.1% (Japan) and 17.1% (Germany) of occupants of 4-wheeled vehicles being killed.

Across nine Contracting Parties, 10 456 occupants of category M1 and N1 vehicles were killed in a single calendar year, with 75% of these associated with vehicle-to-vehicle and non-narrow object impacts; hence 25% of the reported deaths were associated with narrow object side impact crashes.

Within a global context, across the Contracting Parties fatalities associated with pole and vehicle / other object side impact crashes represented an average 4.2% and 13.1% of all persons killed respectively. Given that the World Health Organisation report that 1.3 million road users are killed globally every year,[2] it could be estimated that globally 224 900 occupants of M1 and N1 vehicles are killed annually with 24.2% being due to pole side impact crashes (n = 54 600) and the majority (75.3%, n = 170 300) associated with vehicle-to-vehicle and other object side impact crashes.

2.2.2 Number of people injured in side impact crashes

The number of occupants of M1 and N1 category vehicles seriously injured and hospitalised due to side impact crashes is high[2]. For instance, in the United States over 49,000 drivers and passengers are admitted to hospital, more than 13 000 in Germany and 6830 in Australia. Side impact crashes account for between 5.4% (France) and 22.8% (USA) of all hospital admissions due to road trauma. Up to one-fifth of side impact admissions were due to pole impacts.

2 Refer to Appendix A2 for definitions of 'injury', which are seen to vary across the Contracting Parties in the supply of this data.

Table 2.1 Number and percent of persons killed in pole side impact and other side impact crashes

	Pole Side Impact fatalities				Other side impact crashes				All side impact		
Country	**Number**	**% of all road deaths**	**% 4-wheeled occupants**	**Rate (per 100,000)**	**Number**	**% of all road deaths**	**% 4-wheeled occupants**	**Rate (per 100,000 persons)**	**Number**	**% of all road deaths**	**PSI as % of all side impact**
Australia (2009)	155	10.3	14.8	0.71	152	10.1	14.5	0.7	307	20.4	50.4
Canada (2009)	60	2.7	4.0	0.18	215	9.7	14.2	0.65	275	12.4	21.8
France (2009)	181	4.2	7.5	0.28	333	7.8	13.9	0.52	514	12.0	35.2
Germany (2009)	396	9.5	17.1	0.48	632	15.2	27.3	0.77	1,028	24.8	38.5
Great Britain (2009)	122	5.5	10.9	0.20	353	15.9	31.4	0.59	475	21.4	25.7
Japan (2009)	37	0.6	2.1	0.03	287	4.9	16.2	0.23	324	5.6	11.4
Netherlands (2009)	21	3.3	6.6	0.13	57	8.9	18.0	0.35	78	12.1	26.9
South Korea (2009)	204	3.5	10.3	0.42	1,024	17.4	51.8	2.11	1,228	20.9	16.6
USA (2009)	1371	4.1	5.7	0.45	4,872	14.4	20.4	1.59	6,243	18.5	22.0

Table 2.2 Number and percent of persons seriously injured in pole side impact and other side impact crashes†

	Pole Side Impact				Other side impact crashes				All side impact		
Country	**Number**	**% of all road users**	**% 4-wheeled occupants**	**Rate (per 100,000)**	**Number**	**% of all road users**	**% 4-wheeled occupants**	**Rate (per 100,000 persons)**	**Number**	**% of all road deaths**	**PSI as % of all side impact**
Australia (2009)	1640	2.4	3.4	7.53	5190	7.4	10.8	23.80	6830	9.8	24.0
Canada (2009)	161	1.4	2.1	0.49	720	6.3	9.4	2.19	881	7.7	18.3
France (2009)	325	1.00	2.1	0.50	1474	4.4	9.7	2.29	1,799	5.4	18.1
Germany (2009)	2372	3.5	7.3	2.89	10,893	15.9	33.6	13.28	13,265	19.3	17.9
Great Britain (2009)	484	1.9	4.4	0.81	3,769	15.3	34.4	6.28	4,253	17.2	11.4
Japan (2009)	52	0.1	0.4	0.04	2131	4.0	14.7	1.67	2183	37.8	1.7
Netherlands (2009)	22	1.5	5.3	0.13	79	5.2	19.0	0.48	101	6.7	21.8
South Korea (2009)	1985	-	0.8	4.08	148,442	-	58.9	305.39	165,427	-	10.3
USA (2009)	3813	1.8	2.3	1.24	45,695	21.1	27.4	14.88	49,508	22.8	7.7

†see Appendix A2 for serious injury definitions

2.2.3 Pole side impact fatalities in Australia, 2000 – 2009

The overall number of road users killed in Australia has declined, both on a rate basis as well as in actual numeric terms. In the 2009 calendar year, 1507 road users were killed compared to 1817 in 2000, representing a 17% reduction in deaths.[6-8] For vehicle occupants, in 2009, 1049 drivers and passengers of all vehicle types were killed compared to 1302 in 2000, translating to a 19.4% reduction in the same period.

Of interest is the number of occupants of M1 and N1 vehicles killed in side impact crashes, with particular interest in pole side impacts given the test configuration of the proposed GTR. To supplement the Australian Road Fatality Data, it was necessary to estimate the number of deaths based on Victorian crash data.[3]

As evident in Figure 2.2, there is considerable fluctuation in the number of drivers and passengers killed in side impact crashes involving a narrow object, such as a pole or tree, across the period. For instance, while in 2009, 155 drivers and passengers of M1 and N1 vehicles were killed compared to 196 in the year 2000, the highest number killed (n = 212) occurred in 2008.

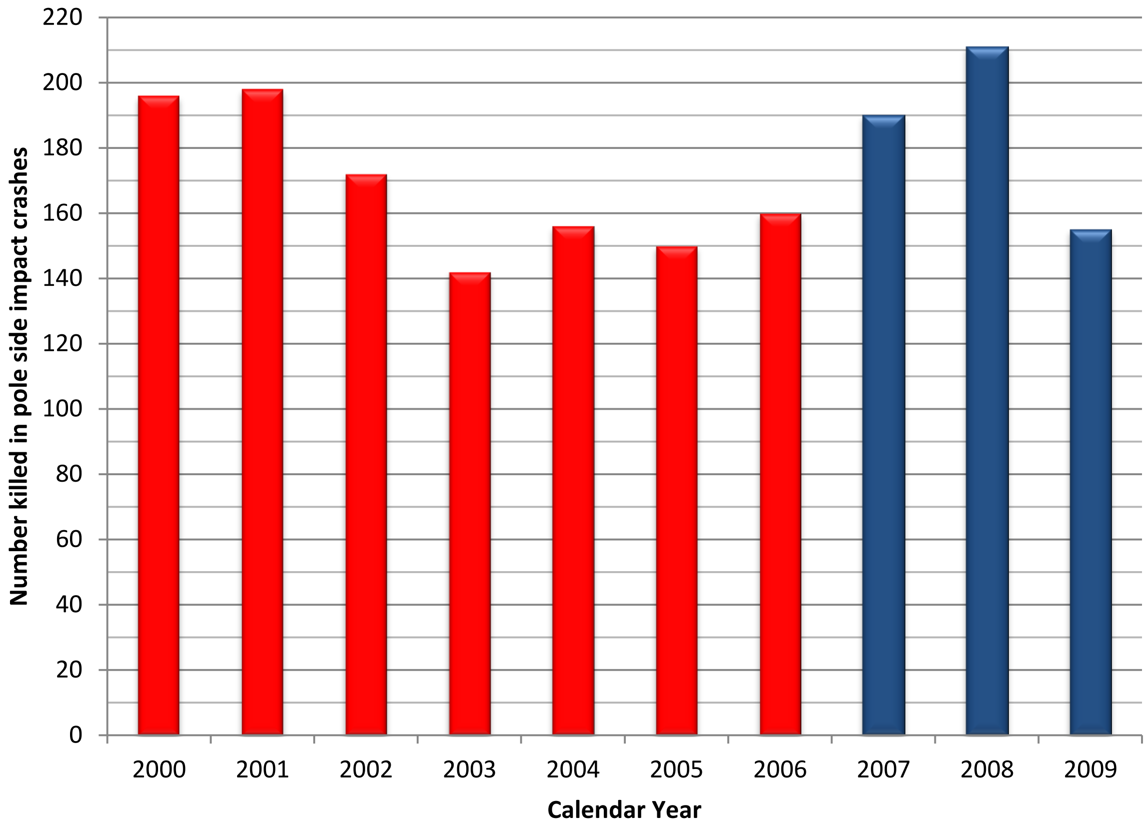


Figure 2.2 Number of occupants killed in pole side impact crashes in Australia, with known (2000-2006; red) and estimated data (2007-2009; population estimate shown in blue)

2.2.4 Number of occupants seriously injured as per AIS 3+ injuries in Victoria, Australia

The data presented in the previous section relates to the number of occupant fatalities, however there were some differences in the definition of serious injury across the jurisdictions. Classification of injury severity using

3 See Chapter 5 for estimation methods. Estimates are based on Victorian Police Reported Crash Data, inflated to represent the national population (multiplier of 4.037) and a yearly multiplier to account for differences in road safety performance in the Victoria relative to all other States and Territories. Victorian fatalities exclude rollover crashes which may have been involved a side impact crash, and involves damage to the side of the vehicle only.

accepted metrics such as the Abbreviated Injury Scale (AIS) severity scores[9] permits greater understanding of the cost burden associated with crashes. However mass crash data as a general rule does not include injury data with sufficient detail to document injury severity beyond 'fatal', 'seriously injured', 'minor injury' or 'uninjured, property damage only'. There is a need therefore to examine other sources of road crash data to adequately document injury severity.

Within Victoria, Australia, all road users have comprehensive no-fault third party insurance. The government authority, known as the *Transport Accident Commission* (TAC), provides an array of benefits for persons involved in road crashes including full coverage for medical and like expenses, loss of earnings (to specified limits), and lifetime care for those seriously injured.[10] The TAC also is mandated to improve road safety in the State of Victoria, which also serves to contain its future liabilities by reducing the incidence of crashes.

Data for the period 2000 to 2009 inclusive was available for analysis, which included details of 174,233 road users, of which 127,254 were four-wheeled vehicle occupants (fatalities: 2482, 1.95%; injured: 124,772, 98.05%). The overall mortality rate was 1.9% for occupants involved in frontal and other impact configurations, and 2.3% for side impact crashes. Nearly half of all fatalities in the 10-year period resulted from side impact crashes (48.6%), followed by frontal impacts (39%) and 'other impacts' (12.4%).

The TAC requires validation for every road user who lodges a claim – including those uninjured, to assess the validity and limits of the claim. The TAC Claims Database therefore holds significant detail on every crash involved road user who makes a claim, including the precise nature of any injury sustained coded using the International Statistical Classification of Diseases and Related Health Problems (ICD) for those initially presenting to hospital for treatment[11]. AIS codes were derived for each ICD injury described (refer Chapter 6 for detail). *It is important to note that ICD codes are not routinely obtained for road users killed at the scene or those that are 'dead-on-arrival' at hospital.* ICD injury data was available for only 19.7% (n = 489) of the 2482 fatalities. As a consequence of the large percentage of killed occupants where comprehensive ICD information was unknown, no data concerning injuries sustained is presented for those killed; rather an analysis of the *Fatal Road Crash Database* including a description of injuries sustained is presented in Section 5 of this report.

Among those injured in Victoria, Table 2.3 presents the percent sustaining AIS 3+ injuries by impact direction using the following categories: frontal impact (n = 49,695); side impact (n = 51,101); 'other' impact (n = 23,976), which includes rollover crashes and rear impact crashes. The analysis reveals that 2891 occupants (5.7%) involved in side impact crashes sustained an AIS 3+ (serious) injury, with the thorax (n = 1571, 3.1%) and then the head (n=959, 1.9%) being most frequently injured regions. There was little difference in the injury distribution of occupants involved in frontal and side impact crashes.

Table 2.3 Number and percent of 4-wheeled vehicle occupants classified as injured that sustained AIS 3+ injuries, Victoria 2000-2009 (excludes fatalities; multiple AIS 3+ injuries per occupant possible)

AIS 3+ (serious injury)	**Impact configuration**						**Total (n = 124,772)**	
	Frontal (n = 49,965)		**Side impact (n = 51,101)**		**Other (n =23,976)**			
	n	**%**	**n**	**%**	**n**	**%**	**n**	**%**
Head	840	1.7%	959	1.9%	295	1.2%	2094	1.7%
Face	20	<0.1%	6	0.1%	2	0.1%	28	0.1%
Neck	1	<0.1%	-	-	-		1	001%
Thorax	1627	3.3%	1571	3.1%	352	1.5%	3550	2.8%
Abdomen-Pelvis	386	0.8%	344	0.7%	64	0.3%	794	0.6%
Spine	304	0.6%	253	0.5%	162	0.7%	729	0.6%
Upper extremity	76	0.2%	72	0.1%	24	0.1%	172	0.1%
Lower Extremity	654	1.3%	511	1.0%	104	0.4%	1269	1.0%
External	14	<0.1%	13	0.1%	5	<0.1%	32	0.1%
Number occupants with AIS 3+ injury	**3091**	**6.2%**	**2891**	**5.7%**	**850**	**3.5%**	**6832**	**5.5%**

The analysis of the *TAC* data for the 10-year period permits an estimation of the number of occupants injured (but not killed) involved in side impact crashes that sustain an AIS 3+ injury. Using population statistics[12] and vehicle registrations[13] as the basis for extrapolation and differences in crash injury rates between jurisdictions[6, 7], the number of occupants with AIS 3+ injuries in Australia can be determined (Table 2.4).

It is estimated that over the 10-year period, 16 583 occupants of 4-wheeled passenger vehicles sustained an AIS 3+ (serious) injury in side impact crashes, equating to 1658 occupants per annum. Analysis of AIS 3+ injuries by body region highlights the large number of occupants sustaining thorax, head and lower extremity injuries in particular.

Despite representing a small proportion of the total number of crash involved occupants – and excluding fatalities, the financial burden is considerable. For instance, using recently published estimates of the lifetime care cost of moderate and severe head injuries[14], it can be estimated that serious head injuries cost the community between $AU 13.75 billion to $AU 27.5 billion over the 10 year period, depending on the value of traumatic brain injury whether a moderate of severe traumatic brain injury is assumed at the AIS 3+ level[(a)].

An alternative estimate of using the number of registered vehicles produces slightly lower estimates.

Table 2.4 Number and percent of 4-wheeled vehicle occupants classified as injured that sustained AIS 3+ injuries, Australia 2000-2009[!!] (Excluding fatalities; multiple AIS 3+ injuries per occupant possible)

AIS 3+ (serious injury)	**Number of occupants sustaining AIS3 + injuries in side impact crashes admitted to hospital (excludes fatalities)**			
	Population estimate†		**Vehicles registered estimate‡**	
	10-year period	**Per annum**	**10-year period**	**Per annum**
	n	**n**	**n**	**n**
Head	5501	550	5258	526
Face	34	3	33	3
Neck	*Defaults to spine, region specific location, or external in mapping from ICD to AIS*			
Thorax	9011	901	8613	861
Abdomen-Pelvis	1973	197	1887	189
Spine	1452	145	1387	139
Upper extremity	413	41	395	40
Lower Extremity	2931	293	2801	280
External	74	7	71	7
Number occupants with AIS 3+ injury	**16583**	**1658**	**15848**	**1585**

†Based on 2000 – 2009 Australian population statistics, Victoria comprises 24.7674% of the Australian national population[12]; inflation factor of 4.0375655 was used + secondary inflation factor of 1.420605 to account for differences in crash injury rates between Victoria and other jurisdictions.
‡Based on 2005, 2006, 2009 Motor Vehicle Census, including passenger cars, campervans and light commercial vehicles; Victoria has 25.9133% of these vehicle types in Australia[13]; inflation factor of 3.859026 was used + secondary inflation factor of 1.420605 to account for differences in crash injury rates between Victoria and other jurisdictions.
[(a)] Lifetime care costs for a person with moderate traumatic brain injury (TBI) was $AU 2.5 million and for severe TBI $AU 5 million.

Injury trends over time in Victoria – The analysis of the injury data presented above disaggregated by year can provide the basis of determining possible future trends, and can also serve as the basis of a national serious injury estimate for side impact crashes. Figure 2.4 presents the number of occupants involved in side impact crashes – excluding fatalities, who sustained an AIS 3+ injury to any body region (blue line) and the number who sustained an AIS 3+ head and face injury (red line). Since 2003 an upward trend in the number of occupants with an AIS 3+ injury is evident, while the number of occupants with an AIS 3+ head and face injury has remained stagnant since 2004 at approximately 100 new cases per annum.

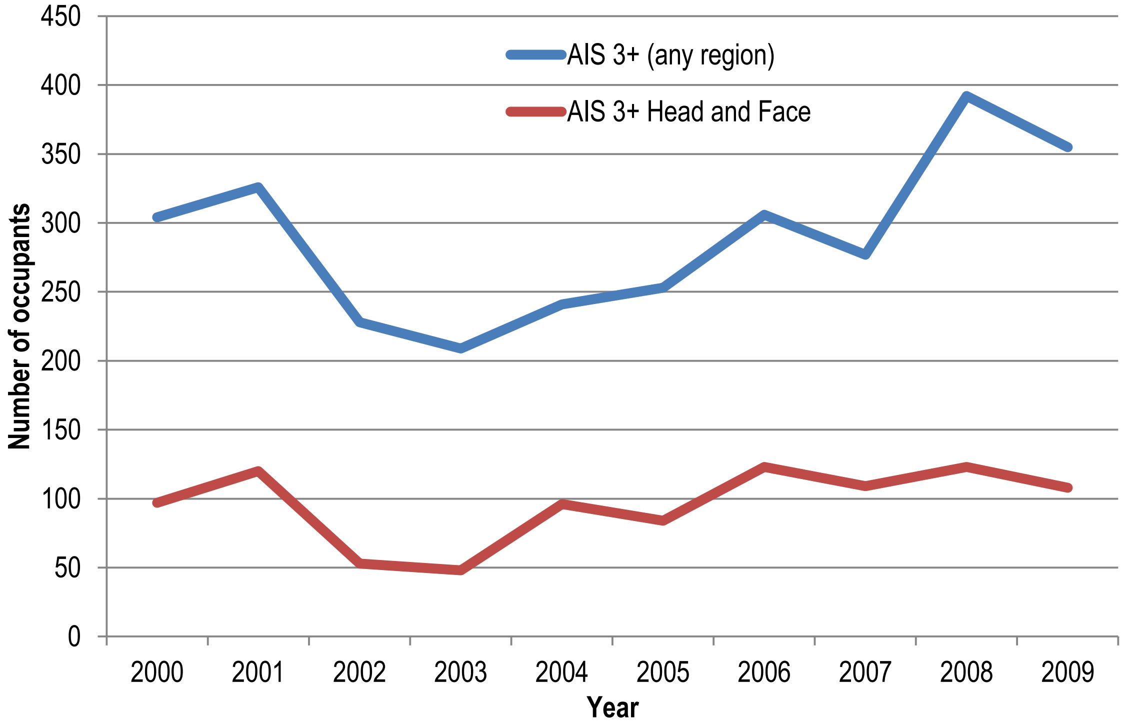


Figure 2.3 Number of occupants in side impact crashes with an AIS 3+ injury to any region and AIS 3+ injuries to the head and face, Victoria 2000-2009

Extrapolated injury trends over time for Australia – Using the Victorian injury data, and following the extrapolation method described above in Table 2.4, the estimated number of persons in Australia involved in side impact crashes who sustain an AIS 3+ injury and an AIS 3+ head and face injury is presented in Table 2.5. While the time-trend is clearly the same as that for Victoria (per Figure 2.3), the number of AIS 3+ incident cases for the latest year (2009) was 1889 (population estimate) and 575 occupants with an AIS 3+ head injury.

Table 2.5 Number of 4-wheeled vehicle occupants injured sustaining AIS 3+ injuries and head and face AIS 3+ injuries, Australia 2000-2009 (excluding killed)

Year	Occupants injured in side impact crashes, Australia (excludes killed)			
	Population estimate†		Vehicles registered estimate‡	
	AIS 3+ All regions	AIS 3+ Head / Face	AIS 3+ All regions	AIS 3+ Head / Face
	n	n	n	n
2000	1618	517	1546	493
2001	1735	639	1659	610
2002	1214	282	1160	270
2003	1113	256	1064	244
2004	1283	512	1226	488
2005	1347	447	1287	427
2006	1628	655	1557	626
2007	1474	580	1409	555
2008	2087	655	1995	626
2009	1889	575	1806	550
Total	15389	5115	14708	4890

†Based on 2000 – 2009 Australian population statistics, Victoria comprises 24.7674% of the Australian national population[12]; inflation factor of 4.0375655 was used + secondary inflation factor of 1.318368 to account for differences in crash injury rates between Victoria and other jurisdictions. ‡Based on 2005, 2006, 2009 Motor Vehicle Census; Victoria has 25.9133% of these vehicle types in Australia[13]; inflation factor of 3.859026 was used + secondary inflation factor of 1.318368 to account for differences in crash injury rates between Victoria and other jurisdictions.

2.3 The current regulatory context

There are a number of regulatory tests that influence vehicle side impact protection, each with different test specifications and requirements. These tests are simply noted here for reference and it is not intended that they are discussed in any detail. Rather, by noting their existence, the broader context and safety need for a pole side impact GTR can be considered. Current regulatory tests relevant to side impact crashes are presented in Table 2.6. It is recognised that there are a number of non-mandatory performance-based side impact crash tests under the auspices of the New Car Assessment Program (NCAP). These are not outlined here as the focus is on the implementation of a mandatory pole side impact regulation.

Table 2.6 Performance-based regulatory tests relevant to side impact protection

Jurisdiction	Regulatory Standard	Description
USA	FMVSS-214, Side Impact Protection	The rule requires a 16 to 20 mph (26-32.2 km/h), 75-degree oblique pole (254 mm diameter) test run in two different configurations, one with a 50th percentile male (ES-2re) dummy and the other with a 5th percentile female (SID-IIs Build D) dummy. Lead times until September 1, 2013. The rule requires a test with the ES-2re in the front seat and the SID-IIs Build D in the rear seat in the moving deformable barrier (MDB) dynamic FMVSS 214 side impact (perpendicular) test (33.5 mph, 54 km/h closing speed). The injury criteria in the MDB test are the same as those required for the vehicle-to-pole test. (Source: NHTSA, 2007)[15]
USA	FMVSS-201, Occupant Protection in Interior Impact	Specifies protection requirements when an occupant's head strikes certain upper interior components. The performance test is a free-motion head-form propelled at specific target points in the vehicle at 15 mph. (Source: NHTSA, 2007)[15] Includes a pole test at 29 km/h at 90 degrees
UN ECE	ECE R 95 *Also adopted as ADR 72 in Australia*[16] as well as other jurisdictions	Perpendicular test with a mobile deformable barrier speed at the moment of impact being 50 ± 1 km/h.[17]

In the context of development of the PSI GTR, the risk of head injury and the coverage afforded by the current performance standards is relevant. This point was made by the *Chairman of the Informal Group (Informal document WP.29-156-29)* who noted:

> The passive safety countermeasures expected to be used in vehicles to meet the requirements of a PSI GTR are likely to reduce injury risk in pole side impact crashes as well as other side impact crashes, including high severity vehicle-to-vehicle side impact crashes and/or where head injury risks not simulated by current regulatory barrier tests occur as a result of geometric incompatibility between vehicles. There may also be benefits in rollovers

It is pertinent to note that the principal purpose for the amendment to FMVSS-214 to add a pole side impact test was to improve the protection to the head and thorax, and NHTSA felt that *'side airbags for the head and thorax will be used to pass the test and that most manufacturers will have to make their current side air bags wider to pass the oblique test'* (p.E-1).[15] In the conduct of their regulatory analysis, NHTSA used incremental costs of enhanced, optimised side airbag systems of $US 66.00 per vehicle in arriving at significant benefits.

2.4 Research into the effectiveness of side airbag systems

Side impact airbags (SAB) are designed to protect the head and/or thorax during a side impact crash. There are three main types of SAB:

1. those designed to protect the torso (or thorax) only;
2. those designed to protect the head only, and
3. those that are designed to protect both the torso and the head.

Several studies have been conducted to assess the effectiveness of SAB in reducing fatalities and injuries with most of the research having been conducted in the USA – where the evaluations were also of FMVSS-214, with a smaller number of studies conducted in Europe.

These published studies provide the basis for understanding risk reductions associated with side impact crashes, and effectiveness of countermeasures. In the review, four studies focussed on estimating reductions in fatality (all of which were US based studies), and nine studies examined the effectiveness of side airbag systems in mitigating injury risk and severity.

2.4.1 Data Sources used in side airbag evaluation studies

The data sources used in the SAB evaluation studies will be briefly described prior to critically evaluating the studies themselves. For each of the data sources used, Table 2.7 contains a brief description and a list of the studies that used data from that source to estimate the effectiveness of SAB.

Table 2.7 List of data sources used to study the effectiveness of SAB

Country	Data source	Description	SAB Effectiveness studies that used this source
USA	Fatality Analysis Reporting System (FARS)	Census of all fatal crashes in the USA	Braver & Kyrychenko, (2004)[18] McCartt & Kyrychenko, (2007)[19] Kahane (2007)[20] Lange et al. (2011)[21]
USA	National Automotive Sampling System (NASS): Crashworthiness Data System (CDS)	Representative random sample of minor, serious and fatal crashes of light passenger vehicles involved in police-reported tow away collisions. Trained crash researchers obtain data from crash sites and crash victims.	McGwin et al. (2004)[22] Scarboro et al. (2007)[23] McGwin et al. (2008)[24] Stadter et al. (2008)[25] UAB CIREN Center (2011)[26]
USA	National Automotive Sampling System (NASS): General Estimates System (GES)	Nationally representative sample of police-reported motor vehicle crashes, minor to fatal. Data is obtained from police accident reports from 60 areas in the US that are representative of the US in terms of geography, distance driven, population and traffic density. Weights are used to derive national estimates.	McGwin et al. (2003)[27] Braver & Kyrychenko (2004)[18] McCart & Kyrychenko (2007)[19] Kahane (2007)[20]

Country	Data source	Description	SAB Effectiveness studies that used this source
USA	Crash Injury Research and Engineering Network (CIREN)	Data pooled from 8 trauma centres on seriously injured occupants in crashes. The occupant must have an AIS 3 injury or two or more AIS 2 injuries in different body regions (except for paediatric and pregnant occupants). Restricted to vehicle model years within the previous 6 years. For frontal crashes, occupants must have been restrained by a seat belt or have had an air bag deploy.	Scarboro et al. (2007)[23] Smith et al. (2010)[28] UAB CIREN Center (2011)[26]
Sweden	Swedish Traffic Accident Data Acquisition (STRADA)	Includes data from police (all districts) and hospitals (a sample) on injuries and crashes in the road transport system	Stiggson & Kullgren (2011)[29]
Germany	German In-depth Accident Study (GIDAS)	In-depth data collected on approx. 2000 crashes each year in Hanover and Dresden. Crashes are a representative sample of national crashes.	Page et al. (2006)[30]
France	LAB	In-depth crash data. Approximately 600 crashes are investigated each year.	Page et al. (2006)[30]
United Kingdom	Co-operative crash injury study (CCIS)	In-depth crash data. Crashes must include a car < 7 years old, and the focus was on fatal and serious injury crashes	Page et al. (2006)[30]

2.4.2 Fatality reductions

Four studies have been conducted that investigated the effectiveness of side impact airbags in reducing fatality risk. Three of the four studies used data from FARS and GES to measure the fatality rate reduction per crash associated with SAB (Braver & Kyrychenko, 2004[18]; McCartt and Kyrychenko, 2007[19]; Kahane, 2007[20]). Kahane[20] also investigated the ratio of near side impact fatalities to front/rear impact fatalities, and how this varied with SAB availability. Lange et al. (2011) used FARS data to estimate the reduction in fatality risk per registered vehicle with SAB. The studies by Braver and Kyrychenko and McCartt & Kyrychenko are discussed in detail below and summarised in Table 2.8, while the studies by Kahane and Lange et al. are discussed but not presented in table format.

Study by Braver and Kyrychenko (2004)[18]

Braver and Kyrychenko (2004)[18] were the first to explore whether the fatality risk for drivers involved in near-side impacts in the period 1999 to 2001 differed according to SAB availability in 1997 to 2002 Model Year (MY) passenger cars.

The fatality rate was calculated using the number of fatal near side impact crashes from the FARS census as the denominator divided by the total number of near side impact crashes estimated from weighted GES data. Relative fatality rates were determined for two comparisons:

1. Torso only SAB compared with no SAB
2. SAB with head protection compared to no SAB.

Estimates were adjusted for mortality in front/rear impact crashes in an attempt to control for socio-economic status (SES) related driver factors; that is, to account for the possibility that drivers who have SAB may differ in terms of crash risk from drivers without SAB in terms of speed of travel, seat belt use, type of travel and vehicle occupant compartment safety features other than SAB

The principal results were:

1. For torso only SAB compared to no SAB, results indicated a non-statistically significant 11% reduction (adjusted RR=0.89, 95% CI 0.79-1.01) in fatality risk, and
2. A statistically significant 45% reduction (adjusted RR=0.55, 0.43-0.71) in fatality risk for SAB with head protection.

The results were also stratified by different factors to determine if the effectiveness of SAB differed according to driver demographics, number of vehicles involved, or the characteristics of the struck car or the crash partner (striking vehicle). There was no evidence for differential effectiveness of SAB with head protection according to the gender or age of the driver, for striking vehicles that weighed more or less than 1724 kg or for single vehicle crashes compared to two vehicle crashes.

Stratification by characteristics of the striking vehicle showed that SAB with head protection were more effective when the crash partner was a car or minivan (adj. RR= 0.26, 95% CI 0.11-0.64) than when it was a large truck or bus (adj. RR=1.93, 95% CI 0.66-5.69), and when the struck car was large or very large (adj. RR=0.41, 95% CI 0.30-0.57) compared to when it was midsize (adj. RR=1.04, 95% CI 0.66-1.64).

For torso only SAB, there was no apparent difference in effectiveness according to the age of the driver, or the characteristics of either the striking or the struck vehicle. However, there was a trend for torso only airbags to be more effective in single vehicle collisions (adj. RR=0.62, 95% CI 0.4-0.96) than two vehicle collisions (adj. RR=1.11, 95% CI 0.94-1.31) and for males (adj. RR=0.79, 95% CI 0.64-0.99) compared to females (adj. RR=1.21, 95% CI 0.98-1.50).

Study by McCartt and Kyrychenko (2007)[19]

McCartt and Kyrychenko (2007)[19] replicated and extended the Braver and Kyrychenko (2004)[18] study using more data from a longer period of time and a slightly different technique for using front/rear impact mortality to adjust for SES related factors.

In a replication of Braver and Kyrychenko[18], crashes that occurred between 1999 and 2001 involving passenger cars from model years 1997 to 2002 were selected and the effectiveness of torso only and SAB with head protection calculated. Secondly, crashes that occurred between 2000 and 2004 for passenger cars and SUVs from model years 2001-2004 were selected and estimates calculated. These results of both of these statistical models were then combined.

For older (1997-2002) passenger cars with SAB with head protection there was a 47% reduction in fatality risk (adj. RR=0.53, 95% CI 0.43-0.65) while for newer passenger cars (2001-2004) there was a 31% reduction (adj. RR=0.69, 95% CI 0.60-0.80) compared to cars without SAB. The combined estimate for SAB with head protection was a 37% reduction in fatality risk, compared to passenger cars without SAB (adj. RR=0.63, 95% CI 0.56-0.71).

Stratification by certain crash factors provided no evidence for differential effectiveness of SAB with head protection according to driver gender or age, the characteristics of the struck vehicle, or weight of the striking vehicle. However, SAB with head protection appeared to be more effective when the striking vehicle was a car/minivan (adj. RR=0.43, 95% CI 0.37-0.51) or SUV/pickup (adj. RR=0.54, 95% CI 0.43-0.67) than when it was a large truck (adj. RR=1.07, 95% CI 0.67-1.70), and when the collision involved two vehicles (adj. RR=0.55, 95% CI 0.48-0.63) compared to single vehicle collisions (adj. RR=0.94, 95% CI 0.68-1.29).

For older (1997-2002) passenger cars with torso-only SAB, there was a 25% reduction in fatality risk (adj. RR=0.75, 95% CI 0.64-0.89), while for newer passenger cars (2001-2004) there was a 27% reduction (adj. RR=0.73, 95% CI 0.61-0.87) compared to cars without SAB. The combined estimate for torso only SAB was a 26% reduction in fatality risk, compared to passenger cars without SAB (adj. RR=0.74, 95% CI 0.66-0.84). Stratification revealed no evidence for differential effectiveness of torso only SAB according to driver gender or age, crash type or characteristics of the striking vehicle. However, for struck cars, torso only SAB appeared to be more effective for small (adj. RR=0.61, 95% CI 0.49-0.75) and midsize cars (adj. RR=0.59, 95% CI 0.49-0.71) than large cars (adj. RR=0.90, 95% CI 0.76-1.08), and there was some evidence for them to be more effective for two door cars (adj. RR=0.54, 95% CI 0.43-0.68) than four door cars (adj. RR=0.77, 95% CI 0.67-0.88).

Separate estimates of effectiveness were also obtained for combination head SAB and curtain SAB for the 2001 to 2004 passenger cars. For both types of head protecting SAB, there was a 31% reduction in fatality risk relative to cars without SAB (adj. RR=0.69, 95% CI 0.58-0.82 and 0.57-0.83, respectively). The effectiveness of both combination SAB and curtain head side airbags varied according to the type of striking vehicle. Combination SAB were more effective when the striking vehicle was a car or minivan (adj. RR=0.36, 95% CI 0.29-0.45) than when it was a SUV/pickup (adj. RR=0.84, 95% CI 0.61-1.15) and when the driver was female (adj. RR=0.54, 95% CI 0.43-0.66) rather than male (adj. RR=0.86, 95% CI 0.69-1.08). There was also a trend for combination SAB to be more effective when the striking vehicle weighed less than 1724 kg (adj. RR=0.51, 95% CI 0.41-0.63) compared to heavier vehicles (adj. RR=0.91, 95% CI 0.62-1.36). In contrast, curtain SAB were more effective when the striking vehicle was a SUV/pickup (adj. RR=0.34, 95% CI 0.25-0.47) than when it was a car/minivan (adj. RR=0.78, 95% CI 0.61-1.00) or a large truck (adj. RR=1.45, 95% CI 0.70-3.01) and when the striking vehicle weighed more than 1724 kg (adj. RR=0.35, 95% CI 0.25-0.49) compared to lighter vehicles (adj. RR=0.64, 95% CI 0.50-0.83).

Estimates of effectiveness were also calculated for 2001 to 2004 model SUVs. SAB with head protection were associated with a 52% decrease in fatality risk (adj. RR=0.48, 95% CI 0.37-0.62), while torso only SAB were associated with a 30% decrease in fatality risk (adj. RR=0.70, 95% CI 0.56-0.88), relative to SUVs without SAB.

Table 2.8 Estimates of fatality reductions associated with side impact airbags

Authors	Data source	Vehicle model year		Relative driver fatality rate per near side impact for vehicle with SAB relative to not fitted, adjusted for front/rear impact fatality rate
Braver and Kyrychenko (2004)	FARS 1999-2001 GES 1999-2001	Passenger cars 1997-2002	**Torso only**	**11%** (ns) [adj. RR=0.89 (95% CI 0.79-1.01)]
			Torso + head	**45%** [adj. RR=0.55 (95% CI 0.43-0.71)]
McCartt and Kyrychenko (2007)	FARS 1999-2001 GES 1999-2001 FARS 2000-2004 GES 2000-2004	Passenger cars 1997-2002 Passenger cars 2001-2004	**Torso only** 1997-2002 veh 2001-2004 veh Combined MY	 **25%** [Adj. RR=0.75 (95% CI 0.64-0.89)] **27%** [Adj. RR=0.73 (95% CI 0.61-0.87)] **26%** [Adj. RR=0.74 (95% CI 0.66-0.84)]
			Torso + head 1997-2002 MY 2001-2004 MY Combined MY	 **47%** [Adj. RR=0.53 (95% CI 0.43-0.65)] **31%** [Adj. RR=0.69 (95% CI 0.60-0.80)] **37%** [Adj. RR=0.63 (95% CI 0.56-0.71)]
			Combination torso + head, 2001-2004	**31%** [adj. RR=0.69 (95% CI 0.58-0.82)]
			Head curtain 2001-2004	**31%** [adj. RR=0.69 (95% CI 0.57-0.83)]
	FARS 2000-2004 GES 2000-2004	SUVs 2001-2004	Torso only	**30%** [adj. RR=0.70 (95% CI 0.56-0.88)]
			Torso + head	**52%** [adj. RR=0.48 (95% CI 0.37-0.62)]

Study by Kahane (2007)[20]

Kahane[20] used data from FARS and GES to estimate the effectiveness of SAB in reducing fatalities in near side and far side impacts for front seat occupants of passenger cars, light trucks and vans. Only vehicles certified according to the Federal Motor Vehicle Safety Standard for side impact protection (FMVSS 214) were included. Three different analyses were conducted

1. A before-after study that involved calculating the rate of fatalities using the number of fatal near side impact crashes from the FARS census as the denominator, divided by the total number of near side impact crashes, estimated from weighted GES data (similar to Braver & Kyrychenko, 2004 & McCartt & Kyrychenko, 2008). Unlike the previous studies however, the vehicles included were restricted to a core group of models with standard SAB, and fatality rates compared before and after SAB were fitted. Torso only SAB and SAB with torso and head protection were considered separately. Models with optional SAB were not included in this comparison.
2. A cross-sectional design using FARS data to compare the ratio of nearside impact fatalities to front/rear impact fatalities for models with and without SAB. Torso-only SAB and torso and head protection SAB were considered separately.
3. Thirdly, the same cross-sectional FARS-based analysis was performed as in analysis two, with models equipped with optional airbags included in the comparison.

It is difficult to simply summarise the results of Kahane because, as well as the three different analyses, the number of estimates of effectiveness was increased further by using a range of different control groups for each analysis.

For torso-only SAB, one estimate per analysis was derived by a) comparing vehicles with torso only SAB to all vehicles in the core group when they had no SAB (including those vehicles that switched straight from having no SAB to torso plus head protecting SAB, that is, the models were not fully matched). A second estimate was derived using b) only those vehicles that changed from having no SAB to torso only SAB as the control group (vehicle models were fully matched).

For torso plus head protecting SAB, there were three potential control groups

a) all vehicles in the core group when they had no SAB (including those that only changed to having torso only SAB, that is, the models were not fully matched,
b) only those vehicles that changed from having no SAB to torso plus head protecting SAB (even if they also had a period of torso only SAB in between), and
c) only those vehicles that changed directly from having no SAB to torso plus head protecting SAB (both b and c included only the same models in the comparison, that is, they are matched).

In addition, some of the estimates were stratified by other factors, yet this was not consistent across airbag types, or different control group types. Despite the complex range of estimates of effectiveness, some patterns emerged:

- **For torso only SAB**, the crude fatality rate reduction was fairly consistent within a small range (15% to 17%) across control groups. The ratio of near side to front/rear fatalities was a little more variable, with estimates ranging from 2% to 26% reduction. For cars with standard torso airbags, the estimated reduction was 26%, while for those with standard and optional airbags, the estimated reduction was 13%.
- **For torso plus head protecting airbags**, the fatality rate reduction was between 31% and 38% depending upon the control groups used. The ratio of near side to front/rear fatalities was also more variable, from 19% (standard plus optional airbags) to 34% (standard airbags).

Kahane[20] performed further analyses to determine if torso plus head combination airbags differed in their effectiveness to torso plus head curtain airbags. Both types were similar in terms of the estimated fatality rate reduction (28% and 29% respectively). However, for the ratio of near impact fatalities to front/rear impact fatalities, combination airbags appeared more effective (28% reduction for standard airbags, 26% when optional airbags included) than torso plus head curtain airbags (14% and 9%).

Kahane[20] also considered whether SAB were effective in far side crashes. They found no significant effect of torso only SAB in reducing fatalities in far side crashes, or for the most part, for torso plus head protecting combination SAB. However, torso plus curtain SAB were found to significantly reduce the fatality rate per far side impact by between 31% to 35%, and the ratio of far side to front rear impact fatalities by 31% to 39%. Further analyses revealed SAB to be effective for unbelted occupants (whether accompanied or unaccompanied by someone else in the front seat) and for belted unaccompanied drivers.

Study by Lange et al. (2011)[21]

Lange et al.[21] took a different approach to estimating fatality risk reductions with SAB by calculating the risk of fatality in a side impact per registered vehicle year rather than the risk of fatality given that a near side impact had occurred. The number of fatalities for front seat occupants involved in a side impact fatality was obtained from FARS and divided by the number of registered vehicle years for each model (registration data from R.L. Polk and Co.) for vehicles with and without SAB. The front seat occupant side impact fatality rate per registered vehicle is related to both the probability of having a side impact and the probability of a front seat occupant being fatally injured in that impact. However, the risk of crash occurrence would not be expected to vary between the same vehicle models with and without SAB, so, the relative reductions with and without SAB can be considered to be a fair measure of fatality risk reduction due to SAB, given a crash has occurred.

Only vehicle models with SAB fitted as standard between 1998 and 2008 were included, and the fatality rate for the 2 years prior to the fitting of SAB was compared to the fatality rate for the 2 years after SAB were installed, separately for torso-only and head curtain SAB. Between 1998 and 2008, 42 models went from having no SAB to a torso-only SAB, while 27 models changed from having no head curtain SAB to a head curtain SAB.

The authors presented data on the reduction in fatality rate for each of the different models, however only the overall results will be discussed here, apart from noting that there was a reduction in fatality rate for almost all of the models for which there were a reasonable number of fatalities (which providing more statistical power to detect a difference). Overall, the fatality rate per registered vehicle fell significantly by *16% when torso-only* SAB were introduced, and by *33% when head curtain SAB* were introduced.

2.4.3 Side airbag systems and Injury Reductions

Several studies have attempted to determine the effect of SAB on injury severity (all injuries, or specific injuries such as thorax, head, upper extremity or renal). By examining the relationship between SAB *availability* and injury, while others have investigated SAB deployment and injury. Some of these studies are characterised by small sample size problems while others were purely descriptive, leading to difficulties in quantifying the relationship between SAB and injury reductions. Emphasis is placed on those studies where a relative injury reduction estimate was presented.

McGwin et al.[22, 24, 27] investigated the relationship between SAB and all injuries, torso and head injuries, and upper extremity injuries. In the analysis the authors classified all vehicles where SAB were available as an option as having an airbag fitted (and deployed). The authors note this limitation and note that the direction of bias as a result of the likely misclassification would be toward SAB appearing to be less effective than they might actually be.

In the 2003 study[20], McGwin et al reported no association with injury outcomes given the ‘presence’ of a SAB, while the 2004 paper[15] reported statistically significant reductions in head and torso injuries associated with SAB using a slightly larger CDS dataset. In their 2008 paper[17], McGwin and colleagues reported no difference in risk of any upper extremity injury, but a significant increase in risk for more severe (AIS 2+: OR: 2.45, 1.10-6.80; AIS 3+: OR: 2.45, 95th% CI: 1.0-6.0) upper extremity injuries, and specifically a significant increase in risk for dislocation of shoulder or wrist.

Stiggson and Kullgren (2011)[29] performed a study using Swedish data focusing on near side car-to-car crashes for front seat occupants. They performed a matched crash analysis, whereby the police–reported injury severity of the person in the struck car (that is, where SAB would be expected to have an effect) was compared to the injury severity of the person in the striking car (where SAB would not be expected to have an effect). SAB were associated with a non-statistically significant 33% reduction in the relative rate of any injury, and a non-statistically significant 35% reduction in the relative rate of serious injury (calculated by the authors of this report). However, for the analysis if SAB were optional for a car model these cars were classified as not having SAB, which would bias the result towards the null (i.e., no effect). A summary of the findings is presented in Table 2.9a.

Stadter et al. (2008)[25] used the NASS CDS to measure the association between several factors (include SAB deployment) and driver injury. A multivariate regression found no association between SAB deployment and the probability of AIS 2+ injury; however, there was evidence for an interaction between delta-v and SAB deployment. This interaction was not specifically assessed in the model and so it is likely that SAB demonstrate differential levels of effectiveness depending on the delta-V. A summary of the findings is presented in Table 2.9a.

Page et al. (2006)[30] used data from in-depth studies in Germany, France and the UK and conducted a multivariate analysis to determine if SAB deployment was associated with AIS 2+ or AIS 3+ injuries, adjusted for other factors that might affect injury risk such as gender, age and speed for front and rear seat occupants. They reported a non-statistically significant 2% reduction in AIS 2+ injuries and a non-statistically significant 10% reduction in AIS 3+ injuries. The injury reductions for torso only injuries were larger, but still not significant; a non-statistically significant 17% reduction in the proportion of AIS 2+ and AIS 3+ injuries of the torso. A summary of the findings is presented in Table 2.9a.

Smith et al. (2010)[28] focused on renal injuries in adult front seat occupants and reported a non-statistically significant 49% reduction in the odds of renal injury with SAB, although it was unclear whether or not they were studying the effect of SAB availability or SAB deployment. A summary of the findings is presented in Table 2.9a.

The University of Alabama (UAB) CIREN Center (2011)[26] conducted a comprehensive study into the effect of SAB deployment on thoracic and head injury rates (Table 2.9b). They compared injuries in crashes with and without SAB deployment, matching the crashes on many factors including driver age, gender, object hit, direction of force, seat position, area of damage and vehicle type and adjusted for delta-V in the analysis. Estimates of head injury and thorax injury reduction were derived for different crash types; all collisions, vehicle to vehicle collisions, and vehicle vs. fixed object collisions.

By combining all SAB systems, there was a non-statistically significant reduction of between 13% and 19% in head injury rates, and there was no association between SAB deployment and thorax injury. Head SAB alone was associated with: a statistically significant 30% reduction in head injury for all collisions; a non-statistically significant 35% reduction in head injury for vehicle to vehicle, and a non-statistically significant 30% reduction in head injury for vehicle to object collisions. Torso SAB were not associated with a reduction in the rate of thorax injury. These findings are presented in Table 2.9b.

The UAB study also reported the association between head SAB and head AIS 2+ injuries (163 pairs) and torso SAB and thorax AIS 2+ injuries in near side impact crashes (263 pairs), adjusting for a range of occupant and crash parameters. Of specific value to the present research project, the UAB study provided estimates for vehicle-to-vehicle side impact crashes and vehicle-to-fixed object side impact crashes, although none were statistically significant:

- Head SAB/Head AIS 2+
  - Vehicle-to-vehicle: 32% lower odds; OR: 0.68, 95^{th}% CI: 0.29-1.58, $p > 0.05$
  - Vehicle-to-Fixed object: 43% lower odds; OR: 0.57, 95^{th}% CI: 0.17-1.96, $p > 0.05$
- Torso SAB/Thorax AIS 2+
  - Vehicle-to-vehicle: OR: 0.99, 95^{th}% CI: 0.61-1.61, $p > 0.05$
  - Vehicle-to-Fixed object: OR: 1.09, 95^{th}% CI: 0.49-2.43, $p > 0.05$

Table 2.9a Estimates of injury reductions associated with side impact airbags

Study	Data source/s, years & crashes	Vehicles	Measure of effectiveness	Type of airbag	Results (% reduction in measure of effectiveness)
Stigson & Kullgren (2011)	STRADA 2003-2009 Near side car to car crashes	Cars 1997+	Matched crash analysis: Ratio of police reported injury severity in struck car with injury in striking car for cars with SAB compared to those without.	All (torso only, torso head combination, torso curtain & curtain only) Any injury Serious injury	33% (ns)[1] 35% (ns)[1]
Stadter et al. (2008)	CDS 2000-2005 Side impact crashes where driver wearing a seat belt	Cars, minivans, light trucks and SUVs with an installed SAB.	Regression to assess the association between various factors (including SAB deployment) and driver injury (ISS 2+)	Not specified	No main effect of SAB deployment on probability of AIS 2+ injury.
Page et al. (2006)	GIDAS CCIS LAB 1998-2004 Near side impacts with energy equivalent speed (EES) of 20-50 km/h	1998+ Vehicles	Two multivariate analyses: Estimate the association between SAB deployment and AIS 2+ thoracic injury (1), and AIS 3+ thoracic injury (2), adjusted for gender, age, EES	Torso Other	AIS 2+: OR=0.83 (0.37-1.86) AIS 3+: OR=0.83 (0.37-1.88) AIS 2+: OR=0.98 (0.49-1.97) AIS 3+: OR=0.90 (0.44-1.85)
Smith et al. (2010)	CIREN 1996-2008 Frontal or side collisions	Vehicles < 6 years old	Compared rates of renal injury and mean renal AIS between vehicles with and without SAB and frontal air bags (availability or deployment? See comment)	Any SAB	No significant difference between mean renal AIS scores with or without SAB. Non significant 49% reduction in odds of renal injury (OR=0.51, 95% CI 0.17-1.20)[1] (No evidence for interaction with delta v).

Table 2.9b Estimates of injury reductions associated with side impact airbags – the UAB CIREN Center study

Study	Vehicles	Measure of effectiveness	Type of airbag / Injury	Results (% reduction in measure of effectiveness)
CDS CIREN 2000-2009 Side impacts	1998+ Vehicles	Conditional logistic regression to measure the association between SAB deployment and head and thoracic injury (AIS 2+), adjusted for delta v, and matched for driver age, gender, object hit, direction of force, seat position, area of damage, vehicle type	**Any / Head Injury**	
			All collisions	0.86 (0.70-1.07)
			Vehicle to vehicle	0.81 (0.60-1.09)
			Vehicle vs. Fixed object	0.87 (0.62-1.22)
			Any / Thorax Injury	
			All collisions	1.02 (0.83-1.27)
			Vehicle to vehicle	0.92 (0.69-1.23)
			Vehicle vs. Fixed object	1.11 (0.79-1.57)
			Head SAB / Head Injury	
			All collisions	0.70 (0.51-0.97)
			Vehicle to vehicle	0.66 (0.42-1.03)
			Vehicle vs. Fixed object	0.70 (0.43-1.14)
			Torso SAB / Thorax Injury	
			All collisions	0.99 (0.79-1.24)
			Vehicle to vehicle	0.93 (0.69-1.26)
			Vehicle vs. Fixed object	0.96 (0.66-1.38)

2.4.4 Study limitations and implications for choosing the best estimate of effectiveness

While large scale population-based studies such as the ones discussed here are one way of determining if SAB are effective in the real world, observational studies are often prone to limitations due to bias and confounding. Following below is a discussion of some general issues relating to studies of SAB effectiveness that inform our selection of the best estimates.

First, for a SAB to be effective, it must deploy. However, in the studies of fatality reductions and some of the studies of injury reductions the evaluation was of the association between airbag *availability* and fatality risk. There was no evidence that the airbag actually deployed in the crash. By including crashes where the airbag may not have deployed, there is potential to underestimate the true effectiveness of airbag deployment. However, these studies do provide a useful crude estimate of the reduction in fatalities expected if all cars were equipped with SAB.

Selection bias

One issue that emerges with all of the data sources used is that they generally only capture injury crashes. Although the databases of police reported crashes sometimes include property damage crashes, these are less likely to be reported than injury crashes. One of the considerations in using injury databases to estimate the effectiveness of technologies designed to reduce injury, is that if the technology prevents the injury altogether, then these crashes will never be included in these databases. Equally, if the injuries are more minor, they also might not be included due to the lower rate of reporting these crashes. In the case of a safety countermeasure, this lack of reporting would mean that the effectiveness of the safety countermeasure in mitigating injury would be underestimated.

Studies of the relationship between injury severity and SAB that use data sources which capture only serious injuries have the potential to be biased. For instance, researchers have investigated the risk of serious injury to the head and/or thorax, however, because only those people with serious injuries are included in the database the outcome measure is really a measure of the ratio of serious head and/or thorax injuries relative to other types of injuries. These studies therefore tend to give an indication of the way that serious injury patterns change when SAB are present compared to when they are not, rather than estimating the effectiveness of preventing these injuries per se.

Confounding

Confounding is a potential issue in observational studies. Confounding occurs when an extraneous variable affects the association between the exposure (in this case SAB) and outcome (in this case, injuries or fatalities) being studied. In these studies, there are two main sources of potential confounding; driver related factors and vehicle related factors, and it is important to use appropriate statistical models and evaluation design strategies to account for these factors.

Implications for selection of best estimate of the effectiveness of SAB

In terms of selecting the most appropriate estimate of SAB effectiveness, preference needs to be given to estimates derived from studies that controlled for confounders by matching for make/model, and/or adjusting for front/rear impact mortality (or some other crash type similarly unaffected by SAB). Further, estimates from data sources that include a representative sample of police reported crashes, rather than tow-away, or serious injury only crashes are preferred.

2.4.5 Summary of estimates of side airbag effectiveness

The exposition of the available studies into the effectiveness of side impact airbag systems, notwithstanding their stated limitations, provides the basis for assessing the likely incremental benefit associated with the implementation of a PSI GTR. The logic here is that a pole impact test – as noted by the Chair of the PSI Informal Group and NHTSA, would lead to the introduction of curtain plus thorax side airbag systems on all vehicles and further, an oblique FMVSS-214 test would require larger systems to contain the impact and protect vehicle occupants. In addition, the biofidelity of the anthropometric test dummy (ATD) to be used in the proposed PSI GTR is superior to those used previously.

On the basis of the fatality studies examined, and specifically the strength of the research conducted by Braver and Kyrychenko[18] and McCartt and Kyrychenko[19], we use a 32% reduction in fatalities due to the presence of a curtain plus thorax side airbag system. This value represents a lower bound, as their estimates are as high as a 45% reduction in fatality risk.

Similarly, we use the point estimate from the UAB CIREN Center as the basis of benefit ascribed to curtain plus thorax side airbag systems. Specifically, we adopt a value of 34% as our basis of reduction in injuries. It must be noted that the intention of this research is to obtain benefit estimates using Australian mass and in-depth crash data, supplemented by an examination of UK in-depth crash data.

Appendix A2 Definitions of fatality and injury data

The data and their accompanying definitions were presented in the document, *PSI-04-05 - Safety Need - High Level Figures* (http://www.unece.org/fileadmin/DAM/trans/main/wp29/PSI-04-05.pdf). They are presented here as they form the context for the development of the PSI GTR and the basis for in-depth examination of the injury risk – and types of injuries, sustained by occupants in pole side impact crashes relative to those involved in vehicle-to-vehicle side impact crashes.

The data for Australia presented in Table 2.1 and Table 2.2 is new and was derived using Victorian and Queensland data as its basis of estimation. Specifically, the ratio of fatalities and injuries per registered vehicle in Victoria was derived. Using this ratio, and with knowledge of the number of registered vehicles in Australia for 2009, the number of occupants killed and injured can be estimated. Implicit within this calculation is the assumption that the crash situation in Victoria reflects that in Australia, and while Victoria represents 24.8% of the Australian population[31], its road safety record is - with the exception of the Australian Capital Territory (3.32 deaths per 100,000 persons; population: 1.6% of Australia[31]), lower than the other jurisdictions in Australia (Victoria: 5.34 deaths per 100,000 persons; national average: 6.89 deaths per 100,000 persons)[32]; the statistics are therefore likely to be conservative. This estimation is necessary as Australia lacks a uniform definition road crash injury reporting system.

Table A2.1 Definitions adopted for injury in the provision of the high level safety need data

Country	Definition of injury
Australia	Serious Injury definition used was an injury where the person was taken to hospital and admitted to hospital (persons taken to hospital but whose admission status is unknown are also included as serious injuries. Australian estimate is based on Victorian police reported casualty and Australian fatality statistics[32] and Census population data[31] (see Section 5.5).
Canada	Serious injuries are estimates and may be understated; figures for pole side and other side impacts and rollovers are for M1 and N1 vehicles only. Percentages of occupant fatalities may therefore be understated
France	Serious injury figures are for AIS3+ injuries.
Germany	Population as at 31 Dec 2008; seriously injured figures represent persons who were immediately taken to hospital for inpatient treatment (of at least 24 hours); figures for pole side and other side impacts and rollovers are for M1 vehicles only. Percentages of occupant fatalities may therefore be understated
Great Britain	Figures do not include Northern Ireland; serious injury definition used: An injury for which a person is detained in hospital as an "in patient", or any of the following injuries whether or not they are detained in hospital: fractures, concussion, internal injuries, crushing, burns (excluding friction burns), severe cuts, severe general shock requiring medical treatment and injuries causing death 30 or more days after the accident. An injured casualty is recorded as seriously or slightly injured by the police on the basis of information available within a short time of the accident. This generally will not reflect the results of a medical examination, but may be influenced according to whether the casualty is hospitalised or not. Hospitalisation procedures will vary regionally.
Japan	Figures for pole side impacts do not include impacts with trees, which are included among other side impacts. Serious injuries are injuries requiring 30 days or more for recovery. Figures for pole side and other side impacts and rollovers are for vehicles up to and including 3.5 tonnes, so percentages and rates may therefore be understated.
Netherlands	Figures for pole side and other side impacts and rollovers are for M1 vehicles and N1 (delivery vans only). Percentages of occupant fatalities may therefore be understated.
USA	Serious injuries are incapacitating injuries
South Korea	The definition for total serious injuries is more than 3 weeks treatment in hospital; the figures for 4-wheeled vehicle occupant serious injuries, pole and other side impact serious injuries and rollover injuries comprise all injuries

3 INCIDENCE AND BURDEN OF SIDE IMPACT CRASHES IN THE UK

The establishment of the 'safety need' for the proposed PSI GTR represents an important first step in the regulatory process. The previous chapter outlined at a high level the 'safety need' based on fatalities and serious injury crashes from nine of the participating contracting parties to the UNECE 1998 Agreement on global technical regulations. This report aims to explore mass crash data and in-depth crash data to examine crash involvement, injury severity (overall and by body region), and the associated cost of injury with the principal aim of determining what differences, if any, exist in these outcomes for occupants involved in pole side impact crashes and vehicle-to-vehicle side impact crashes. We first explore the crash situation in the UK and then in Australia. This chapter examines the incidence and financial burden of side impact crashes in the UK.

3.1 STATS19

'STATS19' is the data system in Great Britain for the collection and reporting of fatal and injury crashes in the United Kingdom (UK). Crashes included in STATS19 are those where police attended the scene of the crash or where police were informed by an involved party. In addition, the crash must have occurred on a public road. STATS19 data provides information about the circumstances of road crashes including vehicle types involved, injury outcomes and police determined contributing factors.

STATS19 is managed by the UK Department of Transport (DfT) which produces a series of reports and makes data available upon request via an online portal, summary tables or raw data. The analysis presented here relies on data tables supplied to the PSI GTR Informal Group by the DfT. The website for the DfT where information can be found on crashes is: http://www.dft.gov.uk/statistics/series/road-accidents-and-safety/.

Data was supplied for fatality and injury crashes for the period 2000 – 2009 inclusive. The following definitions are used:

- Fatality: died within 30 days of the accident.
- Serious injury: in-patient at hospital, or any of the following injuries (irrespective of hospital in-patient status): fractures, concussion, internal injuries, crushing, burns (excluding friction burns), severe cuts, severe general shock requiring medical treatment.

STATS19 codes *Type of Vehicle* and also *Point of First Impact.* For the purpose of the analysis presented here, the following definitions were used and data selected accordingly:

- Type of Vehicle:
  - 'Cars' – this categorization is broadly synonymous with 'M1', but may also include a small number of (M2) minibuses or 3 wheeled bodied vehicles.
  - Note that some larger M1 vehicles such as motor-caravans may not be classed as cars.
- First point of impact:
  - The first point of contact was the nearside or offside of the vehicle.
- First object hit off carriageway:
  - Pole side impacts are where the first point of impact is a pole type object (hence are single vehicle crashes). Statistics therefore exclude secondary impacts into poles. *In the provision of the data, it was also noted that* there may be cases where the initial pole strike does not cause the injury and the injury is caused by a secondary impact.

3.2 Overall fatality and injury burden of crashes in the UK

Across the period 2000 to 2009 inclusive, there were 31,098 fatalities in the UK and a further 312,203 people seriously injured. Using 2009 cost of injury figures[33], the total cost burden of fatalities and serious injuries was £104.93 billion over the period (Table 3.1). Fatalities and serious injuries in M1 category vehicles account for 50% (n = 15,636) and 45% (n = 141,272) of the overall number respectively, translating to £24.79 billion and £25.17 billion respectively.

In the period 2000 to 2009, side impact crashes cost the UK community £18.73 billion, accounting for 40% of occupants of M1 vehicles killed and 35% of M1 occupants seriously injured. In numeric terms, 4890 people were killed and 44,237 seriously injured in vehicle-to-vehicle and other object side impact crashes, while 1369 were killed and 5190 were seriously injured in pole side impact crashes. The increased risk associated with pole side impact crashes is evidenced by 20% of occupants involved in PSI killed compared to 10% overall, and 70% of financial costs to the community being associated with fatalities.

For pole side impact cashes in particular, over the period 2000-2009 there were 1369 occupants of all M1 vehicles killed in pole side impacts, accounting for 8.8% of the total number of M1 fatalities, and 4.4% of the overall road toll. In addition, 5190 occupants of M1 vehicles were seriously injured, representing 3.7% of M1 injuries. Combined, pole side impact fatalities and serious injuries cost the UK community £3.10 billion, with 70% of the costs being associated with fatalities (compared with 47% overall). Despite pole side impact crashes accounting for 4.1% of M1 fatalities and serious injuries, they account for 6.2% of the M1 injury cost burden. Notably, fatalities and serious injuries due to 'other' side impact collision partners out-number pole side impact fatalities and serious injuries by a ratio of 3.6:1 and 8.5:1 respectively.

Table 3.1 Fatality and serious injuries by impact type and associated cost of injury

	Fatalities				**Serious Injury**				**Totals**			
Impact direction	**N**	**% M1**	**Rate (pop)**	**Cost (bn.)**	**N**	**% M1**	**Rate (pop)**	**Cost (bn.)**	**Total (bn.)**	**Prop. Killed**	**% costs fatal**	**% costs, of M1**
Side -pole	1369	8.8%	0.23	£2.17	5190	3.7%	0.89	£0.92	£3.10	20.9%	70.1%	6.2%
Side-other	4890	31.3%	0.84	£7.75	44237	31.3%	7.57	£7.88	£15.63	10.0%	49.6%	31.3%
Rollover	2064	13.2%	0.35	£3.27	14770	10.5%	2.53	£2.63	£5.90	12.3%	55.4%	11.8%
Front/ Rear†	7313	46.8%	1.25	£11.59	77075	54.6%	13.20	£13.73	£25.33	8.7%	45.8%	50.7%
M1 - fatalities	15,636	100%	2.68	£24.79	141,272	100%	24.19	£25.17	£49.96	10.0%	49.6%	100%
UK fatalities	31,098		5.32	£49.31	312,203		53.45	£55.62	£104.93	9.1%	47.0%	

Cost of injury[33]: Fatality £1,585,510; Serious: £178,160; † front and rear impacts were derived from knowledge of side, rollover and total numbers

3.3 Fatality trends over time (2000-2009)

A number of road and vehicle safety initiatives have occurred over the past decade, 2000-2009, that could potentially have influenced the number of occupants killed in side impact crashes. In particular, this includes the effects of UNECE R95 on side impact protection and the role of ESC in crash prevention. In considering the 'safety need' for a PSI GTR, it is important then to examine fatality trends over time. Poisson regression models accounting for the population were used to examine the fatality incidence rate over time.[34]

Figure 3.1 presents the fatality rate per 100,000 persons in M1 vehicles over time for each of the impact configurations. Across all impact configurations, a visible reduction in the fatality rate is evident, with regression modelling indicating an average 5% reduction per annum although this was not statistically significant, IRR:0.95, 95% CI:0.83-1.08, p=0.4. Stratification by impact direction reveals important differences in the fatality trend over time, with a 6.5% per annum reduction in front and rear impact fatalities (IRR: 0.935, 95% CI: 0.93-0.94, p<0.001), and a 4.4% per annum reduction in 'other' (non PSI) side impact fatalities (IRR: 0.956, 95% CI: 0.95-0.96, p<0.001). A 1.7% per annum reduction in the fatality rate from rollovers was observed (IRR: 0.98, 95% CI:

0.97-0.99, p=0.03). *Importantly, there was no observable change in the fatality rate from pole side impact crashes* (IRR: 0.99, 95% CI: 0.97-1.01, p<0.4).

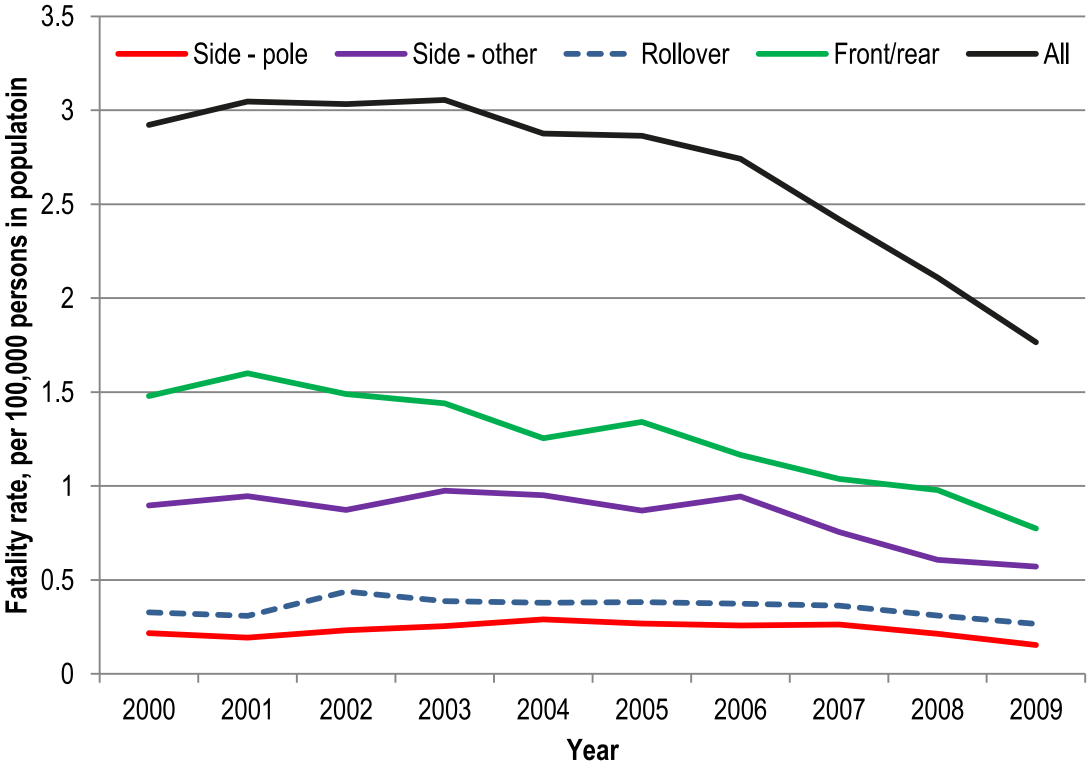


Figure 3.1 Fatality rate (per 100,000 persons) by impact configuration and calendar year

The fatality rate expressed as persons killed per M1 vehicle registered provides an alternative way of examining fatality trends over time. As evident in Figure 3.2, there has been an indicative on average 7% per annum reduction in the fatality rate over the period (IRR:0.93, 95% CI:0.82-1.07, p=0.3). By impact type, there has been an 8% per annum reduction in front/rear fatalities (IRR: 0.92, 95% CI: 0.91-0.93, p<0.001), a 6% p.a. per annum reduction in side impact fatalities (IRR: 0.94, 95% CI: 0.93-0.95, p<0.001), a 3.1% per annum reduction in rollover fatalities (IRR: 0.98, 95% CI: 0.95-0.98, p=0.03), but only a 2% per annum reduction in PSI fatalities (IRR: 0.98, 95% CI: 0.96-0.99, p=0.02).

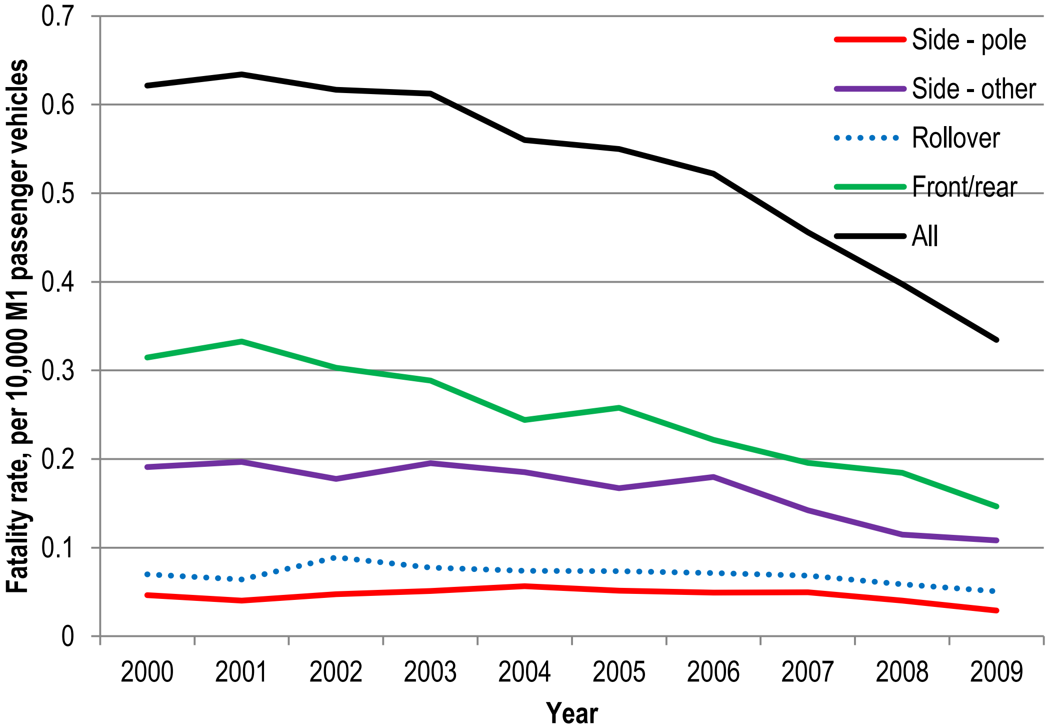


Figure 3.2 Fatality rate (per 10,000 M1 vehicles) by impact configuration and calendar year

Fatalities from pole side impact crashes were noted to account for 8.8% of fatalities in M1 vehicles (see Table 3.1).

The analysis presented above highlights the injurious nature of side impact crashes in M1 vehicles. Combined, pole side impact and vehicle-to-vehicle impact crashes account for 40% of fatalities, representing a cost to the community of £9.92 billion over the 10 year period. The analysis above highlighted that the fatality rate associated with side impacts was either not declining on a per population basis, or its reduction was being outstripped by reductions in other crash configurations on a per M1 registered vehicle basis. Figure 3.3 highlights the proportional shift in the importance of side impact crashes whereby they represent an increasing proportion of the number of people killed.

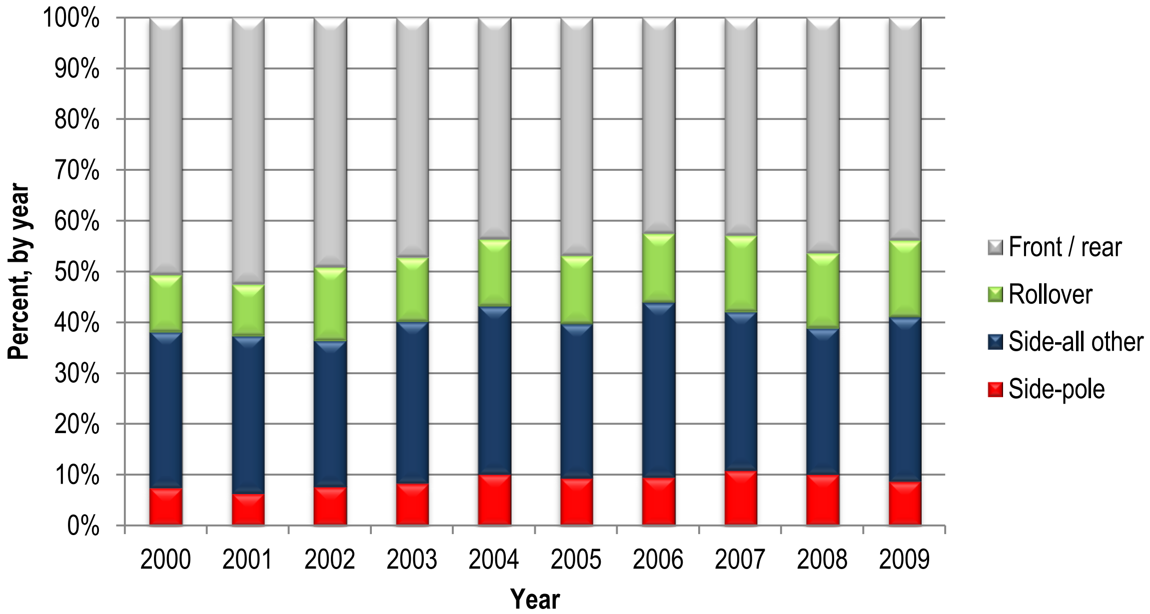


Figure 3.3 Percent of M1 fatalities by impact configuration and calendar year

The proportional increase in fatalities associated with pole side impact crashes can also be observed in Figure 3.4 where fatalities from PSI are expressed as a percent of all M1 side impact fatalities (red line), all M1 fatalities (blue line), and all fatalities in the UK (purple line). With reference to Figure 3.4, the following observations can be made:

- Among side impact fatalities, PSI related fatalities are increasing as a proportion, accounting for an average 20% of M1 involved side impact fatalities (10-year average);
- PSI represent approximately 10% of all fatalities in M1 vehicles (10-year average), and account for an increasing proportion of M1 fatalities, and
- PSI represent 4.5% of all fatalities in the UK (10-year average), and the increase as a proportion of all fatalities in the UK is marginal, if non-existent.

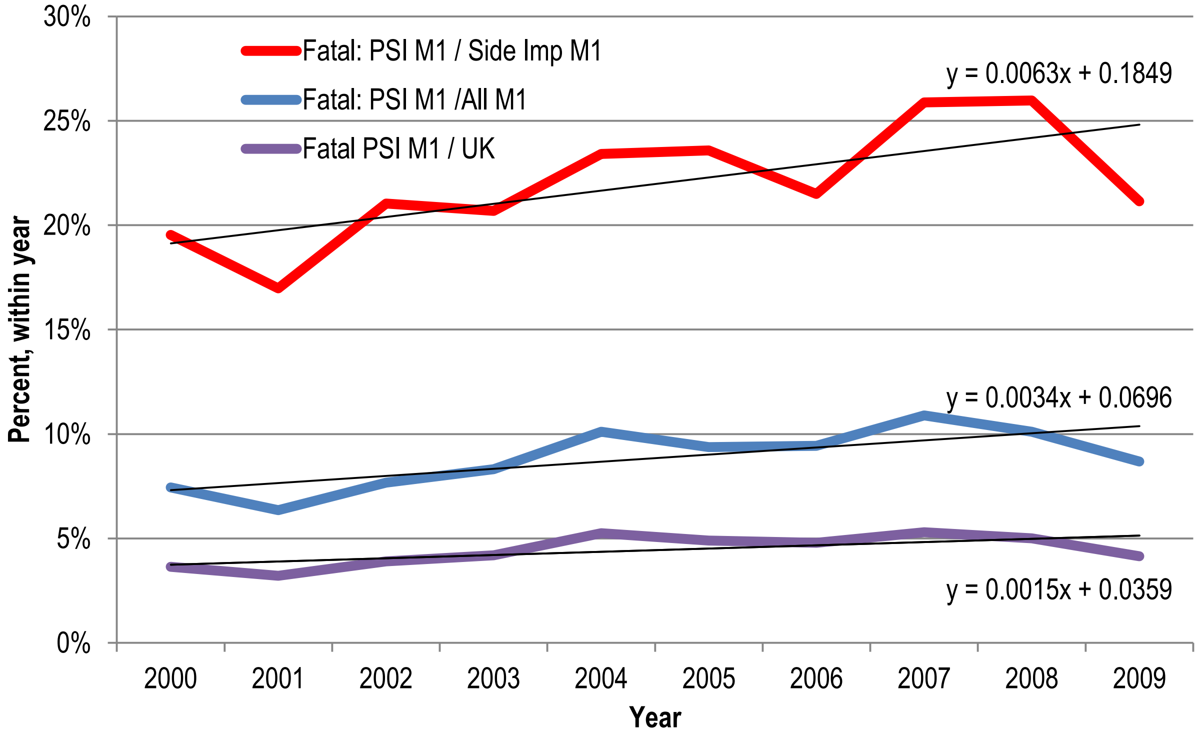


Figure 3.4 Percent of PSI fatalities as a function of fatalities in side impact crashes, all M1 crashes and all fatalities in the UK

3.4 Key findings and Summary

The analysis of STATS19 data highlights the severe nature of side impact crashes. Overall, side impact crashes cost the UK community approximately £18.7 billion from 2000 to 2009 inclusive, of which 15.6 billion in costs was associated with injuries sustained in vehicle-to-vehicle side impact crashes and £3.1 billion due to pole side impact crashes. It is also evident that the injury reduction gains made in other crash types outstrip that seen for side impact crashes. Clearly, road safety gains made elsewhere are not finding their way into the PSI fatality problem and steps are required to address this concern

The analysis above does not address the nature of injuries sustained by vehicle occupants as the mass crash data does not include such detail. Previous studies both in the UK and elsewhere of in-depth crash data highlight the high incidence of head and thorax injuries in side impact crashes (see Chapter 4, this report). Given this, and the number and cost of side impact crashes to the UK community, there is a need to address side impact protection more generally, but with specific reference to protection of the head and thorax. This is true for both vehicle-to-vehicle side impact crashes <u>and</u> pole side impact crashes where current regulatory tests do not specifically engage the head region directly. Thus, any pole side impact regulatory test would likely offer significant benefits to vehicle-to-vehicle side impact crashes.

4 INJURY RISK IN SIDE IMPACT CRASHES: ANALYSIS OF UK CCIS IN-DEPTH DATA

The previous chapter examined fatality and serious injury trends in the UK for the period 2000 to 2009 inclusive using police reported casualty data. The findings highlighted the high cost burden associated with side impact crashes with pole side impact fatalities increasing as a proportion of side impact crashes. The use of in-depth crash data allows for the deeper understanding of the mechanisms of injury and the differences between the different side impact configurations and supplements the mass data analysis.

The objectives of the analysis of CCIS data is to:

1. document the nature of injuries sustained by occupants involved in side impact crashes;

2. explore difference in injury risk, if any, for each body region depending on impact object, and

3. explore the effectiveness of side impact airbags in mitigating injury.

4.1 The CCIS In-depth Study

The Co-operative Crash Injury Study (CCIS) is the UK in-depth crash investigation study which was established in 1983 and operated until 2010. The CCIS is managed by the Transport Research Laboratory (TRL) and in-depth crash data was collected by TRL (Crowthorne), Loughborough University, the University of Birmingham, and the Vehicle Inspectorate Agency. The CCIS was sponsored by the UK Department for Transport.

While the CCIS was designed primarily to investigate the mechanisms of injury in vehicle crashes, the nature of the data collected permits a detailed understanding of crash causation.

The CCIS had four key inclusion criteria:

1. the crash had to have occurred within a predefined geographic region;
2. the vehicle must be less than 7 years old;
3. the vehicle must be towed from the scene, and
4. the vehicle must have at least one injured occupant.

With respect to case selection, a random stratified sampling system is used based on injury severity to ensure sample representativeness. The TRL have constructed sample weights, permitting national injury estimates to be derived.

4.2 Method: case selection criteria

The CCIS database includes a case record for each occupant where information was available. The total number of cases (persons) available for analysis was 21,915 in CCIS for crashes in the period 1998 – 2010. Mr Richard Cuerden (Technical Director, TRL) prepared the CCIS dataset according to the following inclusion criteria:

1. Single impact crashes, (also excluding vehicle rollovers) (N=18,501);
2. Model Year (MY) 2000 onwards (*as a surrogate for meeting ECE95; to limit differences in vehicle structural design);*
3. Front-row occupants only;
4. Struck-side occupants, and
5. Injury data was known.

After application of these criteria, there were 1735 occupants available for analysis (Table 4.1). This represents 7.9% of the total number of occupant cases in CCIS. These cases were made available under licence to Dr Fitzharris, which stipulated the analysis be undertaken on-site at TRL. Further case selection criteria were applied before the analysis dataset was arrived at, and this is explained below. A graphical representation of the case selection process is provided in Figure 4.2.

Using the variables, side and occupant row (i.e., front, rear), and impact direction, the number of cases by position relative to impact can be determined, excluding 17 'rear centre' position occupants and where position was unknown (n = 42).

Table 4.1 Number of occupants by position in vehicle and impact direction

	Occupant position				
Struck Side	**Driver**	**Front passenger**	**Rear–left (near)**	**Rear–right (offside)**	**Total**
	n	**n**	**n**	**n**	**N**
Struck side (near)	732	155	35	40	962
Non-struck (far)	425	207	50	29	711
Unknown	0	0	2	1	3
Total	1157	362	87	70	1676

Object Struck and sample selection

As an objective of this analysis was to determine the differences, if any, in injury risk and severity between vehicle-to-vehicle (V2V) and PSI, the analysis set is further reduced by using the *Object hit* field (to select 'car/derivative' and Pole/Narrow object) to determine the number of struck side cases by occupant position (Table 4.2).

Table 4.2 shows that there were 588 struck-side occupants where the collision partner was a passenger car, while there were 62 struck-side occupants where the collision partner was a pole / tree (narrow fixed object, <41 cm; this category is defined during data collection and data entry and may exclude some pole-like objects, which would then fall into the 'wide, > 41 cm category). The small number of rear seat occupants precludes their separate examination.

Hence, the analysis will focus on front row occupants, with the collision partner being a car or pole on the struck side. The analysis set is comprised of the following:

- 543 occupants (450 drivers and 93 FSP) where the collision partner was a car, and the point of impact was on the side directly next to the occupant, and
- 57 occupants (45 drivers and 12 FSP) where the collision partner was a pole, and the point of impact was on the side directly next to the occupant.

Table 4.2 Occupant position and impact side, by collision partner.

Collision partner	Side of impact relative to occupant	Occupant position				
		Driver	FSP	Rear – left (near-side)	Rear – right (off-side)	Total
		n	n	n	n	N
Car	**Struck side**	**450**	**93**	**18**	**27**	**588**
	Non-struck(far)	**243**	**137**	**38**	**14**	**432**
	Total	**693**	**230**	**56**	**41**	**1020**
PTW	Struck side	14	0		3	17
	Non-struck(far)	1	3		1	5
	Centre, other, unknown	15	3		4	22
MPV-LGV	Struck side	55	9	3	5	72
	Non-struck(far)	35	15	6	2	58
	Centre, other, unknown	0	0	1	1	2
	Total	90	24	10	8	132
HGV-PSV-OTHER	Struck side	69	8	3	2	82
	Non-struck(far)	44	17	1	1	63
	Centre, other, unknown	0	0	1	0	1
	Total	113	25	5	3	146
Pole-narrow Object <41cm	**Struck side**	**45**	**12**	**5**	**0**	**62**
	Non-struck(far)	**25**	**12**	**1**	**6**	**44**
	Total	**70**	**24**	**6**	**6**	**106**
Wide>41cm	Struck side	97	32	6	3	138
	Non-struck(far)	74	22	4	5	105
	Total	171	54	10	8	243
Unknown	Struck side	2	1	-	-	3
	Non-struck(far)	3	1	-	-	4
	Total	5	2	-	-	7
Total	Struck side	732	155	35	40	962
	Non-struck(far)	425	207	50	29	711
	Centre, other, unknown	0	0	2	1	3
	Total	1157	362	87	70	1676

As the proposed PSI GTR will use a belted WorldSID dummy, unbelted occupants were excluded from further analysis (n = 36) (Table 4.3). However, occupants for whom belt use was ‘unknown’ remained in the analysis as it was considered reasonable to expect that a high proportion of these occupants would be belted, and given the relatively small number of pole-impact occupants a decision was made to keep these in the analytical sample.

Table 4.3 Seat-belt use, by occupant position and collision partner (struck side)

		Occupant position		
	Collision partner	**Driver**	**Front passenger**	**Total**
Belt use		**n**	**n**	**N**
Used	Car	321	73	394
	Pole-Narrow object < 41cm	29	11	40
	Total	350	84	434
Not used	Car	26	7	33
	Pole-Narrow object < 41cm	3	-	3
	Total	29	7	36
Unknown	Car	103	13	116
	Pole-Narrow object < 41cm	13	1	14
	Total	116	14	130

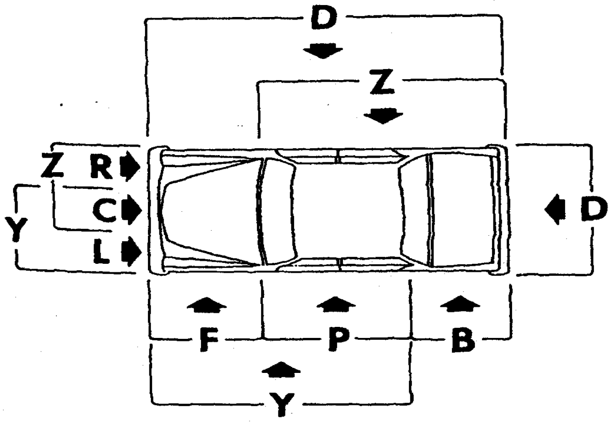
Following the sample selection criteria, the total number of occupants in MY 2000 onwards vehicles, where the collision partner was a ‘car’ or a pole – and the impact was on the side of the occupant (single impact, no rollover, no ejection) was 564 persons (Table 4.4).

Table 4.4 Number and percentage of occupants by occupant position and collision partner

Occupant position	**Collision partner**					
	Car		**Pole**		**Total**	
	n	**%**	**n**	**%**	**N**	**%**
Driver	424	83.1%	42	77.8%	466	82.6%
Front seat	86	16.9%	12	22.2%	98	17.4%
Total	510	100.0%	54	100.0%	564	100.0%

Damage profile of the vehicle relative to the occupant

To be of relevance to the proposed PSI GTR, only those crashes where impact damage occured to the occupant cabin are of interest. Using the Collision Deformation Classification (CDC) damage profile[11], cases with the principal damage occuing in zones D, Z, P and Y were selected; this excludes cases where the damage was exclusively in Zones F and B on the side of the vehicle (refer Figure 4.1).



Location	Classification
Distributed—side or end	D
Left—front or rear	L
Center—front or rear	C
Right—front or rear	R
Side front—left or right	F
Side center section—left or right	P
Side rear—left or right	B
Side or end—F + P or L + C	Y
Side or end—B + P or R + C	Z

Figure 4.1 Collision Deformation Classification (CDC) system[11]

Following the exclusion of the 166 vehicle-to-vehicle and 10 pole side impact cases with damage exclusively in CDC region 'F' and 'B', there were 344 vehicle-to-vehicle and 44 pole side impact cases available for analysis.

Table 4.5 Number of occupants by CDC damage profile and collision partner

CDC Damage	Collision partner		
	Car	**Pole**	**Total**
	n	**n**	**N**
Forward of A-pillar (F)	152	10	162
Behind C pillar (B)	14	0	14
Distributed, full length (D)	36	3	39
Bewtwen A and B pillar (P)	97	33	130
Forward of C pillar (Y)	158	6	164
Behind A pillar to rear (Z)	53	2	55
Total	510	54	564

Finally, we examine cases where the crash severity, as indexed by ETS (equivalent test speed) was known. This is required as the logistic regression models will exclude any case where the ETS is unknown. This final inclusion criterion results in the exclusion of 8 pole side impact occupants, and 89 vehicle-to-vehicle impacts.

The final sample available for analysis was 263 occupants injured in vehicle-to-vehicle side impact crashes and 36 occupants injured in pole side impact crashes.

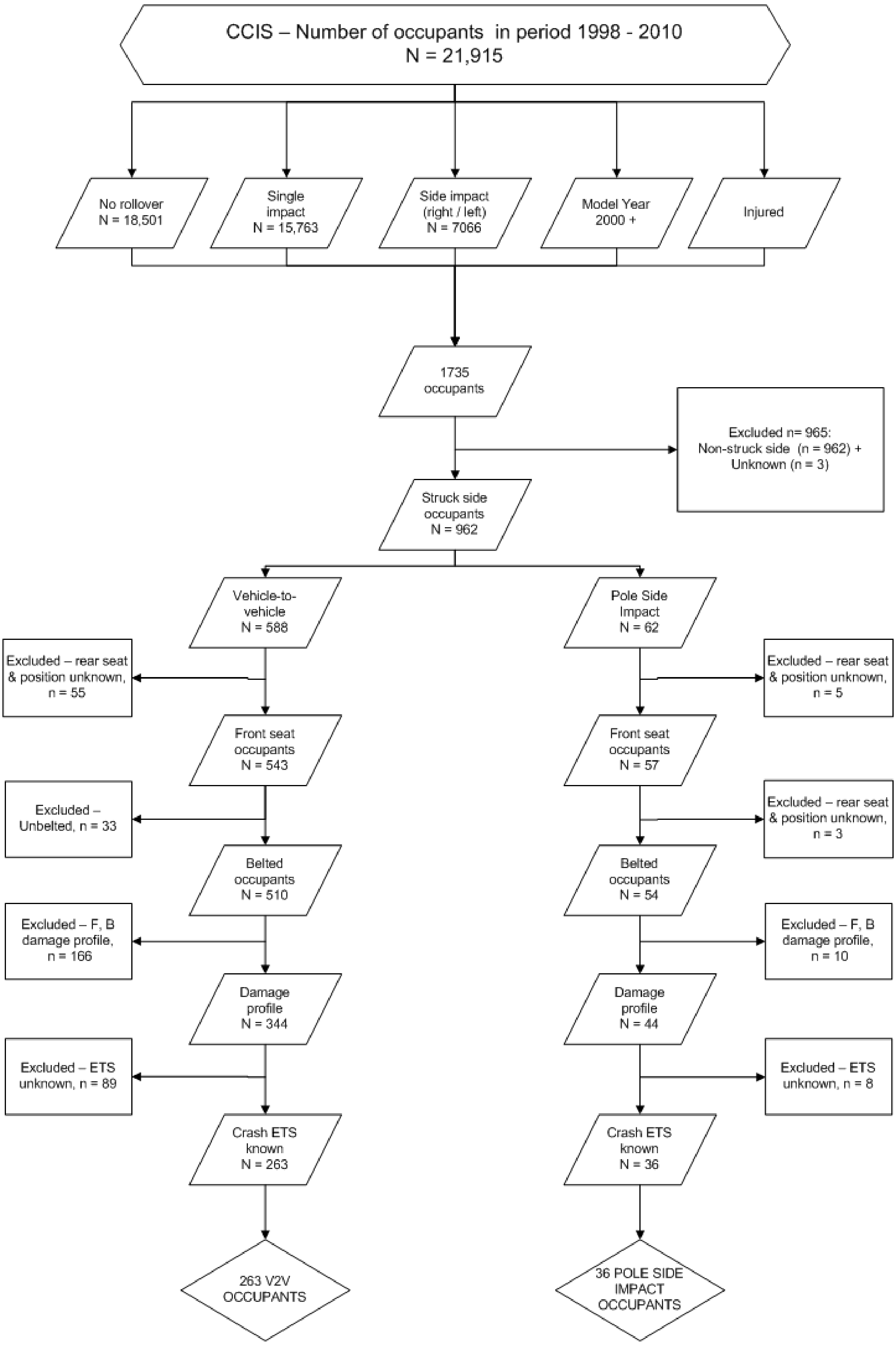


Figure 4.2 CCIS case selection flowchart, showing exclusions

4.3 Results

The following section first outlines the characteristics of the 263 occupants injured in the vehicle-to-vehicle crashes and the 36 occupants injured in the pole side impact crashes. It is important to examine the equivalence, or otherwise, of the characteristics in order to interpret differences, if any, in the injury outcomes between the occupant injury groups. Following this, an examination of injury patterns and injury severity by body region is presented.

4.3.1 Sample characteristics

The demographic characteristics of occupants injured in vehicle-to-vehicle and PSI crashes are presented in Table 4.6. While the proportion of drivers and front passengers between the two groups is similar (~80% drivers), the mean age of occupants injured in PSI was lower (*M = 27.3, SD = 13.0)* than those involved in vehicle-to-vehicle side impact crashes (*M = 42.5, SD = 18.9),* $t(287) = 4.86$, $p<0.01$. Males represented a higher proportion of injured occupants in PSI (72%) than vehicle-to-vehicle impacts (55%), $X^2(1) = 4.20$, $p=0.04$.

Table 4.6 Demographic characteristics of occupants injured in vehicle-to-vehicle and PSI crashes

Characteristic	Collision Partner	
	Vehicle (N=263)	**Tree / Pole (N=36)**
Position	N (%)	N (%)
Driver	213 (81%)	30 (83%)
Front left passenger	50 (19%)	6 (17%)
Number of occupants	263	36
Age* (years)		
Mean (SD), years	42.5 (18.9)[a]	27.3 (13.0)[a]
Mean - 95th% CL	40.1-44.8	22.8-31.8
Median, years	42.0	24.0
Min/Max	4-95	15-72
Sex†		
Female	119 (45%)[b]	10 (28%)
Male	140 (55%)	26 (72%)

*Age – missing 1; V2V; [a](age). $t(287)=4.86$, $p<0.01$;
†. Sex unknown for 4 V2V; [b]. $X^2(1)=4.20$, $p=0.04$

The height and weight characteristics of occupants injured in vehicle-to-vehicle and PSI crashes are presented in Table 4.7. This is of value as the anthropometry of crash involved injured occupants is of direct relevance to the size of the anthropomorphic test device (ATD) used in the crash test.

Occupants injured in the PSI crashes (M = 77.8kg) were heavier than occupants in vehicle-to-vehicle crashes (M = 73.2 kg) and also taller (PSI: 176 cf. V2V: 170), though these differences did not reach statistical significance ($p \geq 0.05$). Notably, the WorldSID 50th percentile adult male ATD has a mass of 77.3 kg and a theoretical standing height of 1753 mm, characteristics almost the same as average occupant injured in PSI crashes.

Due to the data collection protocols of CCIS, occupant height was known for only 45% of V2V occupants (n = 119) and 33% of PSI occupants (n = 12). Similarly, occupant weight was also known for 45% of V2V occupants (n = 119) and 27.8% of PSI occupants (n = 10).

Table 4.7 Anthropometric characteristics of occupants injured in vehicle-to-vehicle and PSI crashes

Characteristic	Collision Partner	
	Vehicle (N=119)	**Tree / Pole (N=10)**
Weight (kg)		
Mean (SD), years	73.2 (17.9)[a]	77.8 (26.1)
Mean - 95th% CL	69.9-76.5	59.1-96.5
Median, kg	72.0	72.5
Min/Max	19-123	47-130
Height (m)	**Vehicle (N=119)**	**Tree / Pole (N=12)**
Mean (SD), years	1.70 (0.11)[b]	1.76 (0.10)
Mean - 95th% CL	1.68-1.72	1.69-1.82
Median (cm)	1.70	1.79
Min/Max	1.07-1.93	1.57-1.93

a(weight). t(127)=0.74, p=0.4; b(height). t(129)=1.68, p=0.09

Using the reported height and weight of occupants, the Body Mass Index (BMI, kg/ height, m^2) was determined (Table 4.8). This gives an indication of whether the occupants are of 'healthy, normal weight' or are 'underweight' or 'overweight' for their height. BMI could be derived for only 43.7% (n = 115) of occupants involved in V2V crashes and 25% (n = 9) of occupants involved in PSI crashes. The two occupant impact groups were well matched overall in terms of mean, median and BMI range, however the small number of PSI occupants makes comparisons difficult.

Table 4.8 Body mass index of occupants injured in vehicle-to-vehicle and PSI crashes

Characteristic	Collision Partner	
	Vehicle (N=115)	**Tree / Pole (N=9)**
Body mass index (BMI)		
Mean (SD)[a]	25.3 (4.2)	25.1 (7.5)
Mean - 95th% CL	24.5-26.0	19.4-30.9
Median	24.8	21.3
Min/Max	17.6-38.8	19.1-41.0
Body mass index - category[b]		
<20, underweight	53 (46%)	3 (33%)
20-25, normal weight	51 (44%)	4 (44%)
>25 overweight	11 (9%)	2 (22%)

(a) t(122)=0.08, p=0.9; *(b)* $X^2(2)$=1.56, p=0.5

4.3.2 Vehicle characteristics and associated damage

The majority of occupants were in vehicles classified as 'hatchbacks' (75-80%) with a smaller proportion being occupants of 'saloon' and 'estate' vehicles. There was no difference in the distribution of occupants in vehicles across the collision partner.

The ETS (km/h) was higher for the PSI crashes (*M: 28.4 km/h, SD = 22.7)* compared to V2V crashes (*M: 19.3 km/h, SD = 10.7),* t(297) = 3.993, p≤0.01. The median speed and the maximum ETS were also higher for PSI crashes. This is an important difference as regression models are required to statistically adjust for the difference in crash severity.

Table 4.9 Vehicle characteristics and crash severity indexed by the ETS for all crash involved occupants

Characteristic	Collision Partner	
	Vehicle (N=263)	**Tree / Pole (N=36)**
Vehicle Class	**N (%)**	**N (%)**
Saloon	19 (7.2%)	2 (5.6%)
Hatchback	195 (74.1%)	29 (80.6%)
Estate	19 (7.2%)	2 (5.6%)
Convertible	5 (1.9%)	1 (2.8%)
Car derivative	2 (0.8%)	2 (5.6%)
Off-road	6 (2.3%)	Nil
Sports	6 (2.3%)	Nil
MPV	11 (4.2%)	Nil
ETS		
Mean (SD), km/h	19.3 (10.7)[a]	28.4 (22.7)[a]
Mean - 95th% CL	18.0-20.6	20.7-36.1
Median, KM/H	17.0	24.0
Min/Max	5-72	4-133

[a] t(297)=3.993, p≤0.01

For occupants sustaining AIS3+ injuries, the ETS (km/h) was higher for the PSI crashes (*M: 40.2 km/h, SD = 27.9, Median: 33; n = 17)* compared to V2V crashes (*M: 34.9 km/h, SD = 115.3; n = 31); the small sample size results in this difference not being statistically significant.*

In assessing the differences in injury severity between those involved in PSI or V2V impacts, consideration must be given to the type of side impact airbag fitted. Table 4.10 presents the number of occupants exposed to side impact airbags by type. While the majority of occupants were not exposed to a side airbag deployment, the proportion was slightly higher in the PSI crashes (75%) than in the V2V crashes (67%). A similar proportion of occupants were exposed to a thorax-only, curtain-only airbag or combination head-thorax airbag. A higher proportion of the V2V occupants (14%) were exposed to a curtain plus thorax side airbag system compared to the PSI occupants (2.8%). Statistically, the two groups did not however differ in their exposure / non-exposure to side airbag systems.

Table 4.10 Side airbag availability, deployment and type (all occupants)

Characteristic	**Collision Partner**	
	Vehicle (N=263)	**Tree / Pole (N=36)**
Side airbag	**N (%)**	**N (%)**
Not fitted / not activated	176 (66.9%)	27 (75.0%)
Curtain + thorax (+/- pelvis)	37 (14.1%)	1 (2.8%)
Combination: head+/thorax (+/- pelvis)	15 (5.7%)	2 (5.6%)
Curtain only	29 (11.0%)	5 (13.9%)
Thorax only (+/- pelvis)	4 (1.5%)	1 (2.8%)
Tube + thorax (+/- pelvis)	2 (.8%)	Nil
R95 compliant		
Not compliant	48 (18.3%)	11 (30.6%)
Compliant	215 (81.7%)	25 (69.4%)

The case selection criteria included specification for vehicles manufactured from calendar year 2000 onwards (i.e., MY2000+). This criteria was specified for consistency with the analysis of Australian crash data and in recognition of the implementation date of UN ECE R95[17], which in Australia was promulgated as Australian Design Rule (ADR) 72/00 - Dynamic Side Impact Occupant Protection.[35] There was however a time difference between the implementation of UN ECE R 95 in Europe and Australia. This is a subtle, yet important consideration as the assessment of the value of the proposed GTR is being done in the context of vehicles meeting the requirements of UN ECE R 95.

An assessment made by TRL Ltd on the likely compliance of vehicles with UN ECE R 95 indicated that 240 vehicles would meet the regulatory performance standard. With reference to the collision partner, 82% of occupants in V2V impacts and 70% of occupants injured in PSI crashes were in UN ECE R95 compliant vehicles. Statistically, there was no difference in the compliance between the two groups, $X^2(1) = 3.03$, p=0.08

Examination of the airbag fitment rate by UN ECE R95 status indicated that 16.9% of pre-UN ECE R95 vehicles had a side impact airbag fitted compared to 35.8% of compliant vehicles. Of the compliant vehicles, the analysis indicated that curtain + thorax side airbag systems (SAB) were most common (15.4%), followed by thorax-only SAB (12.5%) and combination (head/thorax) SAB (5.4%) (Table 4.11). The small number of PSI occupants and the relatively large number of SAB categories precludes any meaningful comparisons to be undertaken.

Table 4.11 Side airbag availability, deployment and type by UN ECE R95 vehicle compliance

SAB system	Vehicle compliance					
	Pre-ECE95		ECE95		Total	
	n	%	n	%	n	%
Not fitted - not activated	49	83.1%	154	64.2%	203	67.9%
Curtain + Thorax	1	1.7%	37	15.4%	38	12.7%
Combination (H+T)	4	6.8%	13	5.4%	17	5.7%
Thorax only	4	6.8%	30	12.5%	34	11.4%
Curtain only	-	-	5	2.1%	5	1.7%
Tube + Thorax	1	1.7%	1	0.4%	2	0.7%
Total	59	100%	240	100%	299	100%

A key inclusion criterion for cases was that damage would engage the occupant compartment directly. Using the CDC as described, the principal damage location can be described. The effect of narrow object impacts can be observed, with the damage for PSI being localised to one region; alternatively the broad aspect of the vehicle as a collision partner is reflected in the damage distributed over one or more regions. Specifically, the damage for the PSI cases is localised to the passenger compartment (83%) compared to 30% of V2V impacts ($p \leq 0.01$).

The crush profile provides an alternative index of crash severity. It is clear that the crush associated with PSI (*$M = 42.8$, $SD = 23.6$*) is twice that of V2V impacts (*$M = 21.8$, $SD = 13.0$*) *($t(297) = 8.04$, $p \leq 0.01$)*, as was the median crush value (i.e., the point where 50% of the cases sit above and below).

Table 4.12 Impact profile and crush for vehicle-to-vehicle (V2V) and PSI for all involved occupants

Impact distribution	Collision Partner	
	Vehicle (N=263)	Tree / Pole (N=36)
	N (%)	N (%)
Distributed (D)	22 (8.4%)[(a)]	2 (5.6%)
Side – centre (left, right) (P)	81 (30.8%)	30 (83.3%)
Y = F + P (forward of C-pillar)	119 (45.2%)	3 (8.3%)
Z =B+P (behind A-pillar)	41 (15.6%)	1 (8.3%)
Crush - maximum		
Mean (SD) mm	21.8 (13.0)[(b)]	42.8 (23.6)
Mean - 95th% CL	20.2-23.4	34.8-50.8
Median, mm	18.0	39.5
Min/Max	3-76	9-96

[(a)] $X^2(3)=38.1$, $p \leq 0.01$; (b) *($t(297)=8.04$, $p \leq 0.01$)*

The location, speed zone and road class are of interest for two reasons: 1) to provide the basis of the representativeness of the sample when compared to the police reported casualty data (STATS 19) and 2) as the basis of understanding the 'safety need' and countermeasure development. The injury analysis is presented as un-weighted and weighted, with sample weights derived from STATS19 (see Appendix A4 at the end of this chapter), largely overcoming any concerns of representativeness.

As expected, nearly two-thirds of PSI impacts occur at the mid-block (61%) rather than junctions or cross intersections than was the case with V2V impacts (29%). A greater proportion of PSI occurred in the 70 km/h speed zone (25%) than the V2V crashes, and 25% in the 30 km/h speed zone, indicating that PSI are not restricted to high end speed zones. Most of the V2V impacts occurred in the 30 km/h zone (34%) and the 60 km/h zone (39.9%).With respect to road class, approximately half of V2V and PSI crashes occurred on A-class roads, a similar proportion on C-class roads (~20%) though a higher proportion of V2V crashes occurred on 'B-Class' roads (21%) than did PSI (8%). These road class findings appear to reflect the combination of surrounding land use, speed zones, intersections and traffic density.

Table 4.13 Location of crash, speed zone and road class

Characteristic	Collision Partner	
	Vehicle (N=263)	**Tree / Pole (N=36)**
Crash location	**N (%)**	**N (%)**
Unknown / missing	41 (15.6%)	6 (16.7%)
Multiple roads	4 (1.5%)	0 (-)
Not at junction	76 (28.9%)	22 (61.1%)
Roundabout	10 (3.8%)	3 (8.3%)
T-junction	92 (35%)	3 (8.3%)
Cross-roads	40 (15.2%)	2 (5.6%)
Speed limit (km/h)		
20	1 (0.4%)	0 (-)
30	90 (34.2%)	9 (25.0%)
40	35 (13.3%	2 (5.6%)
50	17 (6.5%)	3 (8.3%)
60	105 (39.9%)	10 (27.8%)
70	5 (1.9%)	9 (25.0%)
99	10 (3.8%)	3 (8.3%)
Road class		
Unknown	16 (6.1%)	2 (5.6%)
A	131 (49.8%)	19 (52.8%)
B	56 (21.3%)	3 (8.3%)
C	59 (22.4%)	9 (25%)
M	1 (0.4%)	3 (8.3%)

4.3.3 Injury outcomes of occupants

In seeking to examine the nature of injuries sustained and the role of key parameters such as impact object and occupant characteristics, it is useful to document the nature of the overall crash sample in CCIS. This analysis sets the scene in assessing the safety need for a PSI GTR and guides countermeasure priorities by understanding the nature of injury severity across the body regions.

The analysis of injury data is presented (Table 4.14) as individual case data (unweighted) and weighted according to the number of crashes represented nationally in the UK (refer to Appendix A4 for an explanation of the derivation of weighting factors). Once the national CCIS based weights are applied to the 263 V2V and 36 PSI cases, these represent 12,569 V2V and 1531 PSI injured occupants. The CCIS weights do not apply to the non-injury cases due to the fact that STATS19 does not collect information on non-injured persons involved in crashes. As the emphasis is on injury risk and differences at the case level, the analysis places emphasis on the un-weighted data. While the univariate examination of injury patterns is important, in the following sections injury risk is examined using logistic regression models that adjust for known differences between the two groups.

Table 4.14 Injury outcomes for occupants injured in V2V and PSI impacts, unweighted and weighted

	Collision Partner			Collision Partner (WEIGHTED)		
Characteristic	**Vehicle (N=263)**	**Tree / Pole (N=36)**	**TOTAL**	**Vehicle (N=12,569)**	**Tree / Pole (N=1531)**	**Total (N=14,100)**
Severity‡						
Killed	12 (4.6%)	7 (19.4%)	19 (6.4%)	†102 (0.8%)	†60 (3.9%)	162 (1.1%)
Seriously injured	75 (28.5%)	12 (33.3%)	87 (29.1%)	1222 (9.7%)	195 (12.7%)	1417 (10.0%)
Slight	141 (53.6%)	16 (44.4%)	157 (52.5%)	11245 (89.5%)	1276 (83.3%)	12521 (88.8%)
Uninjured	35 (13.3%)	1 (2.8%)	36 (12%)	N/A	N/A	N/A
MAIS – whole body (a)(cw)						
0-uninjured	35 (13.3%)	1 (2.8%)	36 (12%)	-	-	-
1-Minor(	162 (61.6%)	16 (44.4%)	178 (59.5%)	11587 (92.2%)	1213 (79.2%)	12800 (90.8%)
2-Moderate	35 (13.3%)	2 (5.6%)	37 (12.4%)	562 (4.5%)	96 (6.3%)	658 (4.7%)
3=Serious	15 (5.7%)	9 (25.0%)	24 (8.0%)	237 (1.9%)	147 (9.6%)	384 (2.7%)
4=Severe	9 (3.4%)	7 (19.4%)	16 (5.4%)	116 (0.9%)	60 (3.9%)	176 (1.2%)
5=Critical	4 (1.5%)	1 (2.8%)	5 (1.7%)	42 (0.3%)	16 (1.0%)	58 (0.4%)
6=Maximum	3 (1.1%)	0 (Nil)	3 (1.0%_	26 (0.2%)	0 (-)	26 (0.2%)
MAIS 2 + (NUMBER, %) (b)(dw)						
MAIS <2	197 (74.9%)	17 (47.2%)	214 (71.6%)	11587 (92.2%)	1213 (79.2%)	12800 (90.8%)
MAIS 2+	66 (25.1%)	19 (52.8%)	85 (28.4%)	982 (7.8%)	319 (20.8%)	1301 (9.25)
MAIS 3 + (NUMBER, %) (c)(ew)						
MAIS <3	232 (88.2%)	19 52.8%)	251 (83.9%)	12149 (96.7%)	1309 (85.4%)	13458 (95.4%)
MAIS 3+	31 (11.8%)	17 (47.2%)	48 (16.1%)	420 (3.3%)	223 (14.6%)	643 (4.6%)
Injury Severity Score (d)(fw)						
Mean (SD)	5.0 (10.9)	12.6 (10.9)	5.9 (11.8)	2.4 (5.3)	4.4 (8.6)	
Mean - 95th% CL	3.67-6.35	7.44-17.88	4.6-7.3	2.37-2.55	4.00-4.86	
Median	2.0	5.5	2.0	1.0	1.0	
Min/Max	0-75	0-48	0-75	1-75	1-48	
ISS category (major trauma)(e)(gw)						
Minor (<15)	243 (92.4%)	25 (69.4%)	268 (89.6%)	12328 (98.1%)	1406 (91.8%)	13734 (97.4%)
Major (>15)	20 (7.6%)	11 (30.6%)	31 (10.4%)	241 (1.9%)	125 (8.2%)	366 (2.6%)

Unweighted:‡ $X^2(3)=14.7$, $p\leq0.01$; (a) $X^2(3)=35.8$, $p\leq0.01$; OR_{MH} (killed, unweighted) = 5.04, 95% CI: 1.84-13.83, p = 0.02; (b) $X^2(3)=11.9$, $p\leq0.01$ & $OR_{MH}=3.33$ (95% CI: 1.64-6.79, p < 0.01); (c) $X^2(3)=29.5$, $p\leq0.01$ & $OR_{MH}=6.69$ (95% CI: 3.1-14.2, p < 0.01), (d) $t(297)=3.69$, $p\leq0.01$; (e) $X^2(3)=17.9$, $p\leq0.01$ & $OR_{MH}=5.34$ (95% CI: 2.3-12.4, p < 0.01); *Weighted*: † $X^2(2)=132.8$, $p\leq0.01$; OR_{MH} (killed, weighted) = 4.98, 95% CI: 3.61-6.88-13.83, p <0.001; (cw) $X^2(5)=450.9$, $p\leq0.001$; (dw) $X^2(1)=275.9$, $p\leq0.001$ & $OR_{MH}=3.10$ (95% CI: 2.69-3.56, p < 0.01); (ew) $X^2(1)=394.6$, $p\leq0.001$ & $OR_{MH}=4.92$ (95% CI: 4.15-5.85, p < 0.01); (fw) $t(14,098)=12.54$, $p\leq0.01$; (gw) $X^2(1)=210.6$, $p\leq0.001$ & $OR_{MH}=4.54$ (95% CI: 3.64-5.68, p < 0.01)

Examination of the unweighted case data shows the proportion of occupants killed in PSI (19.4%) is considerably higher than for V2V impacts while a slightly higher proportion (33.3%) are seriously injured than in V2V impacts (28.5%). Only one occupant (2.8%) involved in PSI was uninjured compared to 13.3% of those involved in V2V impacts; the differences in the injury severity distribution was seen to be statistically significant, $X^2(3) = 14.7$, $p \leq 0.01$.

Injuries in CCIS are coded according to the Abbreviated Injury Scale (AIS)[9] and Table 4.14 shows the differences in injury severity using the highest recorded severity across all body regions (i.e., the maximum AIS severity), as well as the key metrics of AIS 2+ and AIS 3+ injuries. The key result is that 47.2% of PSI occupants sustained an AIS 3+ (serious injury) or higher severity injury, compared to 11.8% of occupants involved in V2V impacts. Moreover, one-fifth of PSI occupants sustained an AIS 4+ injury compared to 5% of V2V occupants, highlighting the injurious nature of PSI crashes. This increased injury severity associated with PSI crashes is also reflected in the Injury Severity Score (ISS)[36] and the proportion of major trauma cases (ISS > 15) in PSI involved occupants (30.6%) compared to V2V involved occupants (7.6%).

A similar pattern of higher injury risk is seen in the weighted analysis, although the overall percentages differ, noting that the uninjured category was excluded from the analysis. As the weights apply to cases collected across multiple years and due to the exclusion of uninjured cases, their utility as a method of estimating the total number of V2V and PSI injured occupants and injury risk is limited. On this basis, weighted injury data is not presented in any further detail.

Injuries sustained by body region and severity for occupants injured in V2V impacts and PSI is presented in Table 4.15. Across each body region and severity – with the exception of occupants sustaining any injury to the neck (AIS 1+), a higher proportion of occupants in PSI were injured (Figure 4.3). The disparity in injuries sustained is particularly evident with AIS 2+ and AIS 3+ severity injuries (see Figure 4.4a). For instance, 27.8% of occupants injured in PSI sustained an AIS 3+ head injury compared to 4.9% of occupants injured in V2V impacts. The key body regions injured at the AIS 3+ level were the head, thorax, the lower extremity, and the abdomen-pelvis; importantly the proportion of occupants in PSI sustaining these injuries was significantly higher than those involved in V2V impacts.

Also presented is the distribution of AIS 3+ injuries by body region for occupants sustaining an AIS 3+ injury (Figure 4.4b); 40% and 60% of AIS 3+ V2V and PSI occupants respectively sustained an AIS 3+ head injury with nearly 70% of V2V and 60% of PSI injured occupants sustaining an AIS 3+ thorax injury. The sample size is too small to permit examination of the injury distributions for killed and seriously injured occupants separately. Such an analysis would be useful as it would permit assessment of the relativities of head and thorax injuries in the two groups, by impact object.

The percent of occupants sustaining a shoulder injury is presented given the interest in the potential load path for the proposed PSI GTR. A higher proportion of PSI involved occupants sustained an (AIS 1 +) and AIS 2 shoulder injury than did occupants involved in V2V impacts. None sustained an AIS 3 skeletal shoulder injury, of which there is only one AIS 3 shoulder injury defined (AIS 1990 – 1998 Update), that being '*massive destruction of bone and cartilage [crush]*'.

Table 4.15 Injuries sustained by AIS body region and severity (unweighted)

Body region	Injured (AIS 1+)				AIS 2+				AIS 3+			
	V2V		Pole		V2V		Pole		V2V		Pole	
	n	%	n	%	n	%	n	%	n	%	n	%
Head	57	21.7	17	47.2	20	7.6	10	27.8	13	4.9	10	27.8
Face	48	18.3	16	44.4	2	0.8	1	2.8	Nil	Nil	Nil	Nil
Neck	107	40.7	7	19.4	4	1.5	2	5.6	1	0.4	Nil	Nil
Thorax	96	36.5	15	41.7	31	11.8	12	33.3	21	8.0	10	27.8
Upper Ex.	85	32.3	20	55.6	10	3.8	7	19.4	Nil	Nil	Nil	Nil
Shoulder	*23*	*8.7*	*12*	*33.3*	*4*	*1.5*	*5*	*13.9*	*Nil*	*Nil*	*Nil*	*Nil*
Abdomen/ Pelvis	87	33.1	15	41.7	37	14.1	12	33.3	14	5.3	4	11.1
Lower Extremity	71	27.0	15	41.7	13	4.9	9	25.0	8	3.0	7	19.4
Unknown	4	1.5	2	5.6	1	0.4	Nil	Nil	1	0.4	Nil	Nil

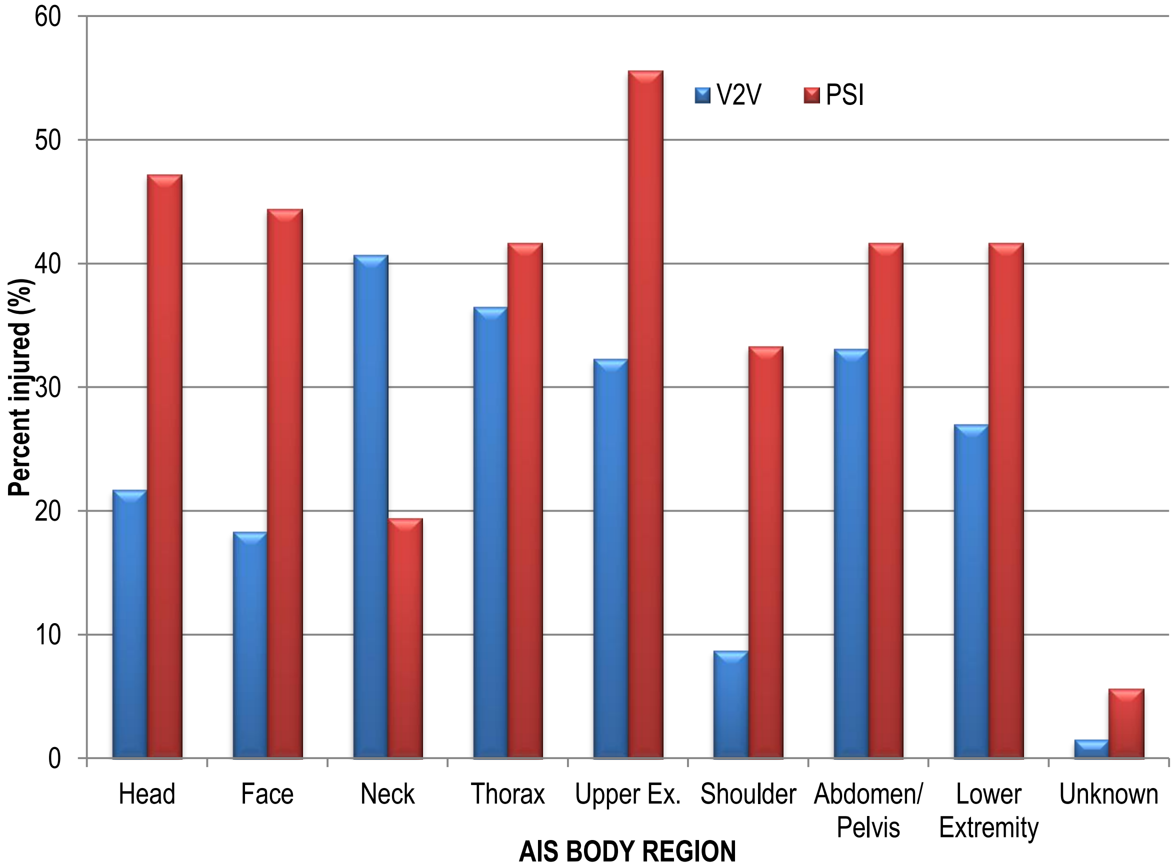


Figure 4.3 Percent of occupants with AIS 1+ injuries, by body region and collision partner (unweighted)

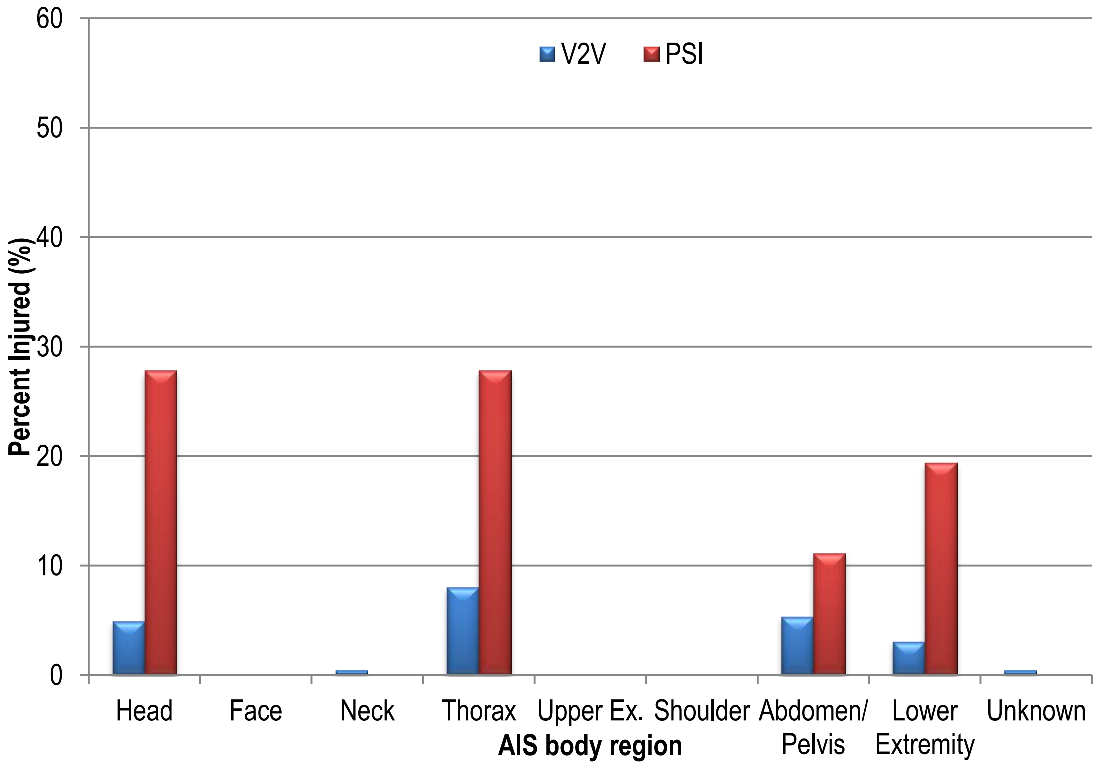


Figure 4.4a Percent of occupants with AIS 3+ injuries, by body region and collision partner (unweighted)

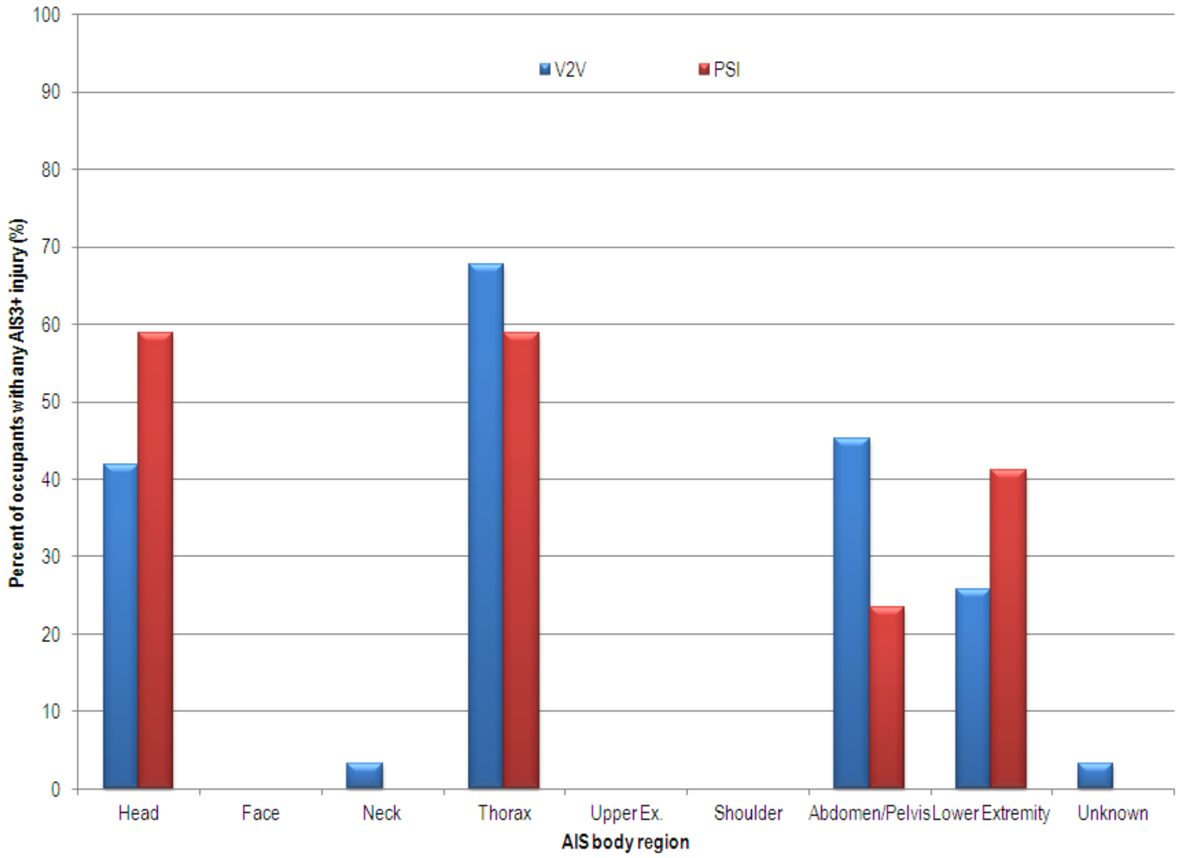


Figure 4.4b Percent of occupants with an AIS3+ injury by body region, for those sustaining <u>any AIS 3+ injury</u> (unweighted)

4.3.4 Estimation of differences in injury risk

4.3.4.1 Mortality and Major Trauma Outcomes

As presented in Table 4.14, 19.4% (n = 7 of 36) of occupants in PSI were killed compared to 4.6% (n = 12 of 263) of those involved in V2V side impact crashes ($p \leq 0.05$). With respect to the major trauma classification, 30% of PSI involved occupants met the ISS > 15 criterion compared to 7.6% of V2V side impact involved occupants ($p \leq 0.05$).

Examination of demographic and crash characteristics highlighted differences in age, sex, R95 compliance and collision severity indexed by ETS.[4] In determining the magnitude of difference in the outcome of interest – in this case mortality, it is important to account for differences in key variables such as age, gender and others that could also influence the outcome of interest. For this purpose, logistic regression is an appropriate statistical model.[37] Each characteristic was assessed to determine the nature of its relationship with each outcome with each also assessed for their role as a potential confounding variable (i.e., source of bias) due to inter-group differences. For continuous variables such as age and ETS, their suitability for inclusion into the model was

4 Consideration need be given to the apparent difference in ETS between the two groups. The higher mean ETS (km/h) could reflect higher impact speeds, however it cannot be dismissed that the higher ETS is driven by the concentrated nature of narrow object impacts and the resultant higher dynamic deformation of these impacts. Whether ETS is an appropriate index of crash severity or as a surrogate of impact speed requires examination. Regardless, it remains important to account for the difference in ETS between the two groups in estimating differences in the risk, or likelihood of injury.

assessed using fractional polynomials[37] as a way of determining whether their relationship, if any, with the outcome of interest was linear, or equal between each successive point (e.g., the change in odds is the same from 41 years to 42 years of age as it is for 67 to 68 years).

The adjusted Odds Ratios (OR) for mortality and major trauma as key outcomes are presented in Table 4.16, as well as OR for the effect of collision severity indexed by ETS and the effect of age on mortality; the inclusion of these variables accounts for group differences in ETS and age.

The odds of being killed in a PSI were 4.37 times higher (OR: 4.37, 95% CI: 1.01-18.9) than for occupants involved in V2V side impact crashes. The odds of PSI involved occupants sustaining multiple and serious injuries such that they meet the major traumas (ISS > 15) criterion is similarly high (OR: 4.17, 95% CI: 1.24-13.9).

Table 4.16 Odds Ratios for mortality and major trauma for PSI relative to V2V side impact occupants

Fatality	*Referent*	**Odds ratio**	**P**
Narrow object (Pole/tree)	Vehicle	4.37 (1.01-18.91)	0.048
Equivalent Test Speed (km/h)		**1.14** (1.09-1.21)	<0.001
Age (years)		1.04 (0.99-1.07)	0.06
Major trauma (ISS>15)	*Referent*	**Odds Ratio**	**P**
Narrow object (Pole/tree)	vs. Vehicle	4.17 (1.24-13.98)	0.02
Equivalent Test Speed (km/h)		**1.16** (1.10-1.21)	<0.001
Age (years)		1.01 (0.98-1.04)	0.5

In both models, ETS (km/h) was an important determinant in the outcome such that for every 1 km/h increase in ETS, the odds of mortality increased by 14%, regardless of collision / impact object (OR: 1.14, 95% CI: 1.09-1.21, $p < 0.001$). A similar effect for ETS was observed when considering the likelihood of sustaining major trauma, (OR: 1.16, 95% CI: 1.10-1.21, $p < 0.001$).

With respect to age and mortality, there was a strong trend apparent that older age was associated with a higher odds of death across both impact configurations (OR: 1.04, 95^{th}%: 0.99-1.07, $p = 0.06$), however this was not the case for major trauma, though it was necessary to include age in the statistical model to account for intergroup differences.

Figure 4.5 presents the probability of mortality for PSI involved occupants and those involved in V2V side impact crashes by ETS (km/h), with a rapid rise from 40 km/h to 75 km/h range, where differences between the collision partners is most evident. For instance, the age-adjusted probability of mortality in a PSI crash at an ETS of 50 km/h was 0.51 compared to a probability of 0.19 for those involved in V2V side impact crashes. While not presented, the pattern and probability of sustaining a major trauma outcome was seen to be similar to the mortality curves.

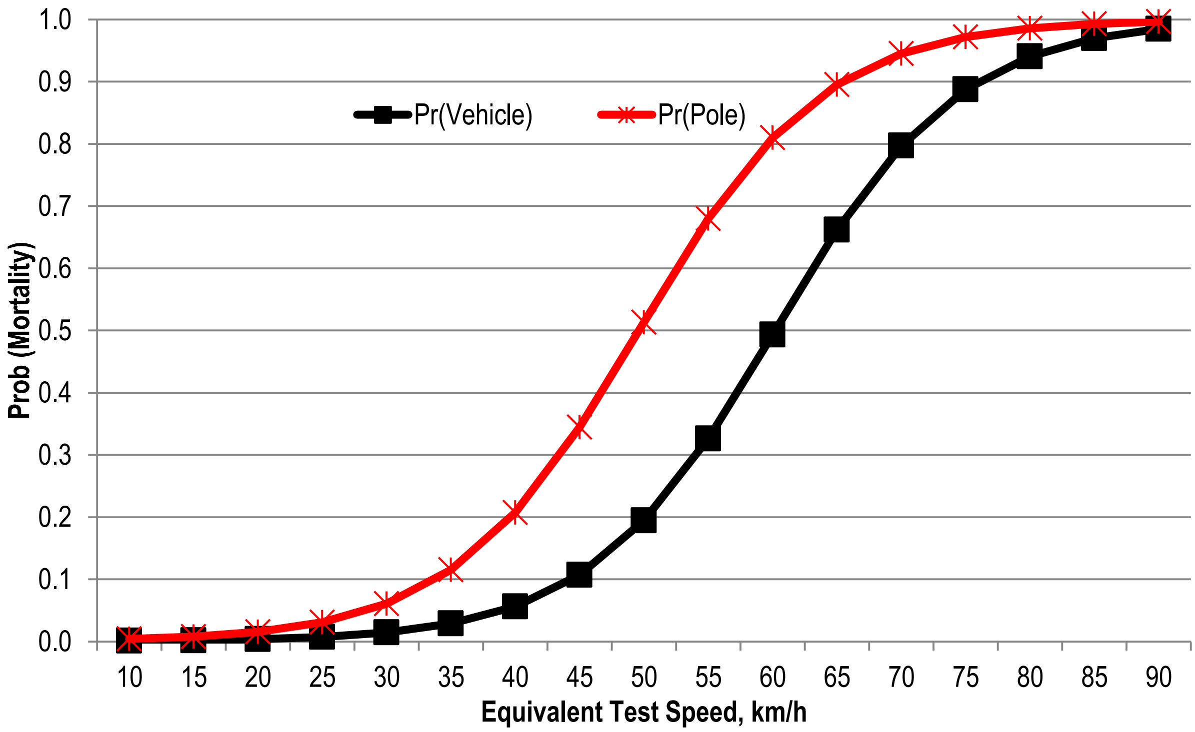


Figure 4.5 Probability of mortality in near-side (struck side) impacts with vehicles and poles/trees

4.3.4.2 Body region specific injury outcomes

The body regions where serious (AIS 3+) injuries were sustained were the head, thorax, abdomen-pelvis and the lower extremity, and there were marked differences in the proportion of PSI crash-involved occupants and V2V crash involved occupants sustaining these injuries. Given some key differences in the age, gender and collision severity profile of the two groups, logistic regression was used in order to statistically adjust for these differences, as well as exploring their influence on the occurrence of each injury type.

Head injury outcomes

Approximately half of the PSI occupants sustained a head injury (47%) (AIS 1+) compared to 21.7% of those involved in V2V side impact crashes, while 27.8% and 7.6% sustained an AIS 2+ injury respectively ($p < 0.05$). Of particular interest though is the proportion sustaining AIS 3+ injuries due to the setting of performance criteria for the PSI GTR. It can be stated the PSI crashes are highly injurious, with 27.8% of occupants sustaining an AIS 3+ head injury compared to 5% of occupants involved in V2V side impact crashes ($p < 0.05$).

Table 4.17 presents the odds ratios for sustaining head injuries across a range of severities. In each impact group comparison, the adjusted odds of sustaining a head injury was higher for occupants of PSI relative to occupants involved in V2V side impact crashes.

The odds of sustaining a head injury (AIS 1+) was twice that for PSI occupants than occupants of V2V side impact crashes (OR: 2.38, 95^{th}% CI: 1.09-5.21, $p = 0.03$); this is 'adjusted' for the influence of impact speed and also the presence and type of side airbag system. Irrespective of impact group, the odds of sustaining a head injury increases by 4% for every 1 km/h increase in ETS (OR: 1.04, 95^{th}% CI: 1.02-1.07, $p < 0.001$).

The influence of side airbags could also be examined for AIS 1+ head injuries and the protective effect of a curtain plus thorax airbag relative to no side airbag can be observed (73% lower odds; OR: 0.27, 95^{th}% CI: 0.08-0.93, $p = 0.04$). No other side airbag system was seen to have a statistically significant influence on the odds of sustaining a head injury relative to not having an airbag present and deployed. A post-test contrast highlighted that the separate curtain-plus-thorax side airbag appeared to offer greater protection than the combination head/thorax side airbag, with the odds ratio translating to a 75% lower odds, although this was not statistically significant at the traditional $p \leq 0.05$ level (OR: 0.25, 95th% CI: 0.05-1.22, p = 0.09). That the curtain-plus-thorax side airbag was seen to be protective relative to no airbag is an important finding. It is also important to note the large, yet not statistically significant, reduction in the odds of head injury for curtain plus thorax airbags relative to combination airbags. The lack of statistical significance may simply be an artefact of the comparatively small sample size.

For AIS 2+ and AIS 3+ head injuries, it was not possible to examine the influence of side airbag systems as there were **no** AIS 2+ or AIS 3+ head injuries with a curtain + thorax SAB in the sample, indicating either the protective effect of the system or possibly the relatively small sample size. Expanded data sets are required to address this important question.

Table 4.17 Odds ratios for sustaining injuries to the head for PSI relative to V2V side impact occupants

Parameter		Head injury		Head AIS 2+		Head AIS 3+	
		Odds ratio	**P**	**Odds Ratio**	**P**	**Odds Ratio**	**P**
	Reference						
Narrow object	Vehicle	**2.38** (1.09-5.21)	0.03	**2.98** (1.10-8.05)	0.03	**5.15** (1.73-15.2)	0.003
Equivalent Test Speed, km/h		**1.04** (1.02-1.07)	<0.001	**1.08** (1.05-1.12)	<0.001	**1.10** (1.06-1.14)	<0.001
Side airbag							
Curtain + Thorax	No SAB	**0.27** (0.08-0.93)	0.04				
Combination (H+T)	No SAB	1.09 (0.36-3.32)	0.9				
Thorax-only	No SAB	0.70 (0.28-1.73)	0.4				
Curtain only	No SAB	Omitted					
Tube	No SAB	2.20 (0.13-36.4)	0.6				
SAB contrast							
Curtain + Thorax	Combination (H +T)	**0.25** (0.05-1.22)	0.09				

Analysis indicated that age and sex had no observable statistically significant relationship with the odds of head injury across all severities. Using the 131 cases where occupant height and weight was known, neither of these factors was associated with sustaining a head injury, although the sample size is extremely low for the analysis to have any value.

At the higher injuries severities, occupants involved in PSI were at higher risk of head injury. The odds ratio indicated that occupants of PSI were 5.15 times more likely than occupants of V2V side impacts to sustain an AIS 3+ head injury (OR: 5.15, 95^{th}% CI: 1.73-15.2, p = 0.003). Also, for every 1 km/h increase in ETS, the odds of sustaining an AIS 3+ head injury increases by 10%. Figure 4.6 presents the probability of sustaining an AIS 3+ injury for occupants involved in PSI and V2V side impact crashes, for a given crash severity expressed as ETS, and the differences between the two groups is evident. At an ETS of 32 km/h, the probability of an AIS 3+ head injury in a PSI was 0.33 compared to 0.08 for V2V side impact crashes. At 50 km/h, the risk of an AIS 3+ injury in a PSI is considerable, at an estimated 0.74 for PSI involved occupants compared to 0.35 for V2V involved occupants.

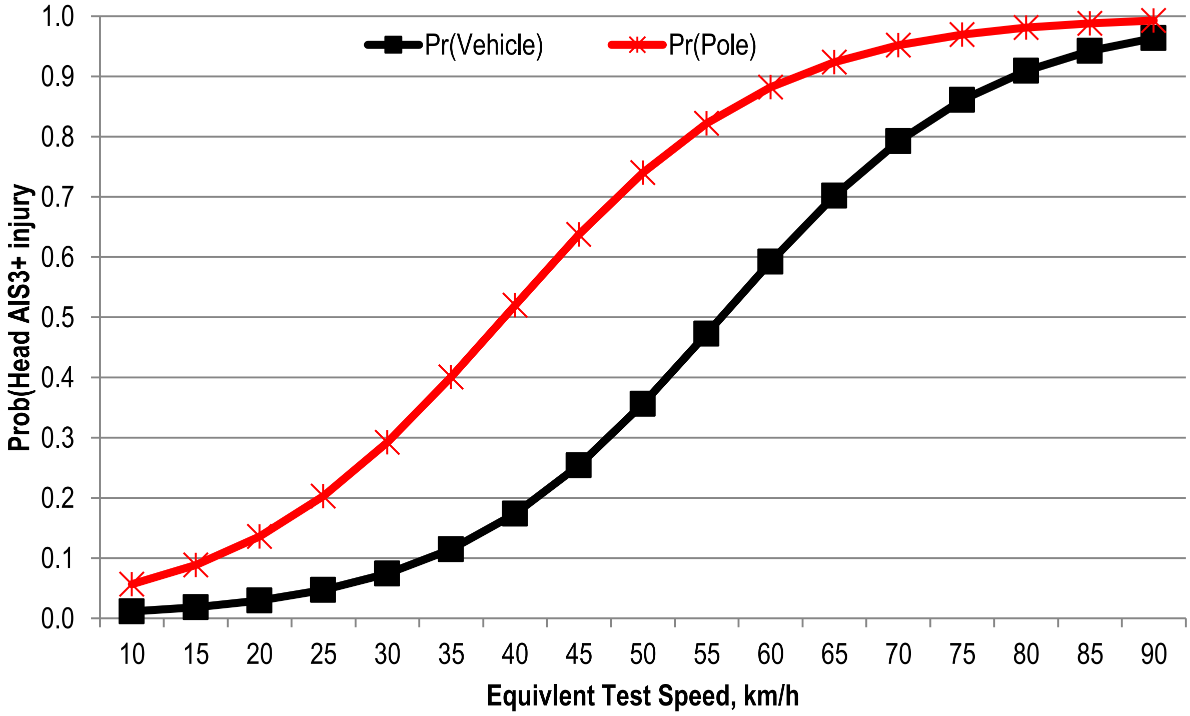


Figure 4.6 Probability of sustaining an AIS 3+ (serious) head injury in near-side (struck side) impacts with vehicles and poles/trees

Thorax injury outcomes

A similar proportion of occupants in PSI (41.7%) and V2V side impact crashes (36.5%) sustained an injury to the thorax, however there was a sizeable difference in the proportion of occupants with an AIS 3+ injury (PSI: 27.8% cf. V2V: 8%). Table 4.18 presents the adjusted odds ratios for thorax injuries for occupants involved in PSI and V2V side impact crashes. While there was no difference in the odds of sustaining a thorax injury (AIS 1+) – as reflected by the similar high percentage of occupants with a thorax injury, the difference in injury at the AIS 2+ and AIS 3+ severity is significant. For instance, the odds of PSI occupants sustaining a thorax AIS 3+ injury was 3.87 times higher than was the case for occupants involved in V2V side impact crashes (OR: 3.87, 95^{th}% CI: 1.31 – 11.42, p = 0.01). Age and ETS were also significantly associated with thoracic injury, with the Odds Ratios presenting the average effect across the impact groups. Hence, for every 1 year increase in age, the odds of an AIS 3+ injury increased by a factor of 1.09, or 9%, and this is the same whether the collision was a PSI or a V2V side impact (OR: 1.09, 95th%: 1.06-1.14, p ≤ 0.001). Increasing age was also associated with an increase in the odds of a thorax AIS 3+ injury, by a factor of 1.02, of 2%, per 1 year increase in age.

Table 4.18 Odds ratios for sustaining injuries to the thorax for PSI relative to V2V side impact occupants

Parameter		Thorax injury		Thorax AIS 2+		Thorax AIS 3+	
		Odds ratio	**P**	**Odds Ratio**	**P**	**Odds Ratio**	**P**
	Reference						
Narrow object	Vehicle	1.22 (0.54-2.79)	0.6	**4.28** (1.07-1.15)	<0.001	**3.87** (1.31-11.42)	0.01
Equivalent Test Speed, km/h		**1.06** (1.04-1.09)	<0.001	**1.11** (1.07-1.15)	<0.001	**1.09** (1.06-1.14)	<0.001
Age, year		**1.03** (1.01-1.04)	<0.001	**1.04** (1.02-1.06)	0.001	**1.02** (0.999-1.05	0.05

Figure 4.7 presents the adjusted probability of AIS 3+ injuries by impact group, with the pattern similar to the AIS 3+ head injury curves. At 32 km/h, the probability of an AIS 3+ injury for those involved in PSI was 0.20 whereas for occupants in V2V impacts the probability was 0.06 (i.e., 6%).

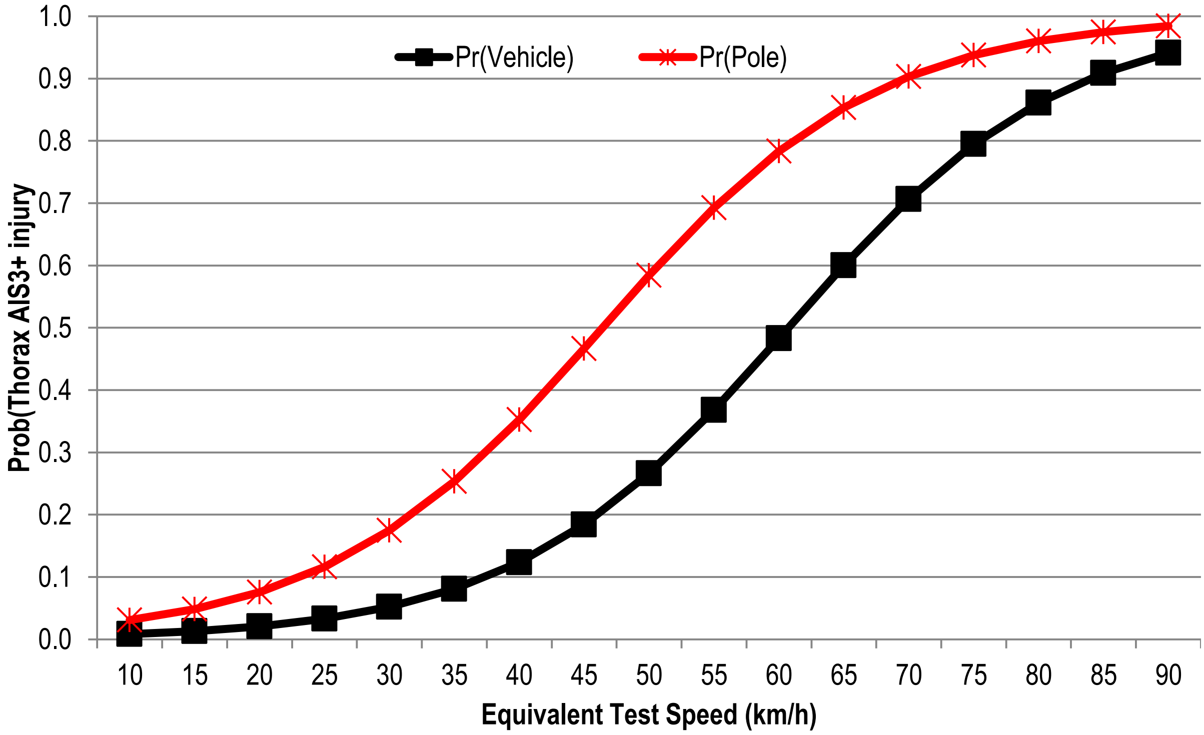


Figure 4.7 Probability of sustaining an AIS 3+ (serious) thorax injury in near-side (struck side) impacts with vehicles and poles/trees

Abdomen-pelvis injury outcomes

While a slightly higher proportion of PSI-involved occupants (41.7%) sustained an abdominal–pelvis injury than occupants in V2V side impact crashes (33.1%), once consideration was given to ETS, age and gender, there was no statistically significant difference in the odds of injury between the two impact groups (OR: 1.17, 95th% CI: 0.49-2.77, p = 0.7). While one-third of PSI occupants sustained an AIS 2+ injury (33.3%) and 11% sustained an AIS 3+ injury compared to 14% and 5% of V2V involved occupants, respectively, the logistic regression analysis indicated no difference in the odds of injury between the two groups for either AIS 2+ or AIS 3+ injuries.

Table 4.19 Odds ratios for sustaining injuries to the abdomen-pelvis for PSI relative to V2V side impact occupants

		Abdomen-pelvis injury		**Abdomen-pelvis AIS 2+**		**Abdomen-pelvis AIS 3+**	
		Odds ratio	**P**	**Odds Ratio**	**P**	**Odds Ratio**	**P**
Parameter	*Reference*						
Narrow object	Vehicle	1.17 (0.49-2.77)	0.7	2.14 (0.76-6.01)	0.1	0.93 (0.19-4.44)	0.9
Equivalent Test Speed, km/h		**1.08** (1.05-1.11)	<0.001	**1.13** (1.09-1.17)	<0.001	**1.11** (1.06-1.15)	<0.001
Age, year		1.01 (0.99-1.02)	0.1	1.01 (0.99-1.03)	0.3	1.01 (0.98-1.04)	0.6
Male	Female	**0.40** (0.23-0.70)	0.001	0.51 (0.23-1.12)	0.09	0.43 (0.13-1.45)	0.2

ETS (km/h) was associated with the occurrence of abdomen-pelvis injuries across the AIS severities, as was the case with injuries to the head and thorax. Age was not associated with abdominal-pelvic injuries but was included to account for differences in the age distribution between the two impact groups.

Notably, males were at a significantly lower likelihood of sustaining an abdominal-pelvis (AIS 1+) injury than females (OR: 0.40, 95th% CI: 0.23-0.70, p = 0.001) and an indicative trend for this was present for AIS 2+ injuries (p = 0.09); conversely, this could be expressed as females have 2.5 times and 1.9 times higher odds of sustaining an abdominal-pelvic injury than their male counterparts in side impact crashes irrespective of the collision partner. While the protective effect for males was evident for AIS 3+ injuries (57% lower odds), this was not statistically significant.

Injuries to the shoulder

Injuries to the shoulder are of interest due to the potential for the shoulder acting as a load path in any side impact crash test due to the nature of the instrumentation of the anthropomorphic test device (ATD). In PSI crashes, one-third of involved occupants sustained an injury to the shoulder compared to 8.7% of occupants involved in V2V side impact crashes. The adjusted odds ratio for shoulder injuries indicated the odds of occupants of PSI crash sustaining a shoulder injury was 4 times higher relative to V2V crash involved occupants (OR: 4.08, 95th% CI: 1.73-9.59, p = 0.001). Collision severity was also associated with the odds of shoulder injury, such that for each 1 km/h increase in ETS the odds of a shoulder injury being sustained increased by 3% (OR: 1.03, 95th% CI: 1.00-1.06, p =0.02).

For AIS 2 injuries, 13.9% and 1.5% of PSI and V2V occupants, respectively, sustained such an injury. No occupants sustained an AIS 3 shoulder injury (i.e. the highest severity possible). The odds of sustaining an AIS 2+ shoulder injury for PSI involved occupants was 7.89 times higher than for V2V crash-involved occupants (OR: 7.89, 95th% CI: 1.85-33.5, p = 0.005), while ETS was not statistically significantly associated with AIS 2+ shoulder injury occurrence (OR: 1.02, 95th% CI: 0.99-1.06, p = 0.1).

Injuries to the lower extremity

As evidenced in Table 4.15, lower extremity injuries were relatively common with 41.7% of PSI involved occupants sustaining an AIS 1+ injury, and this was higher than the proportion of V2V involved occupants (27%). The difference in proportions was higher with increasing injury severity (AIS 2+, PSI: 25% cf. V2V: 4.9%; AIS 3+, PSI: 11% cf. 5%), and this is reflected in the adjusted Odds Ratios where for instance the odds of an AIS 3+ lower extremity injury was 4.79 times higher for PSI involved occupants than for V2V side impact crash involved occupants (OR: 4.79, 95^{th}% CI: 1.22-18.79, p = 0.02) (see Table 4.20). As with the previously discussed body regions, ETS was significantly associated with each injury severity outcome and this is irrespective of impact partner.

In considering sustaining a lower extremity injury, increasing age was associated with an increased odds of injury (2% increased per age year), while the odds of injury was lower for males than for females (OR: 0.56, 95^{th}% CI: 0.31-1.00, p = 0.05). Side airbag type was also assessed; there was an indicative protective effect for thorax-only side airbags with the point estimate suggesting a 64% lower odds of injury (p = 0.07). It is notable that while the weighted logistic regression analysis is not presented, the protective effect of thorax only side airbags was highly statistically significant (79% lower odds; OR: 0.21, 95^{th}% CI: 0.05-0.94, p = 0.04).

Age, sex and side airbag type was not seen to be associated with AIS 2+ or AIS 3+ lower extremity injuries.

Table 4.20 Odds ratios for sustaining injuries to the lower extremity for PSI relative to V2V side impact occupants

		Lower Extremity injury		**Low Ex. AIS 2+**		**Low Ex. AIS 3+**	
Parameter	***Ref.***	**Odds ratio**	**P**	**Odds Ratio**	**P**	**Odds Ratio**	**P**
Narrow object	Vehicle	2.07 (0.88-4.88)	0.09	**4.13** (1.39-12.75)	0.01	**4.79** (1.22-18.79)	0.02
Equivalent Test Speed	km/h	**1.06** (1.03-1.09)	<0.001	**1.09** (1.05-1.13)	0.01	**1.12** (1.07-1.17)	<0.001
Age	years	**1.02** (1.00-1.03)	0.049	N.S		N.S	
Male	Female	**0.56** (0.31-1.00)	0.05	N.S		N.S	
Side airbag							
Curtain + Thorax	None	1.60 (0.74-3.44)	0.2	*Airbag - no statistical relationship with outcome demonstrated*			
Combination (H+T)	None	1.88 (0.61-5.83)	0.3				
Thorax-only†	None	0.36 (0.11-1.09)	0.07				
Curtain only	None	1.43 (0.21-9.63)	0.7				
Tube	None	Omitted					

Note – weighted analysis: †OR: OR: 0.21, 95^{th}%CI: 0.05-0.94, p = 0.04;

The probability of sustaining an AIS 3+ lower extremity injury for occupants of PSI and V2V side impact crashes by ETS is presented in Figure 4.8. The probability of AIS 3+ lower extremity injuries is higher for those involved in PSI than V2V side impact crashes across the speed range. For instance, at 32 km/h, the probability of sustaining an AIS 3+ lower extremity injury for those involved in a PSI crash was 0.29 (29%) compared to 0.07 for occupants of V2V side impact crashes, while at 50 km/h the probability was 0.74 and 0.35 for PSI and V2V crashes respectively.

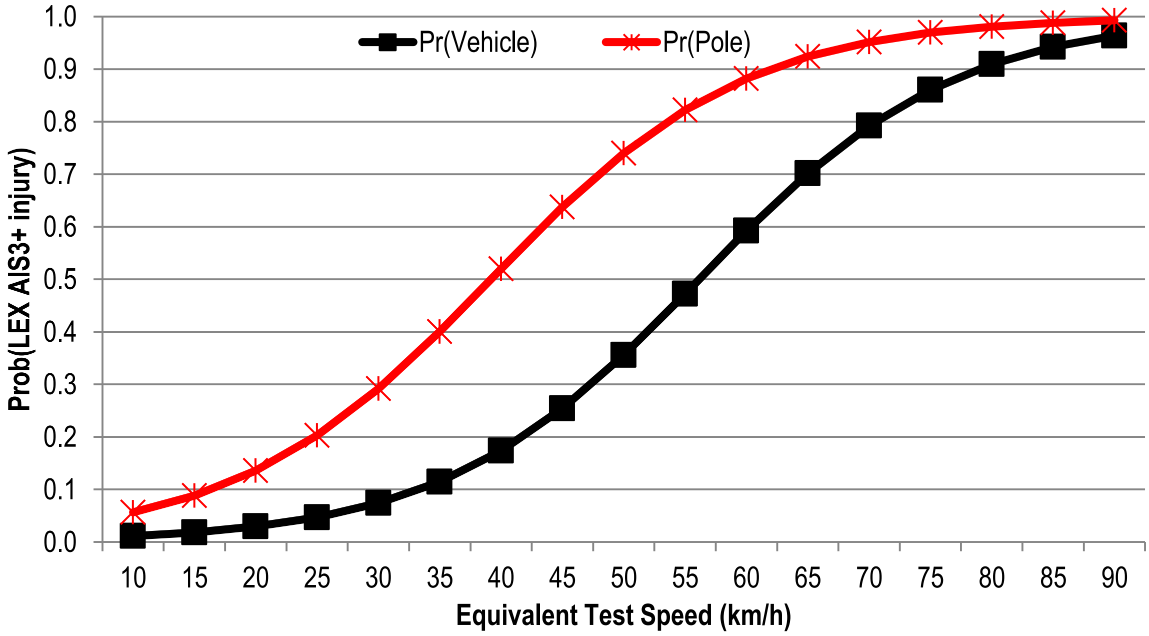


Figure 4.8 Probability of sustaining an AIS 3+ (serious) lower extremity injury in near-side (struck side) impacts with vehicles and poles/trees

4.3.4.3 Summary of injury outcomes

The probability of injury, given the mean ETS and age of involved occupants, is presented in Table 4.21 with their associated Odds Ratios. As discussed above, the probability of injury is higher in PSI than V2V impacts across most injury outcomes examined, further underlining the harm associated with PSI crashes.

Table 4.21 Probability and Odds Ratios for occupants involved in PSI and V2V side impact crashes

Overall severity	Pole side impact	Vehicle-to-vehicle	OR (95% CI)	P
Major Trauma	0.31	0.07	**4.17** (1.24-13.98)	<0.001
Killed	0.15	0.03	**4.37** (1.01-18.91)	0.048
Body region and AIS 2+ and AIS 3+ injuries				
Head AIS 2+	0.38	0.13	**2.98** (1.10-8.05)	0.03
Head AIS 3+	0.34	0.07	**5.15** (1.74-15.29)	0.003
Face 2+	0.03	0.02	2.09 (0.11-36.44)	0.6
Neck 2+	0.06	0.03	1.98 (0.25-15.5)	0.5
Thorax 2+	0.72	0.17	**4.28** (1.07-1.15)	<0.001
Thorax 3+	0.46	0.12	**3.87** (1.31-11.42)	0.01
Ab-Pelvis 2+	0.76	0.35	2.14 (0.76-6.01)	0.1
Ab-Pelvis 3+	0.10	0.11	0.93 (0.19-4.44)	0.9
Upper Ext. 2+	0.30	0.07	**4.05** (1.31-12.47)	0.01
Lower Ext. 2+	0.30	0.07	**4.13** (1.39-12.27)	0.01
Lower Ext. 3+	0.13	0.03	**4.79** (1.22-18.79)	0.02

4.4 Key findings and Summary

The primary objective of the analysis of the CCIS in-depth data was to determine the nature of injuries sustained in side impact crashes and the extent of differences, if any, in the injury outcomes of occupants involved in pole side impact crashes compared to those involved in vehicle-to-vehicle side impact crashes. The analysis highlighted a number of key points:

- Of the side impact crashes within the case selection criteria in the UK CCIS database, 88% were vehicle-to-vehicle crashes and 12% PSI crashes.
- For occupants involved in PSI crashes, approximately 28% of occupants sustained an AIS 3+ injury of the head (cf. 5% V2V) and also the thorax (cf. 8%), with AIS 3+ injuries of the lower extremity (19%; cf. 3% V2V) and abdomen-pelvis (~11; cf. 5% V2V) being prominent.
- Pole side impact crashes were associated with significantly higher likelihood of injury and death than vehicle-to-vehicle side impacts, specifically:
  - Involvement in pole side impact crashes was associated with a higher odds (and probability of injury) of serious head, thorax, upper extremity and lower extremity injuries (defined as AIS 3+ injuries);
  - Pole side impact crashes were associated with a four times higher odds of death and major trauma (ISS>15);
  - The probability of sustaining a serious (AIS 3+) injury was as high as 0.46 in PSI (cf. 12% for V2V) in the case of the thorax, and
  - The observed probability of sustaining a serious head injury was 0.34 (i.e., 34%) in PSI crashes compared to 0.07 (7%) for vehicle-to-vehicle side impact crashes.
- Regardless of collision object, head plus curtain airbags offered significant injury reduction benefits for head injuries, and appeared to offer better protection than combination head-thorax airbags.
- Increasing age was a risk factor for increased likelihood of thorax, abdominal / pelvis and lower extremity injuries, but not the head.
- Females were more at risk of injuries to the abdomen-pelvis and lower extremity than were males.
- The volume of missing occupant height and weight data meant that these variables could not be examined.

Based on the analysis of UK CCIS in-depth data, it is clear then that PSI carry a significantly higher burden of injury than vehicle-to-vehicle side impact crashes; however V2V impacts represent the majority of available cases in the database.

While the number of available occupant cases available for analysis was relatively small (PSI, n = 36; V2V, n = 263), the magnitude of the difference between the two crash impact groups is significant. Notwithstanding the difference in the risk of injury overall, the head and thorax were the body regions most susceptible to injury in both PSI and V2V side impact crashes.

It must be noted that the inclusion criteria were highly focussed and these results are applicable to recent vehicles (MY 2000+) where side impact standards are applicable (i.e., ECE R95) and EuroNCAP side impact crash tests are performed.

Appendix A4 Derivation of weighting factors based on STATS19

Using STATS19, weighting factors were derived for application to the CCIS case data. This data was obtained from TRL Ltd report PPR-501, *Side Impact Safety* by Edwards et al. [38] The report investigated options for enhanced side impact protection to contribute to the development of UK policy and its contribution to EEVC activities.

The weights were derived by Mr Richard Cuerden, TRL Ltd, specifically for the analysis performed here. The weighting factor applied and used in Table 4.14 was that based on CCIS injury severity and presented in Table A4.2. As STATS 19 does not report on the number of uninjured road-users, a weighting factor cannot be derived. The weighting factors derived from police reported severity of the CCIS crashes were similar to the CCIS coded injury severity.

Table A4.1 Distribution of STATS19 car occupant side impact casualties (2006-2007)

Impact Type	All Car Occupant Injury Severity			Total
	Fatal	Serious	Slight	
Car / LGV-Car	237 (0.64%)	1,763 (4.7%)	35,174 (94.6%)	37,174 (100%)
HGV / PSV-Car	67 (1.6%)	215 (5.2%)	3,870 (93.2%)	4,152 (100%)
Other-Car	442 (2.2%)	2,294 (11.5%)	17,223 (86.3)	19,959 (100%)
Multiple-Car	415 (2.3%)	1,951 (10.6%)	15,988 (87.1%)	18,354 (100%)
Total	1,161 (1.5%)	6,223 (7.8%)	72,255 (90.7%)	79,639 (100%)

Source: Table 2-10, Edwards et al.[38]

Table A4.2 CCIS Severity and reference to STATS19

Injury severity	Sample from CCIS	Sample in STATS19	Weighting factors
Fatal	136	1,161	8.54
Serious	382	6,223	16.29
Slight	906	72,255	79.75
Uninjured	311	-	

Note: CCIS variable *OCSEVCIS*

Table A4.3. Police Severity and reference to STATS19

Injury severity	Sample from CCIS	Sample in STATS19	Weighting factors
Fatal	137	1,161	8.47
Serious	347	6,223	17.93
Slight	1027	72,255	70.36
Uninjured	201	-	
N/K	23		

Note: CCIS variable OCSEVCIS

5 INCIDENCE AND BURDEN OF SIDE IMPACT CRASHES IN AUSTRALIA

This section of the report presents information concerning occupants killed in road crashes in Australia. The analysis provides the basis for the assessment of the safety need for enhanced side impact protection for Australia. The Australian *Fatal Road Crash Database (FRCD)* was used to document the number of side impact crashes and associated injuries for the period 2001 to 2006 inclusive. Data pertaining to side impact crashes in the Australian States of Tasmania, Queensland and Victoria is presented, and forms the basis of a national side impact fatality estimate for 2007 to 2009 inclusive.

5.1 Fatality crashes in Australia

Fatality data represents a key way of understanding the societal burden of crashes. Australia is fortunate in that it collects an extensive range of data on all deaths due to road crashes that occur on public roads. The *Fatal Road Crash Database* (FRCD) is maintained by the Victorian Institute of Forensic Medicine under agreement with the Australian Department of Infrastructure and Regional Development. For the purposes of this report, the principal objective is to understand both the magnitude of road deaths in Australia due to side impact crashes – and their attendant circumstances, and causes of death. This then provides the basis of understanding the financial cost to the Australian community of deaths associated with side impact crashes.

5.1.1 Description of the Fatal Road Crash Database (FRCD)

The FRCD represents a national census of all deaths that occur on public roads in Australia. The basis for the database is police-reported crashes, as every unnatural death must be reported to the Police in the jurisdiction where the death occurs. The FRCD draws together a number of disparate information sources concerning the road crash and all associated occupants, including those that survive.

The FRCD is integrated with the *National Coroners Information System (*www.ncis.org.au/*)* and thus relies on Coronial records of each death. For each death, the cause of death is specified by the investigating Coroner. Specific reports for each crash and associated death include[39]:

1. Police report of the crash;
2. Vehicle inspection report;
3. Autopsy report;
4. Toxicology report (for alcohol and other drugs, medications);
5. Other specialist reports, including Police Major Collision Squad Investigations, and
6. Coronial Inquest Brief / Report.

The FRCD includes 231 variables and includes specific information concerning the crash, the person, and the involved vehicle. At the time of the research, data was available for the period 2000 to 2006 inclusive, although data for the period 2001 – 2006 was used.

Access to the FRCD requires approval by the Victorian Department of Justice Research Ethics Committee, and an Access Agreement to be signed between the Researcher and the Victorian Institute of Forensic Medicine (VIFM). Approval was also obtained from the Monash University Human Research Ethics Committee.

5.1.2 Definitions

The definitions adopted in the analysis presented were:

- Fatality – defined as deaths on a public road, where the death occurred within 30 days of the crash
- Vehicle categories:

- M1 includes power-driven vehicles having at least four wheels and used for the carriage of passengers and comprising not more than eight seats in addition to the driver's seat, and
- N1 includes power-driven vehicles having at least four wheels and used for the carriage of goods and having a maximum mass not exceeding 3.5 tonnes.

5.1.3 Vehicle occupant fatalities

Analysis of the *Australian FRCD* indicates that 5761 occupants of M1 / N1 passenger vehicles were killed in the period 2001 to 2006. Fatalities due to side impact crashes represent 36.4% of the total number of M1 / N1 occupants killed, with fatalities due to side impact crashes against narrow objects such as poles and trees accounting for 15.6% (n = 898) of the total number of fatalities in M1 / N1 vehicles, or 9.1% of all road deaths in Australia. Notably, 91.8% of occupants killed in pole side impacts were occupants of M1 vehicles with 8.2% being occupants of N1 vehicles[5]. It is important to note the large number of occupants killed due to other (non narrow object) side impact crashes.

Fatalities associated with side impact crashes cost the community $AU 10.3 billion over the 6-year period, with pole side impact crashes accounting for 43% of this economic cost. On an annual basis, an average of 350 M1 and N1 occupants are killed in side impact crashes, with an average of 150 deaths due to pole side impacts.

Table 5.1 Number of M1 / N1 occupant fatalities in Australia, 2001 – 2006 by impact direction and cost

Impact direction	Period 2001 - 2006			Per Annum		Summary (2001-2006)		
	N	**Percent**	**Cost (bn., $AU) †**	**Number**	**Cost (bn., $AU) †**	**As % all road crash deaths**	**Rate (pop)**	**Rate (M1/N1 vehicles)**
Frontal	1909	33.1%	$9,430	318	$1,571	19.3%	1.59	0.26
Side - Other	1197	20.8%	$5,914	200	$0.985	12.1%	1.00	0.16
Side - Pole	**898**	**15.6%**	**$4,434**	**150**	**$0.739**	**9.1%**	**0.75**	**0.12**
Rear	123	2.1%	$0.605	20	$0.100	1.2%	0.10	0.02
Rollover	1367	23.7%	$6,751	228	$1,125	13.8%	1.14	0.18
Roof	163	2.8%	$0.805	27	$0.134	1.7%	0.14	0.02
Other	15	0.3%	$0.074	3	$0.012	0.2%	0.01	0.00
Natural Causes	89	1.5%	$0.437	15	$0.072	0.9%	0.07	0.01
Total	5761	100.0	$28,453	960	$4,742	58.3%	4.79	0.77

† Department of Finance and Deregulation. Best Practice Regulation Guidance Note: Value of statistical life. Canberra: Office of Best Practice Regulation, Australian Government, 2008[40]; value used was $AU 4,938,964.[40-42]

55 M1 includes cars and vehicles based on car designs; N1 includes vehicles up to 3.5t GVM.

5.1.4 Fatality trends over time (2001-2006)

A total of 898 occupants of M1 and N1 vehicles were killed in pole side impact crashes in the period 2001 – 2006. As in the UK (see Chapter 3.3, pp.27-28), there is reason to believe that innovations in road safety policy and improved impact protection will have a beneficial effect in reducing the fatality rate over time.

Figure 5.1 presents the fatality rate per 100,000 persons in the population for occupants of M1 and N1 vehicles over time. Poisson regression accounting for the population indicates a 5% average per annum reduction in the overall vehicle fatality rate in the period (IRR: 0.95, 95% CI: 0.94-0.97, $p<0.001$). There are notable fatality reductions across each impact configuration, specifically:

- A 12% p.a. reduction in frontal impact fatalities (IRR: 0.88, 95% CI: 0.86-0.92, $p<0.001$);
- A 11% p.a. reduction in other (non-pole) side impact fatalities (IRR: 0.89, 95% CI: 0.86-0.92, $p<0.001$);
- A 13% p.a. reduction in PSI fatalities (IRR: 0.87, 95% CI: 0.83-0.91, $p<0.001$), however this is driven by the reduction from 2001 to 2003 with no change from 2003-2006, and
- A non-statistically significant 2% p.a. reduction in rollover fatalities (IRR: 0.98, 95% CI: 0.96-1.01, $p=0.4$).

An important comparison can be made between the fatality rate due to PSI and non-PSI side impact crashes. There is a clear convergence of the fatality rate in these two impact configurations, but notably no change in the fatality rate associated with PSI since 2003. That few (0.2%, n = 5) had a side airbag deployment could be a consequence of low penetration in to the vehicle fleet more generally at this time, the effectiveness of side impact airbags - hence occupants are less likely to be killed, and / or the effects of structural improvements associated with ADR 72 / UN ECE R95; it is important to note that ESC had extremely low vehicle penetration and this is presented in Chapter 8.

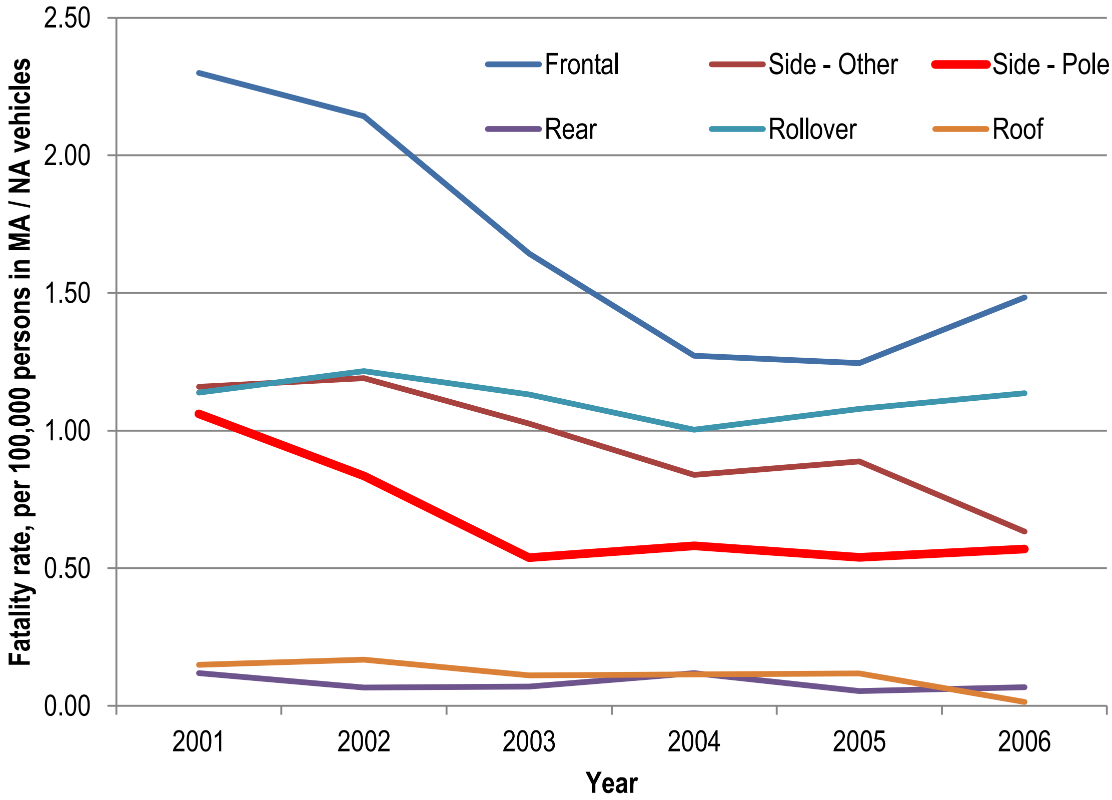


Figure 5.1 Fatality rate (per 100,000 persons) by impact configuration and calendar year

The reduction in the per-population fatality rate is mirrored by the reduction in the fatality rate per number of registered vehicles (Figure 5.2). The findings are as follows:

- An overall 5% reduction in the overall per vehicle fatality rate (IRR:0.95, 95% CI: 0.94-0.97, $p<0.001$);
- A 12% p.a. reduction in the frontal impact fatality rate (IRR: 0.88, 95% CI: 0.86-0.92, $p<0.001$);
- An 11% p.a. reduction in the 'other' (non pole) side impact fatality rate (IRR: 0.89, 95% CI: 0.86-0.92, $p<0.001$);
- A 13% p.a. reduction in PSI fatalities (IRR: 0.87, 95% CI: 0.83-0.91, $p<0.001$), however this is driven by the reduction from 2001 to 2003 with no change from 2003-2006, and
- A 2% p.a. average reduction in rollover fatalities (IRR: 0.98, 95% CI: 0.96-1.02, $p=0.4$).

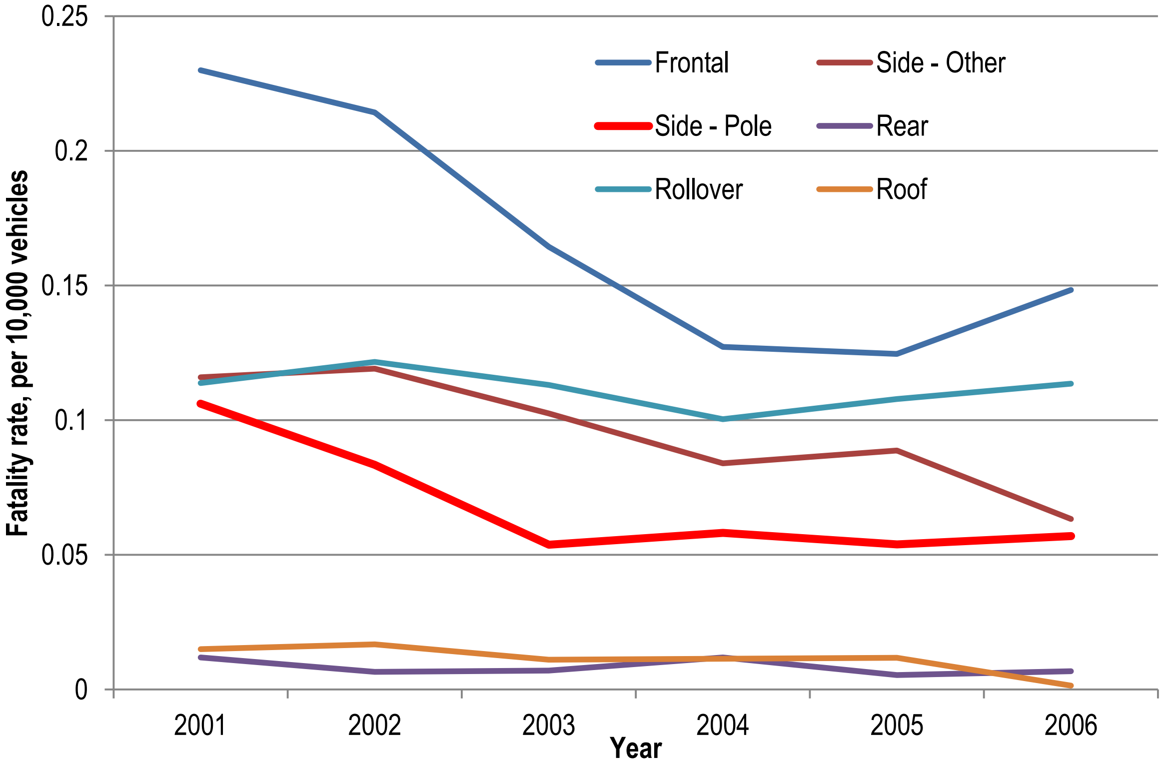


Figure 5.2 Fatality rate (per 10,000 M1 vehicles) by impact configuration and calendar year

Given the largely uniform fatality rate reductions, little change in the relative proportions of fatalities across the period can be expected with the exception of rollover crashes. As can be observed in Figure 5.3, fatalities associated with rollover crashes account for an increasing proportion of deaths; this is the case as the fatality reductions on a per vehicle basis and a per population basis was a non-statistically significant 2% while the other impact configurations experienced rate reductions ranging from 11% to 13%.

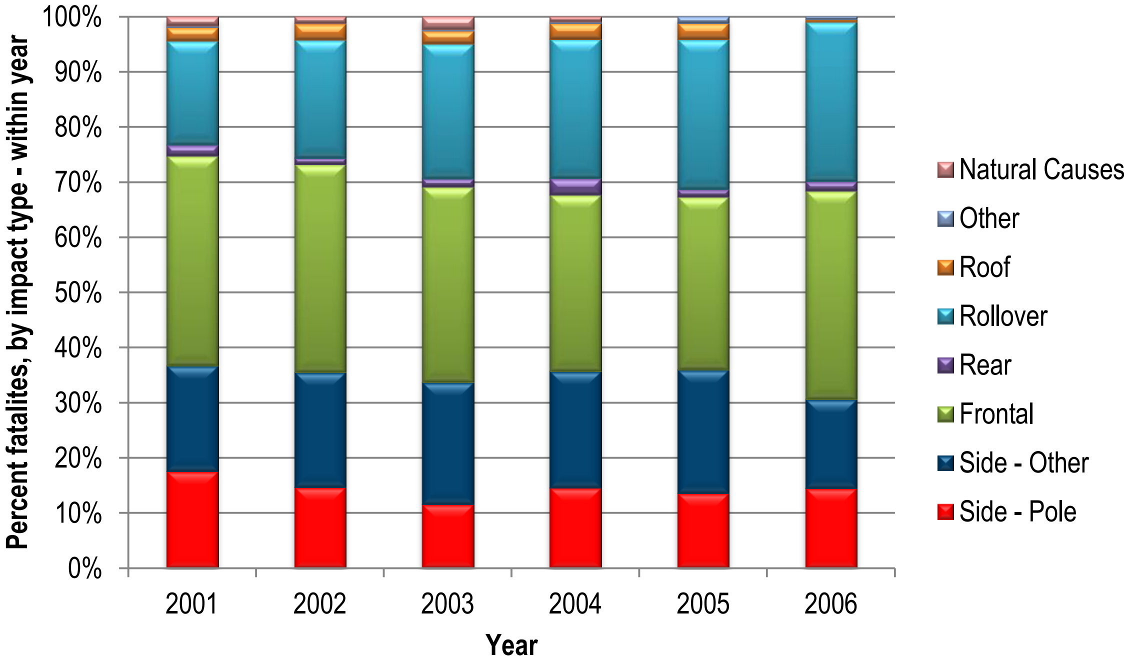


Figure 5.3 Percent of M1 / N1 fatalities by impact configuration and calendar year

The proportion of fatalities associated with pole side impact crashes as a function of all side impact fatalities, all fatalities in M1 / N1 vehicles and all road crash fatalities in Australia is presented in Figure 5.4. Between 2001 and 2006 fatalities due to pole side impact crashes accounted for 45% of all side impact deaths (cf. UK of 20%, see Chapter 3), 12% of all fatalities in Class M1 / N1 vehicles (cf. UK of 10%) and 9.1% of all road crash fatalities in Australia (cf. UK of 4.5%).

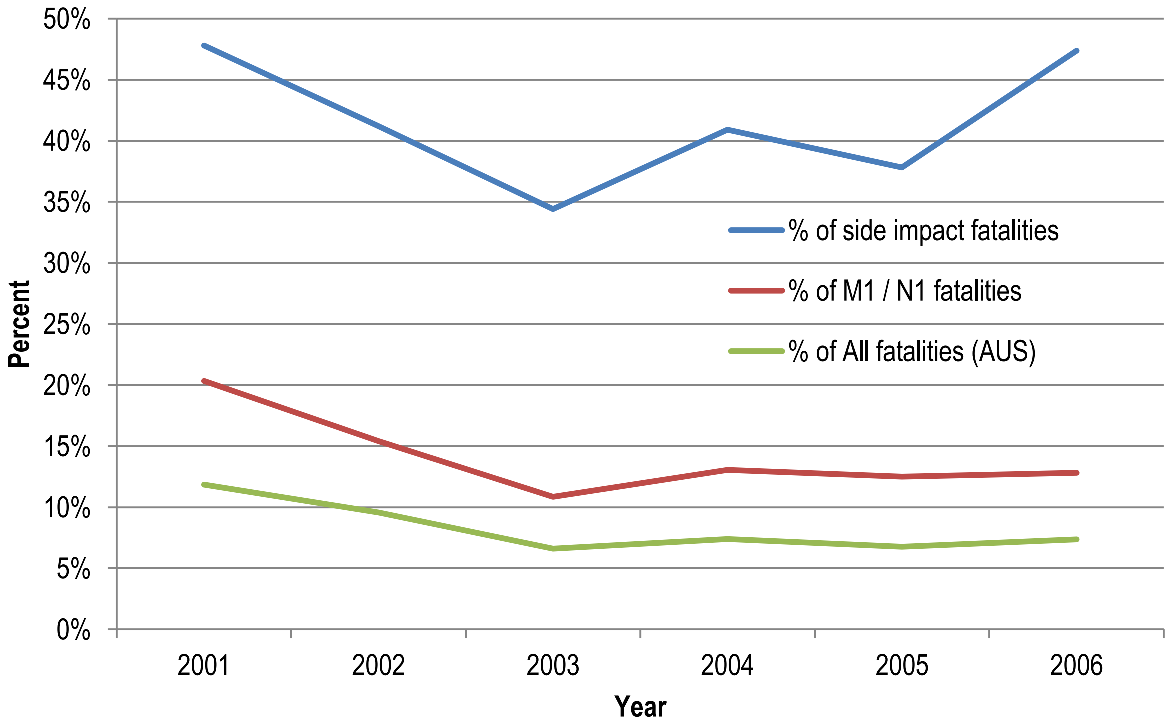


Figure 5.4 Percent of PSI fatalities as a function of fatalities in side impact crashes, all M1/N1 crashes and all fatalities in Australia

5.1.5 Cause of death

As the FRCD is essentially a coronial reporting system, the database contains robust information concerning the cause of death[6] of each fatality case which relies on the *Medical Certificate of Cause of Death,* coded using ICD-10 injury and External Cause codes (E-codes).[44, 45] This data is of particular value when combined with detailed information of the crash circumstance and occupant characteristics.

Data screening indicated that the availability of airbag systems, be they frontal or side impact airbags, was very low. Side airbags were known to be available and deployed for only 13 cases, of which two were for occupants involved in PSI crashes, 3 in vehicle-to-vehicle side impact crashes, 4 in rollover crashes and the balance among other crash types (including multiple impact crashes). Given the small number of cases of definite side airbag airbag deployment[7], it was considered opportune to examine fatalities where side airbags were unavailable, thereby establishing a baseline for the prioritisation of injury countermeasures. Frontal airbags deployed for 12% of frontal impact occupants.

Table 5.2 and Figure 5.5 presents Coroner ruled cause of death for frontal, PSI and other side impact crash-involved occupants of M1 and N1 vehicles; side impact crashes include 'struck-side' and 'non-struck side' occupants.[8] Injuries to the head, the thorax and multiple regions were the three leading causes of death as ruled by the Coroner. There were marked differences between frontal (42.9% of occupants killed), PSI (54.2% of occupants killed) and other side impact crashes (47.8%) occupants with a head injury as cause of death. It is important to note that a similar proportion of fatalities were classified as having sustained 'multiple injuries'[9], which mostly includes a head injury plus injuries to one or more body regions (~ 37%); this could mean that 92% of PSI deaths were associated with severe head injury.

Table 5.2 Coroner ruled causes of death for frontal, pole side impact and other side impact crashes for occupants of M1 / N1 vehicles combined, 2001 – 2006.

Coroner ruled cause of death	**Frontal**	**PSI**	**Side – other**
	% of 1272 occupants	% of 616 occupants	% of 795 occupants
Head	42.9%	54.2%	47.8%
Face	12.3%	9.9%	6.2%
Neck	8.3%	8.0%	9.4%
Thorax	42.1%	36.4%	43.0%
Abdominal/pelvic	22.4%	25.0%	25.9%
Spine	9.8%	7.5%	10.9%
Upper extremity	10.6%	11.0%	7.5%
Lower extremity	16.4%	11.0%	8.9%
External	4.8%	1.9%	1.3%
Multiple	36.7%	37.8%	36.1%
Injury not specified	2.8%	2.4%	2.3%

6 Cause of death is specified by the Coroner in his/her 'Findings' following autopsy and / or other investigations including medical records and Medical Practitioner reporting of the cause of death. In the coding of deaths: 'Deaths resulting from external causes require the information surrounding the circumstances of injury to be reported. This includes the place of incident and activity. There is no time frame on when the injury occurred as long as there is a direct link between the injury or condition and the death' (p.121) 43. National Coronial Information Service. National Coronial Information System Coding Manual and User Guide, Version 4.0. Melbourne: Victorian Institute of Forensic Medicine; 2010. Cause of death was known for 1272 (84.5%) of frontal impact occupants, 795 side-other impact occupants (84.2%) and 616 (87%) pole side impact occupants; occupants can have multiple injuries specified as cause of death; note – where specified as 'multiple', no specific region is provided.

7 *Note: airbag status was unknown for 49% of cases, and these are included in the analysis.*

8 Cause of death was not coded available for 637 frontal, 282 PSI and 402 other side impact occupants

9 The autopsy reports of a random sample of 5% of PSI cases with 'multiple injuries' coded as COD were examined and all 12 cases (100%) had a head injury noted as COD.

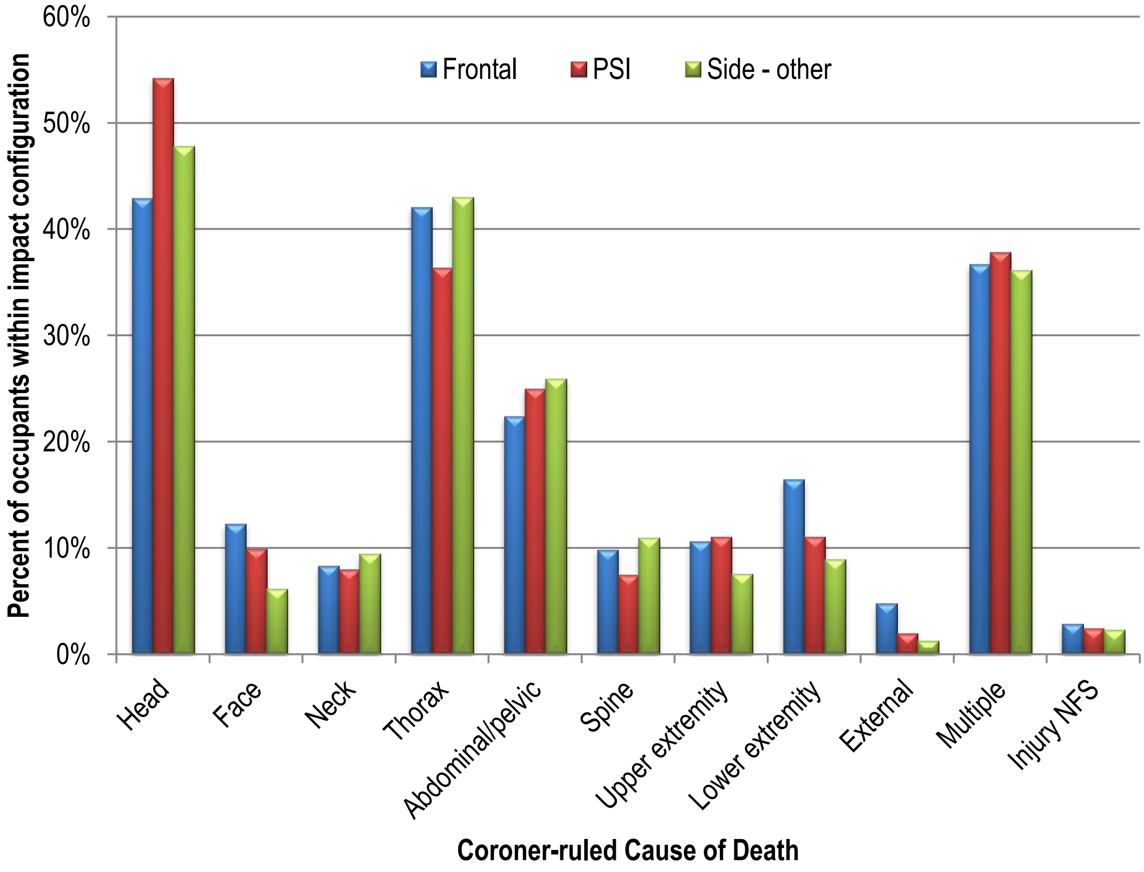


Figure 5.5 Coroner ruled causes of death for frontal, pole side impact and other side impact crashes for occupants of M1 / N1 vehicles combined

The analysis on causes of death combined fatalities that occurred in M1 and N1 passenger vehicles. In the development of the PSI GTR, there is interest in including both M1 and N1 vehicle types (Category 1 and Category 2 vehicles under Special Resolution 1 of the UNECE 1998 Agreement) in the scope of the GTR.

The Coroner ruled *Cause of Death* for occupants killed in frontal, PSI and other side impact crashes for M1 and N1 vehicles is presented in Table 5.3 and Figure 5.6. While injuries to the head, thorax and to multiple regions were the leading causes of death as ruled by the Coroner, there is considerable variation across the impact configurations. Over half of the fatalities that occurred as a result of PSI crashes sustained a head injury resulting in death (M1: 54%; N1: 56% of occupants) compared to frontal crashes where 43% and 41.8% of M1 and N1 vehicle occupants sustained a similar injury. Interestingly, a smaller proportion of PSI fatalities were ruled as having sustained a 'fatal' thorax injury than did occupants killed in frontal and other side impact crashes. A noticeably high proportion of occupants killed in N1 vehicles involved in PSI crashes were coded as having sustained fatal injuries to multiple body regions, which as noted above most usually includes a catastrophic head injury.

These findings highlight two things: first, injuries to the head represent the primary cause of death, and second, that PSI crashes are associated with a higher incidence of fatal head injuries than frontal and other side impact crashes. This is true for both M1 and N1 vehicles involved in side impact crashes.

Table 5.3 Coroner ruled causes of death for frontal, pole side impact and other side impact crashes for occupants of M1 and for N1 vehicles

Coroner ruled cause of death	M1 vehicles			N1 vehicles		
	Frontal	PSI	Side - other	Frontal	PSI	Side - other
	% of 1071 occupants	% of 566 occupants	% of 735 occupants	% of 201 occupants	% of 50 occupants	% of 60 occupants
Head	43.1%	**54.1%**	47.3%	41.8%	**56.0%**	53.3%
Face	13.4%	10.1%	5.9%	6.5%	8.0%	10.0%
Neck	8.5%	8.3%	9.4%	7.5%	4.0%	10.0%
Thorax	41.8%	36.2%	43.1%	43.3%	38.0%	41.7%
Abdominal/pelvic	21.8%	25.3%	26.3%	25.4%	22.0%	21.7%
Spine	10.3%	7.6%	10.7%	7.5%	6.0%	13.3%
Upper extremity	9.8%	10.6%	7.5%	14.9%	16.0%	8.3%
Lower extremity	16.1%	11.1%	9.0%	18.4%	10.0%	8.3%
External	4.5%	1.8%	1.4%	6.5%	4.0%	Nil
Multiple	35.9%	37.1%	36.1%	41.3%	46.0%	36.7%
Injury NFS	3.2%	2.7%	2.4%	1.0%	Nil	Nil

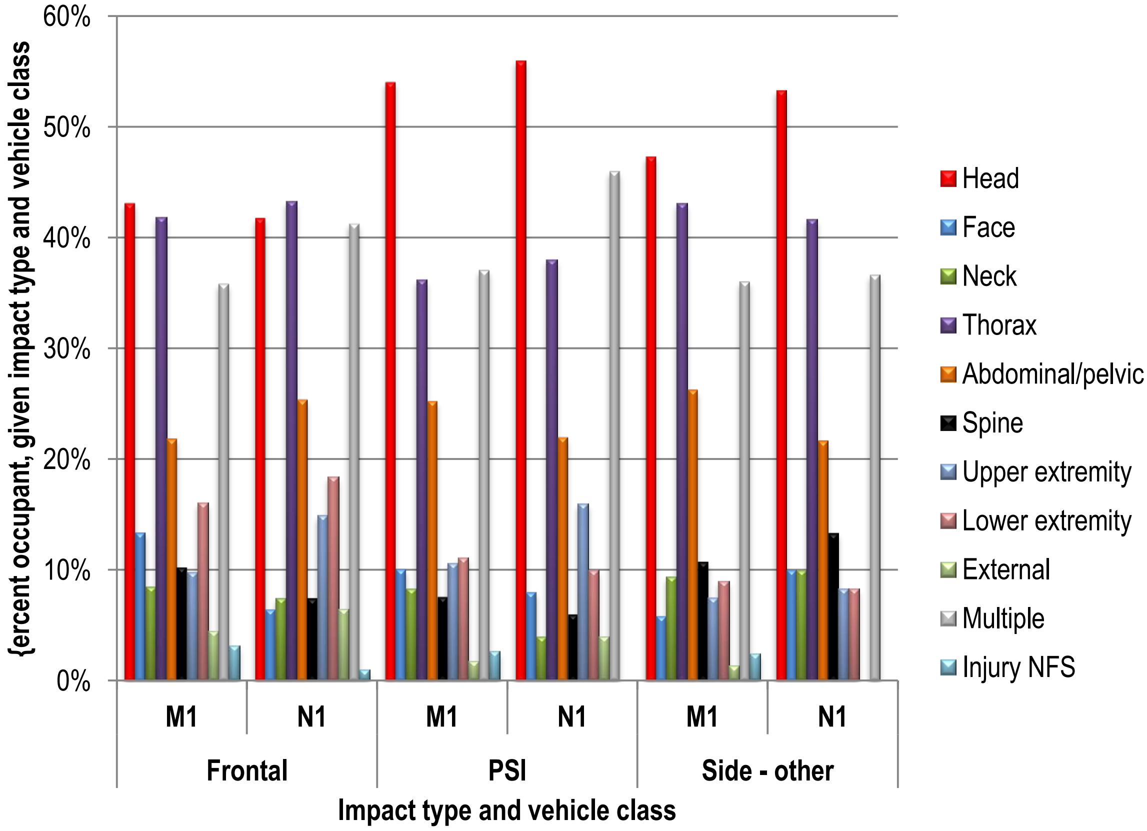


Figure 5.6 Coroner ruled causes of death for frontal, pole side impact and other side impact crashes for occupants of M1 and N1 vehicles

Head and face injuries as causes of death

Injuries of the head and face are of prime interest for a number of reasons: serious injuries to these regions are associated with high levels of morbidity among survivors; they are associated with high mortality rates, and they carry considerable financial cost implications for the community with lifetime care costs being high[14]. With advanced side impact protection countermeasures, including airbags, there is an opportunity for these injuries to be mitigated.

Figure 5.7 presents the percent of occupants involved in frontal, vehicle-to-vehicle side impact crashes, and pole side impact crashes who sustained a head injury, face injury, or both injuries where these were classified as the cause of death; this excludes occupants classified by the Coroner as having sustained 'multiple injuries' (as the cause of death). Approximately 56% of PSI occupants sustained an injury to the head and / or face, which was classified as the cause of death, in contrast to 49% and 45% of occupants involved in other side impact crashes and frontal crashes.

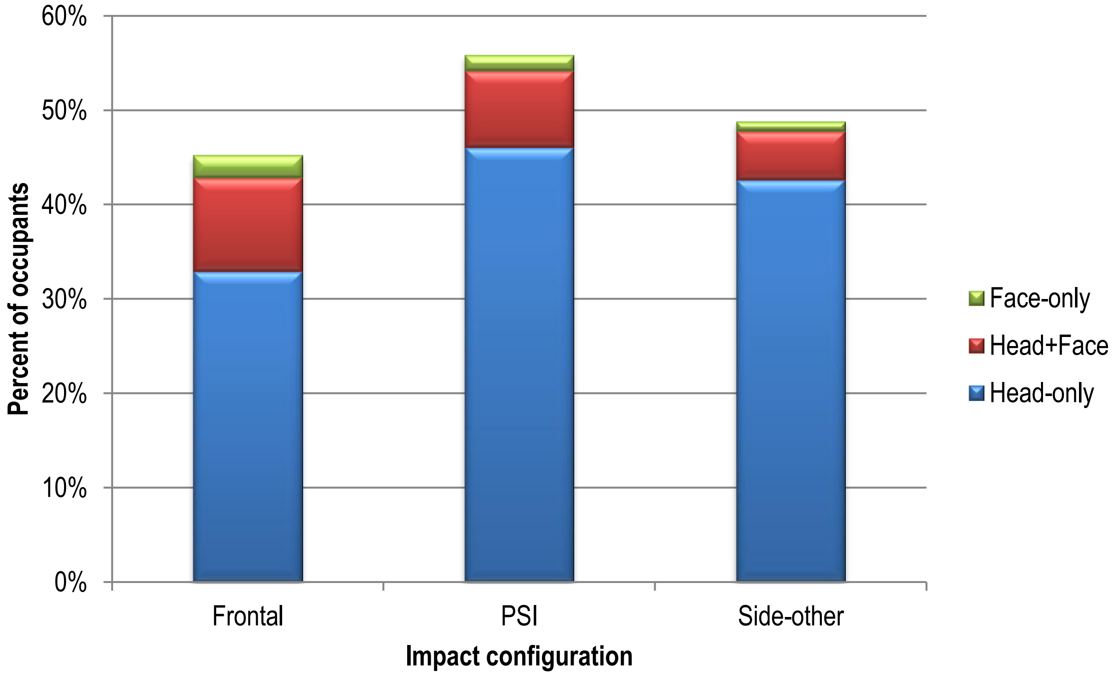


Figure 5.7 Percent of occupants with cause of death specified as head-only, face-only or both, by impact configuration

While Figure 5.7 demonstrates that a higher proportion of occupants involved in PSI are classified as having an injury of the head and/or face as a *cause of death,* Figure 5.8 disaggregates this further into vehicle class. Occupants of M1 and N1 vehicles killed in PSI had similar rates of head and/or face injuries as a *cause of death. However* a higher percentage of occupants of N1 vehicles involved in side impacts with other collision partners sustained head / face injuries as the cause of death (55%) than M1 vehicle occupants (~48%). These proportions are also higher than M1 (~45%) and N1 (42%) occupants killed in frontal impacts.

These findings clearly highlight the need for head protection for both M1 and N1 vehicle occupants in side impact crashes generally. It is clear then that any enhanced protection required to meet pole side impact GTR performance requirements may also address a more generalised need for side impact head protection.

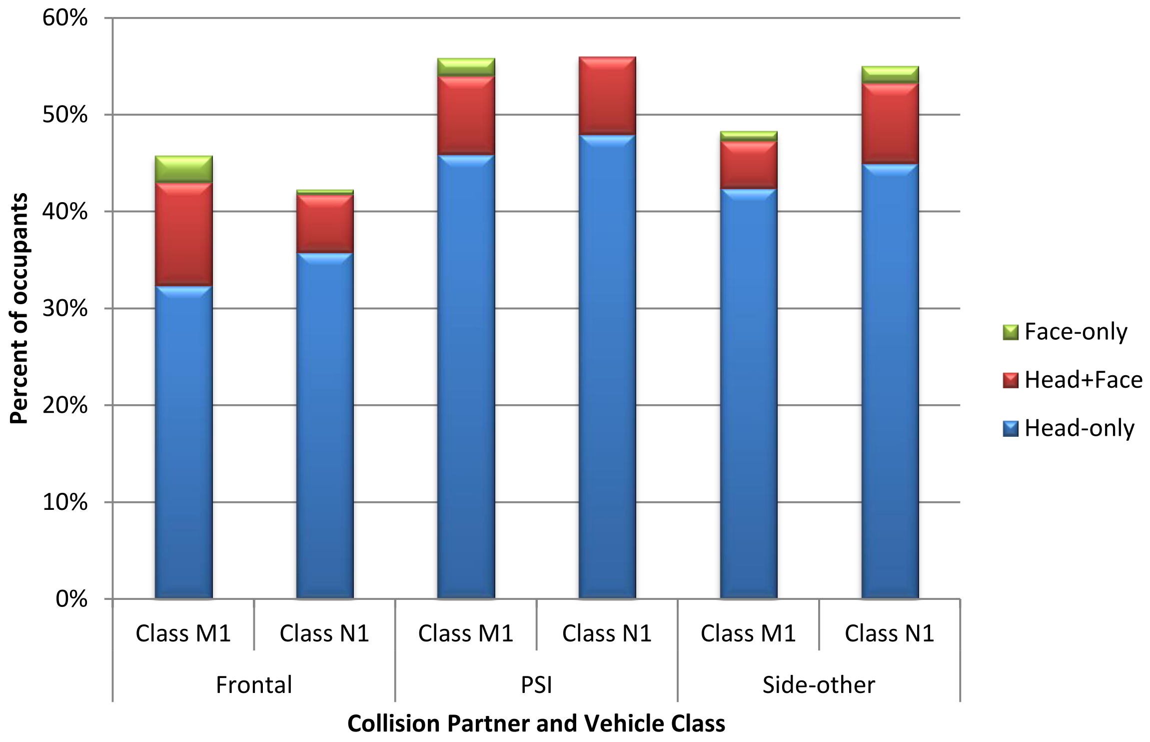


Figure 5.8 Percent of occupants with cause of death specified as head-only, face-only or both, by impact configuration and vehicle class

5.1.6 Australian Fatality data - Key findings and Summary

Fatalities due to side impact crashes represent 36.4% of the total number of M1 / N1 occupants killed, with fatalities due to side impact crashes against narrow objects such as poles and trees accounted for 15.6% (n = 898) of the total number of fatalities in M1 / N1 vehicles, or 9.1% of all road deaths in Australia. Most of the occupants killed in pole side impacts were occupants of M1 vehicles (91.8%). There were also a large number of occupants killed due to other (non narrow object) side impact crashes.

Side impact fatalities cost the community $AU 10.3 billion over the 6-year period, with pole side impact crashes accounting for 43% of this economic cost. On an annual basis, an average of 350 M1 and N1 occupants are killed in side impact crashes, with an average of 150 deaths due to pole side impacts. Trend analysis indicates reductions in the fatality rate have been achieved, although the reductions in PSI fatalities reached a plateau from 2003 to 2006.

Side airbags were known to be available and have deployed in only 0.3% of side impact fatalities (n=5) and 13 cases overall, with the status of airbags unknown for 49% of cases as the data was not collected. It is the case though that airbag penetration rates in the 2001 – 2006 period were extremely low. The data is useful for presenting a 'base case' against which the effects of improved safety can be assessed. Analysis of the Coroner ruled cause of death data indicated that head injuries were the most common cause of death, with 55% of PSI deaths sustaining a 'fatal' head injury, and this was higher than for occupants killed in frontal impacts (44%) and other side impact crashes (49%). Injuries to multiple body regions were also noted to be a common cause of death, and these frequently include injuries to the head and one or more body regions. The pattern of injuries was similar in Class M1 and Class N1 vehicles, with head injuries being the most common cause of death in PSI for both vehicle types (~55% of occupants).

5.2 Fatalities and injuries associated with side impact crashes in Tasmania, 2000 - 2009

The Australian State of Tasmania (2.4% of the national population[31] and 4.2% fatalities in Australia[32]) was able to supply accurate data relating to the number of occupants of Class M1 and Class N1 vehicles killed in pole side impact crashes. Despite representing only a small proportion of the national population, the data is informative with regard to the percent of fatalities and serious injuries PSI represent as a function of M1 / N1 fatalities and the overall fatality and serious injury number.

PSI fatalities account for, on average 22.4% of M1 / N1 fatalities and 13.9% of all road user fatalities in Tasmania; in contrast, the Australian PSI proportion is approximately 12% for M1/N1 fatalities and 9.1% of all persons killed in road crashes in Australia. Serious Injuries from PSI crashes represent 14% of all seriously injured occupants in M1/N1 vehicles and 8.1% of all seriously injured persons in the State (Table 5.4). The data did not include the total number of side impact crashes; hence it is not possible to determine the proportion of PSI relative to all side impact fatalities and injuries.

Table 5.4 Number of fatality and serious injury pole side impact crashes in Tasmania over the period 2000 to 2009, with the percent of all M1 / N1 occupants killed and rates per population and per vehicles registered shown

	Fatalities			**Serious Injuries**			**Per 100,000 pop.**		**Per 10,000 vehicles**	
Year	**Number M1/N1**	**% of M1/N1 killed**	**% of all killed**	**Number M1/N1**	**% of M1/N1 serious injuries**	**% of all serious injuries**	**Fatal**	**Serious Injury**	**Fatal**	**Serious Injury**
2000	3	12.0%	7.0%	29	9.4%	5.5%	0.64	6.17	0.10	0.98
2001	9	25.7%	14.8%	22	9.2%	4.7%	1.91	4.66	0.30	0.74
2002	4	21.1%	10.8%	26	10.6%	6.1%	0.85	5.50	0.13	0.87
2003	6	27.3%	14.6%	55	23.2%	14.0%	1.26	11.53	0.20	1.80
2004	10	25.0%	17.2%	27	12.2%	7.1%	2.07	5.59	0.32	0.85
2005	9	29.0%	17.6%	23	12.0%	6.2%	1.85	4.73	0.28	0.71
2006	6	14.3%	10.9%	28	15.2%	8.8%	1.22	5.71	0.18	0.84
2007	6	21.4%	13.3%	34	16.3%	10.3%	1.22	6.89	0.18	1.00
2008	9	32.1%	23.1%	24	14.2%	8.7%	1.81	4.82	0.26	0.69
2009	6	16.2%	9.4%	29	21.2%	10.0%	1.19	5.76	0.17	0.84
Av.	7	22.4%	13.9%	30	14.3%	8.1%	1.40	6.14	0.21	0.93

5.3 Fatalities and injuries associated with side impact crashes in Queensland, 2009

In 2009 the Australian State of Queensland represented 20.2% of the national population (4,466,458 of 22,131,177[31]) and 21.9% (331 of 1507[32]) of the number of road-users killed nationally. Examination of crash data from Queensland is valuable as it provides the basis, along with the crash data in Victoria, for estimating the number of occupants of M1 and N1 vehicles killed and seriously injured in Australia.

Table 5.5 presents the number of M1 and N1 occupants involved in crashes by injury severity, and by impact type for 2009. In 2009 in Queensland, 16 occupants were killed and 134 seriously injured in single vehicle side impact crashes into a fixed object such as a tree or pole; this represents 8% and 2.8% of the total number killed and injured in the period in M1 / N1 vehicles and 36.4% of side impact fatalities and 25.8% of side impact serious injuries respectively. The majority of PSI fatalities (75%) and serious injuries (88%) occurred in M1 vehicles.

Table 5.5 Number of killed and injured occupants of M1 and N1 vehicles, Queensland 2009

Class / injury severity	**All crashes**			**Single vehicle Crashes**				**% PSI of All Side**	**% PSI of All M1/N1**
M1, occupants	**Side Impact**	**Other**	**Total**	**Side Impact**	**Side / object†**	**Other**	**Total**		
Fatal	51	105	156	15	12	49	64	23.5%	7.7%
Admitted	1066	2963	4029	170	118	1236	1406	11.1%	2.9%
Not admitted - medical treatment	1530	4164	5694	159	102	1020	1179	6.7%	1.8%
Not admitted - minor injury	764	2145	2909	60	36	470	530	4.7%	1.2%
No injury	5868	12793	18661	450	300	1815	2265	5.1%	1.6%
Total	9279	22170	31449	854	568	4590	5444		
Class / injury severity	**All crashes**			**Single vehicle Crashes**				**% PSI of All Side**	**% PSI of All M1/N1**
N1, occupants	**Side Impact**	**Other**	**Total**	**Side Impact**	**Side / object†**	**Other**	**Total**		
Fatal	11	33	44	8	4	25	33	36.4%	9.1%
Admitted	123	556	679	37	16	316	353	13.0%	2.4%
Not admitted - medical treatment	173	627	800	36	17	255	291	9.8%	2.1%
Not admitted - minor injury/no treatment	125	362	487	18	10	122	140	8.0%	2.1%
No injury	1338	3345	4683	94	48	501	595	3.6%	1.0%
Total	1770	4923	6693	193	95	1219	1412		
Class / injury severity	**All crashes**			**Single vehicle Crashes**				**% PSI of All Side**	**% PSI of All M1/N1**
M1 / N1, occupants	**Side Impact**	**Other**	**Total**	**Side Impact**	**Side / object†**	**Other**	**Total**		
Fatal	62	138	200	23	16	74	97	25.8%	8.0%
Admitted	1189	3519	4708	207	134	1552	1759	11.3%	2.8%
Not admitted - medical treatment	1703	4791	6494	195	119	1275	1470	7.0%	1.8%
Not admitted - minor injury	889	2507	3396	78	46	592	670	5.2%	1.4%
No injury	7206	16138	23344	544	348	2316	2860	4.8%	1.5%
Total	11049	27093	38142	1047	663	5809	6856		

† Derived from run-off-road crashes into fixed object using Queensland Police Reported Crash Casualty Data

5.4 Fatalities and injuries associated with side impact crashes in Victoria 2007 - 2009

This section presents the number of occupants of M1 and N1 category vehicles killed, injured, or otherwise involved in a side impact crash against either another vehicle or a fixed object, with the latter being split into narrow fixed objects (i.e., pole, tree, traffic light) and 'other fixed objects' (i.e., embankment, wall etc...).

The side impact crashes involved damage to the left or right side of the vehicle but excluding damage described as 'front' / 'rear' right-left corner; the coding of crashes in the mass database is such that it is not possible to determine with complete certainty whether crashes with damage described as involving the 'corner' were a consequence of 'offset' type front / rear crashes, or whether the vehicle(s) were impacted in a perpendicular manner. The consequence of this is that the number of side impact fatalities and injuries is likely to be understated. Rollover crashes are also excluded, even if secondary to an initial side impact.

5.4.1 2007 side impact fatalities and injuries, Victoria

Table 5.6 presents the number of M1 and N1 occupants involved in side impact crashes by injury severity and impact partner for 2007. In 2007, 66 occupants were killed and 1195 occupants were admitted to hospital following involvement in a side impact crash. Side impact crashes are highly injurious, as indicated by persons killed accounting for 20% of the entire 2007 road toll (i.e., all persons killed in the State), and one-third of occupants of M1 and N1 vehicles. Of the occupants killed, 59% struck a narrow object. In contrast, 79% of M1 – N1 occupants admitted to hospital were struck by a vehicle.

Table 5.6 Number of killed and injured M1 – N1 occupants in side impact crashes, Victoria 2007[10]

	Side impact collision partner				**PSI as % of total side impact**	**Side impact as a % of all M1 – N1 occupants**	**Side impact as a % of all road users**
M1 / N1, occupants	**Vehicle**	**Pole**	**Other fixed**	**Total**			
Fatal injury	26 (0.9%)	39 (9.5%)	1 (1.7%)	66 (2.0%)	59%	31.6%	19.9%
Admitted to hospital	911 (32.6%)	253 (61.6%)	31 (53.4%)	1195 (36.6%)	21%	15.0%	10.4%
Injured – not admitted	422 (15.1%)	40 (9.7%)	10 (17.2%)	472 (14.5%)	8.5%	10.8%	7.7%
No injury	1438 (51.4%	79 (19.2%)	16 (27.6%)	1533 (46.9%)	1.0%	11.1%	10.0%
Total	2797 (100%)	411 (100%)	58 (100%)	3266 (100%)	12.5%	23.7%	9.8%

† Derived from run-off-road crashes into fixed object using Victoria Police Reported Crash Casualty Data

10 The data presented reflects crashes where vehicle damage was recorded to the passenger compartment. Only occupants of M1 and N1 category vehicles involved in vehicle-to-vehicle impacts or with a fixed object are presented; multiple impact crashes were excluded, as were rollover crashes. The benefits analysis first reported to the *Informal Group* (PSI-05-03 - (Australia) Analysis of in-depth and mass crash data to inform the development of the Pole Side Impact Global Technical Regulation, http://www.unece.org/trans/main/wp29/wp29wgs/wp29grsp/psimpact_5.html used a broader definition, and was more inclusive. Following feedback from the Informal Group, the benefits analysis presented in Section 8 of this Report uses only those crashes and injured occupants where the collision object directly engaged the passenger compartment and were seated in out-board positions.. This latter approach is considerably more restrictive and mimics more closely the intent of the proposed GTR and the test specification.

In numeric terms, more occupants were killed as a result of pole impacts (n = 39) compared to vehicle-to-vehicle impacts (n = 26), however the number of occupants admitted to hospital following a side impact crash with another vehicle was 3.6 times higher than pole side impact crashes (i.e., 911 cf. 253), highlighting the pressing need for improved side impact protection.

5.4.2 2008 side impact fatalities and injuries, Victoria

Table 5.7 presents the number of M1 and N1 occupants involved in side impact crashes by injury severity and impact partner for 2008. Side impact deaths account for 26% of the entire road toll, and 10% of persons seriously injured. Over 1300 occupants were admitted to hospital due to involvement in a side impact crash.

Table 5.7 Number of killed and injured M1 – N1 occupants in side impact crashes, Victoria 2008

	Side impact collision partner				PSI as % of total side impact	Side impact as a % of all M1 – N1 occupants	Side impact as a % of all road users
M1 / N1, occupants	**Vehicle**	**Pole**	**Other fixed**	**Total**			
Fatal injury	37 (1.32%)	38 (8.5%)	4 (6.0%)	79 (2.4%)	48.1%	42.7%	26.1%
Admitted to hospital	987 (35.3%)	297 (66.2%)	41 (61.2%)	1325 (40.0%)	22.4%	15.5%	10.7%
Injured – not admitted	360 (12.9%)	48 (10.7%)	9 (13.4%)	417 (12.65)	11.5%	12.0%	8.3%
No injury	1410 (50.5%)	66 (14.7%)	13 (19.4%)	1489 (44.9%)	4.4%	11.1%	9.9%
Total	2794 (100%)	449 (100%)	67 (100%)	3310 (100%)	13.6%	12.9%	10.1%

5.4.3 2009 side impact fatalities and injuries, Victoria

Table 5.8 presents the number of M1 and N1 occupants involved in side impact crashes by injury severity and impact partner for 2009. In contrast to 2007 and 2008, there were significantly lower side impact fatalities, as well as fewer persons admitted to hospital. Despite the overall lower number, there were comparatively fewer vehicle-to-vehicle side impact crashes, and hence, narrow object side impacts accounted for 55% of all side impact deaths. Side impact deaths represented 27% of all deaths in M1 and N1 category vehicles, and 17% of all deaths, which was lower than 2008 (cf. 26%) but similar to 2009 (19.9%).

Table 5.8 Number of killed and injured M1 – N1 occupants in side impact crashes, Victoria 2009

M1 / N1, occupants	Side impact collision partner				PSI as % of total side impact	Side impact as a % of all M1 – N1 occupants	Side impact as a % of all road users
	Vehicle	Pole	Other fixed	Total			
Fatal injury	19 (0.7%)	27 (6.3%)	3 (1.5%)	49 (1.5%)	55.1%	27.4%	16.9%
Admitted to hospital	879 (31.4%)	286 (66.7%)	26 (36.4%)	1191 (36.4%)	24.0%	14.2%	9.8%
Injured – not admitted	342 (12.2%)	45 (10.5%)	6 (12.5%)	393 (12%)	11.5%	10.5%	7.2%
No injury	1555 (55.6%)	71 (16.6%)	13 (27.1%)	1639 (50.1%)	4.3%	11.8%	10.7%
Total	2795 (100%)	429 (100%)	48 (100%)	3272 (100%)	13.1%	12.5%	9.9%

The above analysis indicates a downward trend in side impact fatalities and serious injuries, although there is considerable volatility from year-to-year. Certainly, deaths due to side impact crashes range from 16.9% to 26% of the total number of people killed, and approximately 10% of all persons admitted to hospital due to road crashes. The 2010 Victorian fatality and injury values form the basis of BCR calculations and are presented in Chapter 8.

5.5 Estimation of side impact fatalities and injuries in Australia, 2007-2009

5.5.1 Victorian based national estimates

Using crash and injury data from Victoria (Vic) - which represents 24.7% of the national population[31] and 25.91% of all registered passenger cars and light commercial vehicles[13], a national fatality and serious injury estimate for the year 2009 can be derived. Estimates were derived using known population values from the Australian Bureau of Statistics (Table 5.7, Estimate A) and the Motor Vehicle Census (Table 5.8, Estimate B) and yearly differences in the road safety performance in each jurisdiction relative to Victoria. The estimates are used as the basis for the Safety Need calculations presented in Table 2.1, Table 2.2 and Figure 2.2. The 2010 estimates form the basis of BCR calculations presented in Chapter 8.

Table 5.10 Number of occupants killed and injured in Australia, 2007

	Side impact collision partner Estimate A - population				**Side impact collision partner Estimate B - registration**			
M1 / N1, occupants	**Vehicle**	**Pole**	**Other fixed**	**Total**	**Vehicle**	**Pole**	**Other fixed**	**Total**
Fatal injury	127	190	5	322	121	182	5	308
Admitted to hospital	4427	1254	151	5833	4232	1199	145	5576
Injured – not admitted	2055	200	49	2304	1964	191	47	2202
No injury	7009	395	78	7482	6700	378	75	7153
Total	13 618	2040	283	15 941	13 018	1950	271	15 239

Population: Vic represent 24.7% of the national population[31]; inflation factor **(A)** = 4.037 and a secondary factor to account for jurisdictional differences in road safety performance (*1.209); the inflation factor was 4.88.
Vehicle registrations: Victoria accounts for 25.91% national vehicle registrations[13]; inflation factor **(B)** = 3.859026 and a secondary factor to account for jurisdictional differences in road safety performance (*1.209); the inflation factor was 4.66.

Table 5.11 Number of occupants killed and injured in Australia, 2008

	Side impact collision partner Estimate A - population				**Side impact collision partner Estimate B - registration**			
M1 / N1, occupants	**Vehicle**	**Pole**	**Other fixed**	**Total**	**Vehicle**	**Pole**	**Other fixed**	**Total**
Fatal injury	206	212	22	441	197	203	21	421
Admitted to hospital	5505	1657	229	7390	5262	1584	219	7065
Injured – not admitted	2008	268	50	2326	1919	256	48	2223
No injury	7864	368	73	8305	7518	352	69	7939
Total	15 584	2504	374	18 462	14 897	2394	357	17 648

Population: Vic represent 24.7% of the national population[31]; inflation factor **(A)** = 4.037 and a secondary factor to account for jurisdictional differences in road safety performance (*1.38); the inflation factor was 5.577.
Vehicle registrations: Victoria accounts for 25.91% national vehicle registrations[13]; inflation factor **(B)** = 3.859026 and a secondary factor to account for jurisdictional differences in road safety performance (*1.3812); the inflation factor was 5.33.

Table 5.12 Number of occupants killed and injured in Australia, 2009

M1 / N1, occupants	Side impact collision partner Estimate A - population				Side impact collision partner Estimate B - registration			
	Vehicle	**Pole**	**Other fixed**	**Total**	**Vehicle**	**Pole**	**Other fixed**	**Total**
Fatal injury	109	155	17	281	104	148	16	269
Admitted to hospital	5041	1640	149	6830	4819	1568	143	6529
Injured – not admitted	1961	258	34	2254	1875	247	33	2154
No injury	8918	407	75	9400	8525	389	71	8985
Total	16 029	2460	275	18 765	15 323	2352	263	17 938

Population: Vic represent 24.7% of the national population[31]; inflation factor **(A)** = 4.037 and a secondary factor to account for jurisdictional differences in road safety performance (*1.4206); the inflation factor was 5.735.
Vehicle registrations: Victoria accounts for 25.91% national vehicle registrations[13]; inflation factor **(B)** = 3.859026 and a secondary factor to account for jurisdictional differences in road safety performance (*1.4206); the inflation factor was 5.482.

Appendix A.5-1 Side impact fatalities and injuries in Queensland

For completeness, the number of occupants killed and injured in side impact crashes in 2007 and 2008 is presented below.

2007 side impact fatalities and injuries, QLD

Table A5.1a Number of killed and injured occupants of M1 and N1 vehicles, Queensland 2007

Class / injury severity	All crashes			Single vehicle Crashes				% PSI of All Side	% PSI of All M1/N1
M1, occupants	**Side Impact**	**Other**	**Total**	**Side Impact**	**Side / object†**	**Other**	**Total**		
Fatal	48	128	176	17	14	69	86	29.2%	8.0%
Admitted	866	2711	3577	117	81	1137	1254	9.4%	2.3%
Not admitted - medical treatment	1364	4119	5483	145	106	1044	1189	7.8%	1.9%
Not admitted - minor injury/no treatment	1287	3241	4528	117	71	736	853	5.5%	1.6%
No injury	5594	12999	18593	365	248	1747	2112	4.4%	1.3%
Total	9159	23198	32357	761	520	4733	5494	5.7%	1.6%
Class / injury severity	**All crashes**			**Single vehicle Crashes**				**% PSI of All Side**	**% PSI of All M1/N1**
N1, occupants	**Side Impact**	**Other**	**Total**	**Side Impact**	**Side / object†**	**Other**	**Total**		
Fatal	5	30	35	3	3	19	22	60.0%	8.6%
Admitted	103	516	619	18	12	288	306	11.7%	1.9%
Not admitted - medical treatment	140	549	689	18	7	214	232	5.0%	1.0%
Not admitted - minor injury/no treatment	164	531	695	25	14	193	218	8.5%	2.0%
No injury	1087	2818	3905	76	48	334	410	4.4%	1.2%
Total	1499	4444	5943	140	84	1048	1188	5.6%	1.4%
Class / injury severity	**All crashes**			**Single vehicle Crashes**				**% PSI of All Side**	**% PSI of All M1/N1**
M1 / N1, occupants	**Side Impact**	**Other**	**Total**	**Side Impact**	**Side / object†**	**Other**	**Total**		
Fatal	53	158	211	20	17	88	108	32.1%	8.1%
Admitted	969	3227	4196	135	93	1425	1560	9.6%	2.2%
Not admitted - medical treatment	1504	4668	6172	163	113	1258	1421	7.5%	1.8%
Not admitted - minor injury/no treatment	1451	3772	5223	142	85	929	1071	5.9%	1.6%
No injury	6681	15817	22498	441	296	2081	2522	4.4%	1.3%
Total	10658	27642	38300	901	604	5781	6682	5.7%	1.6%

† Derived from run-off-road crashes into fixed object using Queensland Police Reported Crash Casualty Data

2008 - side impact fatalities and injuries, QLD

Table A5.2a Number of killed and injured occupants of M1 and N1 vehicles, Queensland 2008

Class / injury severity	**All crashes**			**Single vehicle Crashes**				**% PSI of All Side**	**% PSI of All M1/N1**
M1, occupants	**Side Impact**	**Other**	**Total**	**Side Impact**	**Side / object†**	**Other**	**Total**		
Fatal	52	114	166	22	18	54	76	34.6%	10.8%
Admitted	1023	3113	4136	148	114	1295	1443	11.1%	2.8%
Not admitted - medical treatment	1566	4088	5654	144	109	972	1116	7.0%	1.9%
Not admitted - minor injury/no treatment	1094	2655	3749	79	47	542	621	4.3%	1.3%
No injury	5948	12732	18680	403	285	1828	2231	4.8%	1.5%
Total	9683	22702	32385	796	573	4691	5487	5.9%	1.8%
Class / injury severity	**All crashes**			**Single vehicle Crashes**				**% PSI of All Side**	**% PSI of All M1/N1**
N1, occupants	**Side Impact**	**Other**	**Total**	**Side Impact**	**Side / object†**	**Other**	**Total**		
Fatal	4	25	29	3	2	14	17	50.0%	6.9%
Admitted	130	522	652	31	22	284	315	16.9%	3.4%
Not admitted - medical treatment	187	600	787	33	23	239	272	12.3%	2.9%
Not admitted - minor injury/no treatment	162	470	632	24	16	140	164	9.9%	2.5%
No injury	1393	3297	4690	93	65	467	560	4.7%	1.4%
Total	1876	4914	6790	184	128	1144	1328	6.8%	1.9%
Class / injury severity	**All crashes**			**Single vehicle Crashes**				**% PSI of All Side**	**% PSI of All M1/N1**
M1 / N1, occupants	**Side Impact**	**Other**	**Total**	**Side Impact**	**Side / object†**	**Other**	**Total**		
Fatal	56	139	195	25	20	68	93	35.7%	10.3%
Admitted	1153	3635	4788	179	136	1579	1758	11.8%	2.8%
Not admitted - medical treatment	1753	4688	6441	177	132	1211	1388	7.5%	2.0%
Not admitted - minor injury/no treatment	1256	3125	4381	103	63	682	785	5.0%	1.4%
No injury	7341	16029	23370	496	350	2295	2791	4.8%	1.5%
Total	11559	27616	39175	980	701	5835	6815	6.1%	1.8%

† Derived from run-off-road crashes into fixed object using Queensland Police Reported Crash Casualty Data

6 INJURY RISK IN SIDE IMPACT CRASHES: ANALYSIS OF VICTORIAN MASS CRASH DATA

The goal of the present research was to explore the differences in injury risk associated with side impact crashes. These are separated into two categories, these being: side impact crashes where the collision partner was a narrow object, such as a tree or a pole, and vehicle-to-vehicle side impact crashes. The intent is to assess the need for, and the potential value of, a new Global Technical Regulation on pole side impact which is expected to provide benefits for both pole side impacts and vehicle-to-vehicle side impacts. Thus far data has been presented on the present safety situation for a number of the Contracting Parties to the UNECE 1998 Agreement on global technical regulations (Chapter 2) and a detailed examination of crashes and casualties using 'mass' police reported casualty data (Chapter 3) and in-depth crash investigation data from the UK (Chapter 4). Following this, we examined the injury outcomes of crashes in a number of Australian jurisdictions and calculated fatality and serious injury estimates for Australia.

In all of the analysis conducted, side impacts were seen to represent a significant proportion of the overall fatality and serious injury crash problem. In this chapter and the following, we explore the injury severity outcomes of side impact crashes in Victoria using 'mass' data and in-depth crash data.

6.1 Crash data in Victoria and the role of the Transport Accident Commission

The Victorian Transport Accident Commission (TAC) is the statutory authority responsible for the care and rehabilitation of all road-users involved in road crashes in Victoria.[10] The TAC is also charged with improving road safety in Victoria. The TAC operates as a no-fault insurer and provides a range of medical and like expenses as well as loss of earnings payments and lifetime care where required. The TAC is required by virtue of its operations to hold extensive data relating to all road-users injured in road crashes in the State. The data, herein known as the TAC Claims Data, contains information on the crash, each involved person, their injuries where sustained and health service utilisation and financial data post-crash. For every claimant, the *Claims Data* also incorporates the Police Report of each crash and details of the road network from the Roads Corporation (known as VicRoads). This data represents one of the most extensive road injury databases in Australia and forms the basis of our examination of injuries sustained in pole side impact and vehicle-to-vehicle side impact crashes.

6.1.1 Injury coding and derivation of injury severity scores

The TAC Claims Data File contains details of injuries sustained by all claimants, or persons injured in road crashes, regardless of severity. For claimants attending hospital, injuries are as per the ICD-9[46] or ICD-10 classification system[45] depending on the year of claim; where ICD-10 data is supplied to the TAC this is 'back-mapped' internally at the TAC to ICD-9 codes for consistency. For those not attending a hospital, a different coding scheme is used where body region and nature of injury is defined. It is important to note that claims can be lodged in the absence of physical injuries as there are a range of benefits available to all road-users involved in crashes.

The ICD coded injury data was mapped to AIS body region and severity codes. For this purpose, the STATA[47] User Written Program, *ICDPIC Version 3.0* was used. ICDPIC uses injury information from the US National Trauma Database including AIS and ICD as the basis of its translation map (http://www.facs.org/trauma/ntdb/index.html). The translation program also calculates the ISS based on accepted calculation protocols.[36]

Data for the period 2000 to 2010 inclusive was used in the analysis.

6.1.2 ‘Case’ inclusion criteria

The analysis of the TAC Claims data was performed with a view to informing the safety situation with regards to vehicles that would meet the existing side impact standard ECE R 95, known in Australia as ADR 72. Case inclusion and exclusion are as follows:

Inclusion criterion -

- Vehicle Model year 2000 or later, as a surrogate for ADR 72 (ECE R 95) compliance; this also acts to control for structural design differences between vehicles;
- The initial point of impact being the front or rear side driver or passenger door;
- The collision partner being a tree / pole, or other vehicles for vehicle-to-vehicle side impact crashes;

Exclusion criteria -

- Impact point of front, front / rear side corner, rear, rollovers
- Collisions with ‘other’ types of partners (e.g., animals, trains etc...)

6.2 Results

As a first step in determining the patterns of injury sustained by M1 and N1 occupants of model year 2000 and newer vehicles involved in side impact crashes, the number of injured occupants available for analysis was examined.

As shown in Table 6.1, there were 194 front seat occupants of M1 passenger cars (ADR MA Category passenger cars) injured in near side (struck-side) pole side impact crashes and 794 front seat occupants of M1 passenger cars injured in vehicle-to-vehicle near side impact crashes. In addition, there were 20 rear seat pole impact cases and 86 rear seat vehicle-to-vehicle cases.

Table 6.1 Number of injured claimants in near and far side impacts

Vehicle class	**Near side impact**				**Far-side impact**			
	Front occupants		**Rear Occupants**		**Front occupants**		**Rear Occupants**	
	Pole	**Vehicle**	**Pole**	**Vehicle**	**Pole**	**Vehicle**	**Pole**	**Vehicle**
Passenger (M1)	194	794	20	86	117	434	16	63
SUV (M1)	4	20	2	3	4	21	1	3
Light commercial (N1)	9	19	0	2	5	13	2	2

To examine factors associated with injury risk, complete data is required on each variable for appropriate modelling. Due to this requirement, cases with missing data are excluded from the analysis; hence, two front seat occupants of both PSI and vehicle impacts are excluded, and 7 rear seat occupants involved in vehicle-to-vehicle side impact crashes. Occupants of SUVs (ADR MC Category off-road passenger vehicles) and N1 light commercial vehicles were excluded from the analysis due to their low numbers and the fact they are structurally very different to M1 passenger cars.

The final sample size for analysis is 1077 occupants of MY 2000 or later Class M1 passenger cars, of which all but 99 were front seat occupants. While the GTR will apply only to front seat occupants, it remains useful to examine the influence of seating position.

6.3 Characterstics and injury outcomes of front and rear seat PSI and side impact cases

6.3.1 Demographic characteristics, airbag availability and speed zone

Table 6.2 presents the key characteristics of the occupants of struck on the side of their vehicle. There are clear differences in the sex distribution, age and speed zone of crash such that occupants involved in side impact crashes were more likely to be male (65% cf. 33%), were younger (mean age: 30 years cf. 42 years), and more crashes occurred in speed zones 100 km/h and higher (33% cf. 11%).

Table 6.2 Characteristics of M1 passenger car front and rear occupants involved in near side pole and vehicle-to-vehicle impacts

	Collision Partner			
Characteristic	**Pole impact (n = 212)**		**Vehicle-to-vehicle (n=865)**	
		%	**N**	**%**
Seating position				
Front	192	90.6%	786	90.9%
Rear	20	9.4%	79	9.1%
Sex				
Male	138	65.1%	285	32.9%
Female	74	34.9%	580	67.1%
Age				
Mean (SD), years	30.4 (14.9)		42.5 (19.5)	
95^{th}% CI of mean	28.4-32.4		40.9-43.6	
Median	24.0		41.0	
Range	6-85		2-92	
Age category				
0-9	2	0.9%	14	1.6%
10 to 16	9	4.2%	36	4.2%
17 to 29	121	57.1%	223	25.8%
30 to 39	30	14.2%	145	16.8%
40 to 49	24	11.3%	151	17.5%
50 to 59	16	7.5%	115	13.35
60 +	10	4.7%	181	20.9%
Side Airbag				
Deployed	8	3.8%	43	5.0%
Not fitted / not deployed	204	96.2%	822	95.0%
Speed Zone				
<=50	35	16.5%	199	23.0%
60-75	76	35.8%	437	50.5%
80-90	30	14.2%	130	15.0%
>=100	71	33.5%	99	11.4%

A similar proportion of occupants were exposed to side airbags (PSI: 3.8%; V2V: 5.0%) and 90% of occupants were in the front row ($p \geq 0.05$). There was a higher proportion of males in the PSI group (PSI: 65% male cf.V2V 32.9% male; $X^2(1) = 73.7$, $p < 0.001$) while occupants involved in PSI were younger (PSI *M - 30.4 vs. V2V: M –*

42.5; t(406.4) = 9.70, $p < 0.001$). Figure 6.1 highlights the difference in the age distribution of male and female front row occupants, by impact partner.

Nearly two-thirds of occupants involved in V2V side impact crashes were female. Notably, one-third of PSI crashes occurred in 100 km/h or higher speed zones compared to 11% of vehicle-to-vehicle side impact crashes of which half occurred in 60-75 km/h speed zones $X^2(1)=63.5$, $p<0.001$).

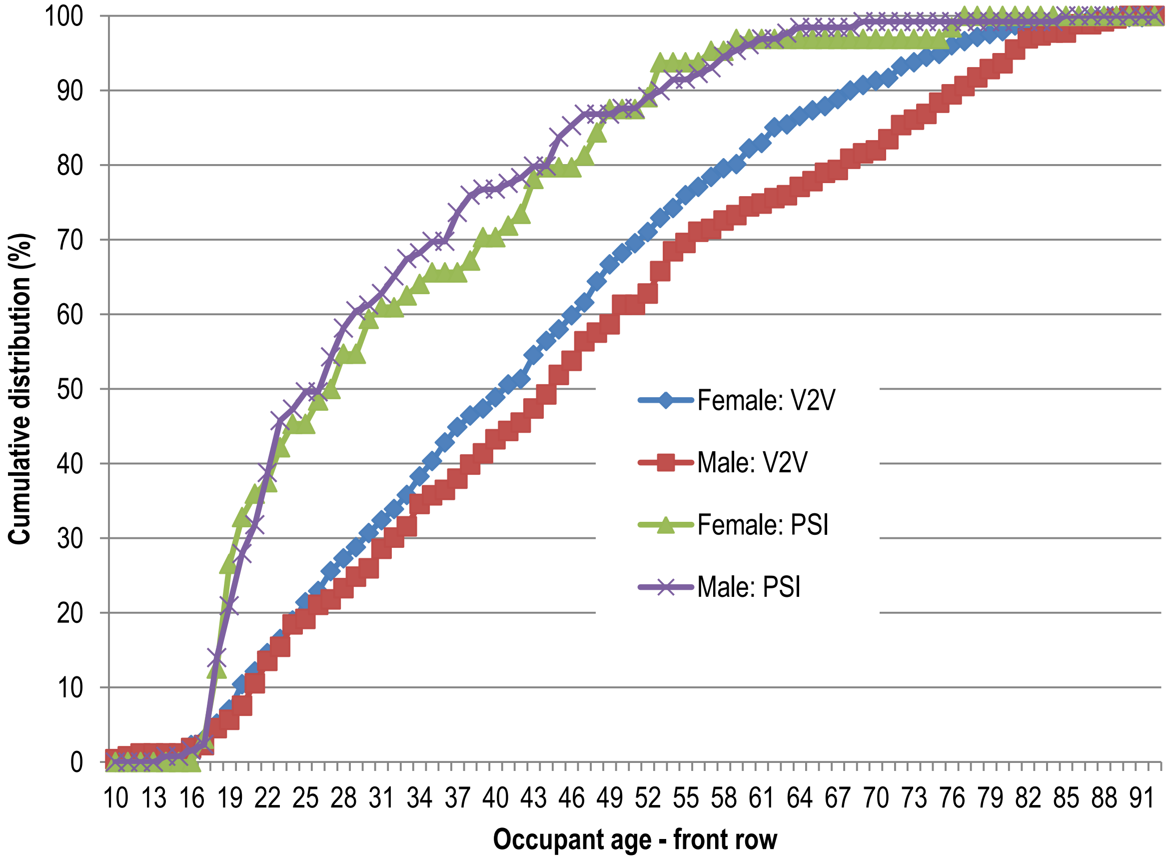


Figure 6.1 Cumulative age distribution for front row occupants in M1 vehicles

6.3.2 Patterns of injury for PSI and side impact cases

Overall, 11.8% of occupants were classified as a 'major trauma' case. Occupants involved in pole side impacts had a higher level of injury severity than occupants involved in vehicle-to-vehicle side impact crashes, with 22% and 9% respectively being classified as 'major trauma' patients (ISS>15)[36, 48] ($X^2(1)=27.05$, $p<0.001$; Table 6.3). The mean ISS was also higher for occupants involved in PSI crashes (M: 9.4, SD = 8.9) compared to occupants involved in vehicle-to-vehicle side impact crashes (M: 5.1, SD = 6.6). The MAIS is also presented in Table 6.3 and is graphically presented in Figure 6.2, where it is evident that substantially more occupants in V2V side impacts sustained minor injuries (53%) compared to PSI crash involved occupants (30%). Occupants involved in PSI crashes sustained higher severity injuries.

Table 6.3 Injury outcomes of M1 passenger car front and rear occupants involved in near side pole and vehicle-to-vehicle impacts

	Pole		**Vehicle**		**All**	
ISS	**N**	**%**	**N**	**%**	**N**	
% Major Trauma (ISS>15)	22.2%		9.3%		11.8%	
Mean (SD),	9.4 (8.9)		5.1 (6.6)		6.0 (7.3)	
95^{th}% CI of mean	8.1-10.6		4.7-5.6		5.5-6.4	
Median	6.0		3.0		3.0	
Range	0-43		0-43		0-43	
MAIS	**N**	**%**	**N**	**%**	**N**	**%**
No injury (0)	2	.9%	36	4.2%	38	3.5%
Minor (1)	63	29.7%	454	52.5%	517	48.0%
Moderate (2)	73	34.4%	249	28.8%	322	29.9%
Serious (3)	47	22.2%	77	8.9%	124	11.5%
Severe (4)	24	11.3%	39	4.5%	63	5.8%
Critical (5)	3	1.4%	9	1.0%	12	1.1%
Maximum (6)	Nil	Nil	Nil	Nil	Nil	Nil
Unknown	Nil	Nil	1	.1%	1	.1%
Total	212	100.0%	865	100.0%	1077	100.0%

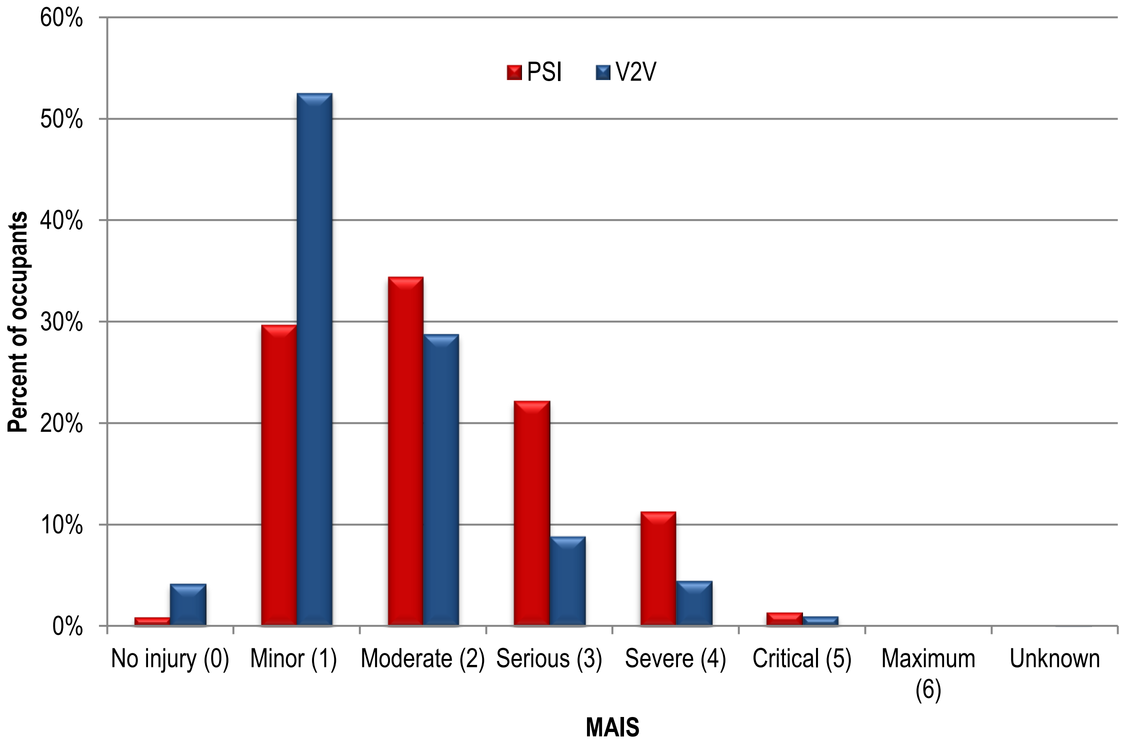


Figure 6.2 MAIS distribution for occupants involved in PSI and V2V side impact crashes

Table 6.4 presents the percent of front seat occupants who sustained injuries by body region and the proportion that sustained serious AIS 3+ injuries; these percentages are also presented in Figure 6.3 (injured) and Figure 6.4 (AIS 3+).

Head injuries were the most common, with 57% of PSI occupants and 37% of V2V occupants having an injury to the head. A higher proportion of occupants involved in PSI crashes sustained upper extremity injuries, while there was a marginal difference in the proportion with thorax and abdominal-pelvic injuries.

At the AIS 3+ (serious) injury level, a considerably higher proportion of PSI occupants sustained injuries of the head, thorax, abdomen-pelvis and lower extremity. The most commonly injured body region was the thorax (PSI: 21% cf. V2V: 8.7%) followed by the head (PSI: 11.8% cf. 5.5%).

Figure 6.5 presents the percent of AIS 3+ injured occupants who sustained an AIS 3+ injury to specific body regions. This is useful as it states the injury types sustained, having been seriously injured. The figure highlights the importance firstly of the thorax with approximately 60% of seriously injured occupants sustaining a thorax injury, and secondly the head, where approximately 30% of seriously injured PSI and V2V involved occupants sustained an AIS 3+ injury. For both the head and the thorax, there was little difference between the impact groups; **this is a critical finding and highlights the need for improved side impact protection for all side impact crashes.**

Table 6.4 Injuries sustained by occupants of M1 passenger cars in near side impacts

AIS body region	AIS 1 +				AIS 3+			
	PSI		Vehicle		PSI		Vehicle	
	N	%	N	%	N	%	N	%
Head	121	57.1%	321	37.1%	25	11.8%	48	5.5%
Face	45	21.2%	70	8.1%	Nil	Nil	Nil	Nil
Neck	2	0.9%	3	0.3%	Nil	Nil	Nil	Nil
Thorax*	76	35.8%	276	31.9%	45	21.2%	75	8.7%
Abdomen-pelvis	80	37.7%	281	32.5%	14	6.6%	17	2.0%
Spine	63	29.7%	286	33.1%	3	1.4%	6	0.7%
Upper extremity	107	50.5%	294	34.0%	2	0.9%	Nil	Nil
Lower extremity	67	31.6%	213	24.6%	18	8.5%	11	1.3%

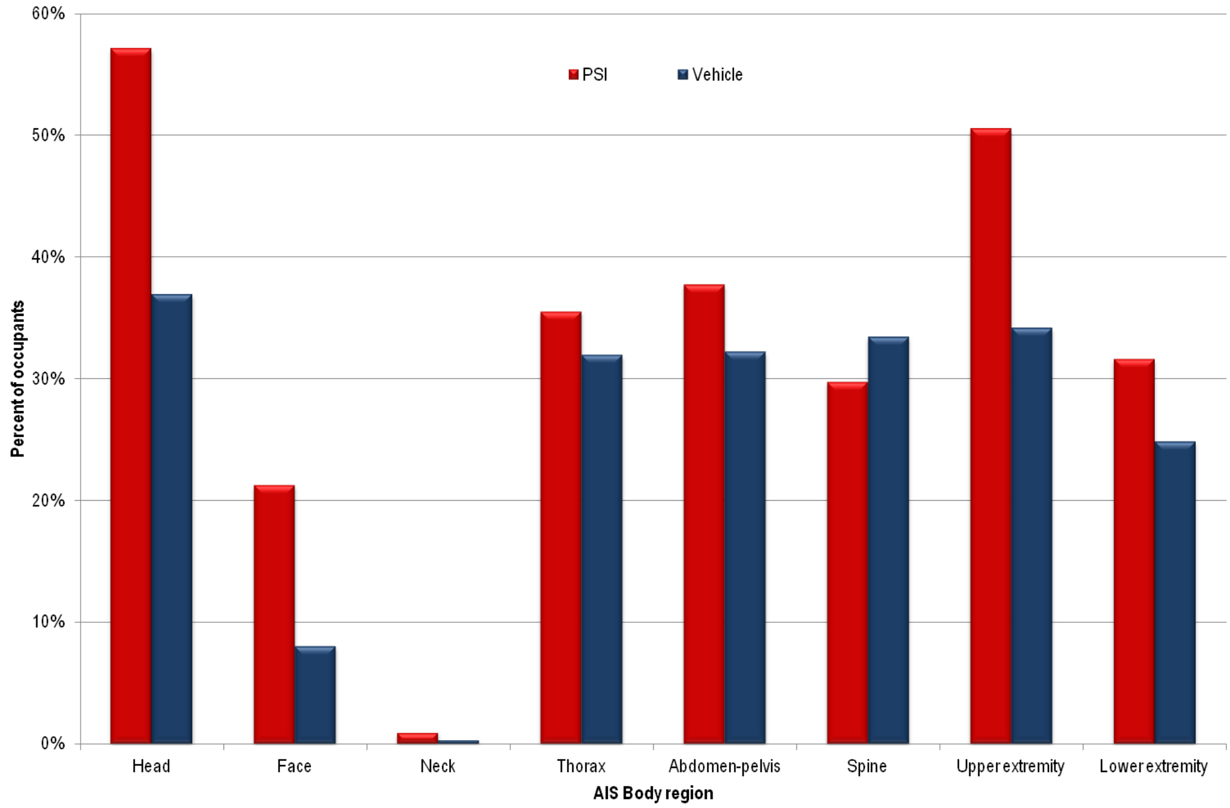


Figure 6.3 Percent of M1 passenger car occupants injured in near side PSI and vehicle-to-vehicle crashes, by body region

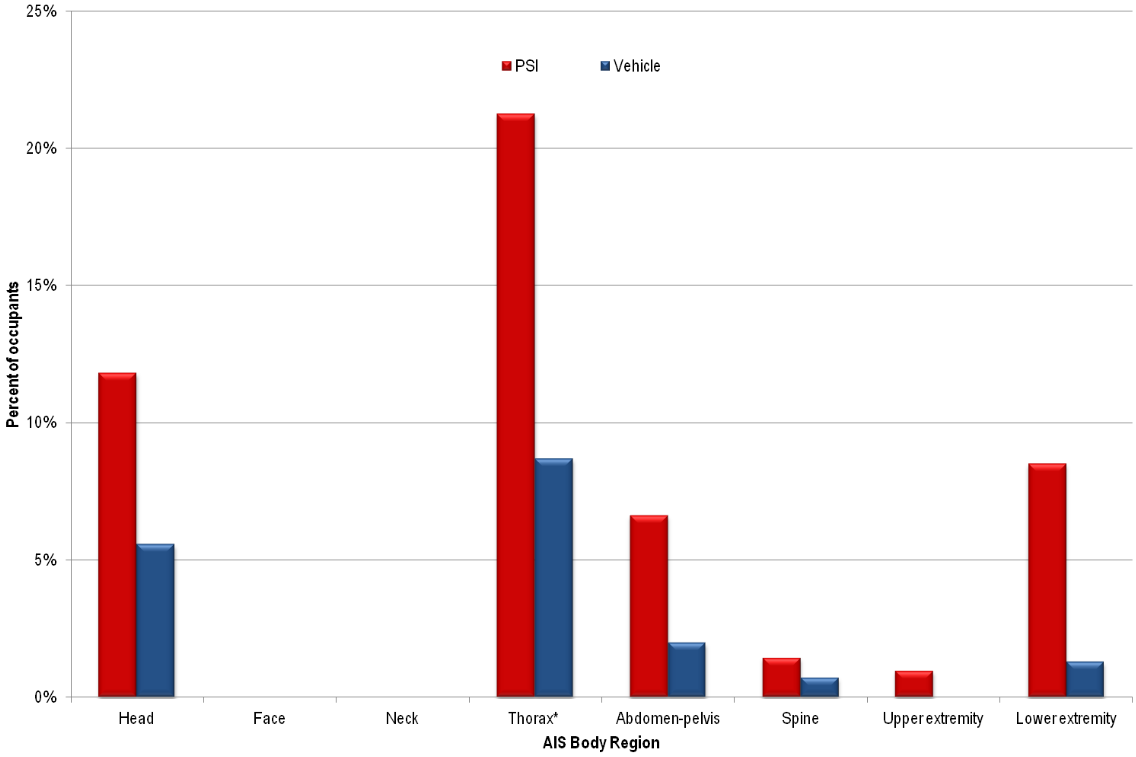


Figure 6.4 Percent of M1 passenger car occupants with AIS 3+ injuries in near side PSI and vehicle-to-vehicle crashes, by body region

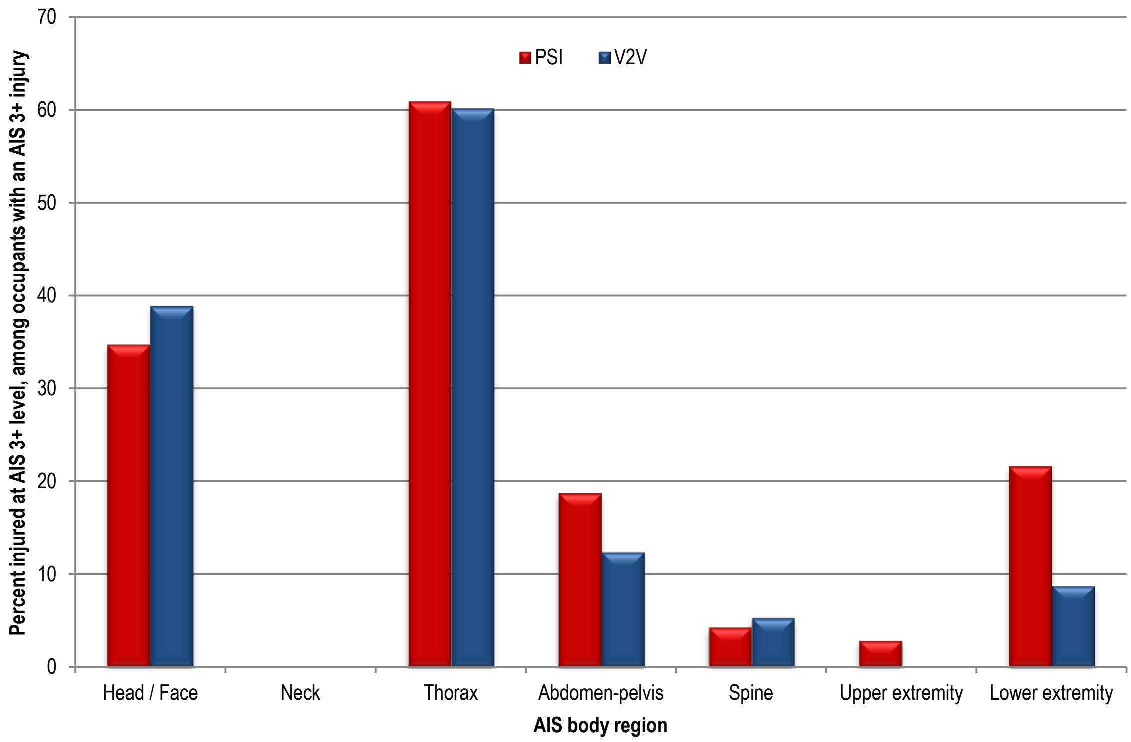


Figure 6.5 Percent AIS3+ injuries, given serious injury sustained by front row occupants (AIS3+)

6.3.1 Regression modelling of injury risk

The tables presented in this section (Table 6.5 to Table 6.9) present the Odds Ratios adjusted for availability of side impact airbags and occupant position.

Head injury models: PSI were associated with a significantly higher odds of sustaining an AIS 1+ and an AIS 3+ head injury, with the odds being 2.25 times greater (Table 6.5). While side impact airbag deployment demonstrated an indicative 40% and 73% reduction in AIS 1+ and AIS 3+ injuries respectively, these were not statistically significant (*note: it was not possible to determine the specific type of airbag system)*. There was no association between front and rear seat occupants, irrespective of collision partner in the risk of injury.

Table 6.5 Adjusted Odds Ratios for AIS 1+ and AIS 3+ head injury

Head AIS 1+						
Parameter	**Group**	**Referent**	**OR**	**P**	**95th% CI**	
					Lower	**Upper**
Collision partner	Pole	Vehicle	**2.25**	<0.001	1.65	3.05
Side airbag	Deployed	Not fitted/deployed	0.60	0.1	0.32	1.12
Occupant position	Front	Rear	0.75	0.2	0.49	1.15
Head AIS 3+						
Parameter	**Group**	**Referent**	**OR**	**P**	**95th% CI**	
					Lower	**Upper**
Collision partner	Pole	Vehicle	**2.26**	<0.001	1.36	3.76
Side airbag	Deployed	Not fitted/deployed	0.27	0.2	0.04	2.01
Occupant position	Front	Rear	1.43	0.4	0.56	3.65

Thorax injury models: Occupants involved in PSI had a 2.8 times higher odds of sustaining an AIS 3+ injury compared to those involved in vehicle-to-vehicle side impact crashes. Neither airbag deployment nor seating position showed a statistically significant association with thorax injuries.

Table 6.6 Adjusted Odds Ratios for AIS 1+ and AIS 3+ thorax injury

Thorax AIS 1+						
Parameter	**Group**	**Referent**	**OR**	**P**	**95th% CI**	
					Lower	**Upper**
Collision partner	Pole	Vehicle	1.20	0.2	0.88	1.65
Side airbag	Deployed	Not fitted/deployed	1.47	0.2	0.83	2.60
Occupant position	Front	Rear	1.40	0.2	0.87	2.23
Thorax AIS 3+						
Parameter	**Group**	**Referent**	**OR**	**P**	**95th% CI**	
					Lower	**Upper**
Collision partner	Pole	Vehicle	**2.83**	<0.001	1.89	4.24
Side airbag	Deployed	Not fitted/deployed	0.70	0.5	0.25	2.00
Occupant position	Front	Rear	1.01	0.9	0.52	1.98

Abdomen - pelvis injury models: Occupants involved in PSI had a 3.5 times higher odds of sustaining an AIS 3+ abdomen or pelvis injury compared to those involved in vehicle-to-vehicle side impact crashes (OR: 3.5, 95^{th}% CI: 1.72-7.33, p = 0<0001) (Table 6.7). Neither airbag deployment nor seating position showed a statistically significant association with abdomen or pelvis injuries.

Table 6.7 Adjusted Odds Ratios for AIS 1+ and AIS 3+ abdomen or pelvis injury

Abdomen or Pelvis AIS 1+						
Parameter	**Group**	**Referent**	**OR**	**P**	**95^{th}% CI**	
					Lower	**Upper**
Collision partner	Pole	Vehicle	1.26	0.1	0.92	1.72
Side airbag	Deployed	Not fitted/deployed	1.09	0.8	0.61	1.97
Occupant position	Front	Rear	1.18	0.5	0.75	1.84
Abdomen or Pelvis AIS 3+						
Parameter	**Group**	**Referent**	**OR**	**P**	**95^{th}% CI**	
					Lower	**Upper**
Collision partner	Pole	Vehicle	**3.55**	<0.001	1.72	7.33
Side airbag	Deployed	Not fitted/deployed	1.54	0.6	0.35	6.76
Occupant position	Front	Rear	0.51	0.2	0.19	1.37

Spine injury models: There was no statistically significant difference in the odds of sustaining an AIS 1+ or AIS 3+ spinal injury according to collision partner. Neither side airbag deployment nor occupant position showed a statistically significant association with injuries to the spine.

Table 6.8 Adjusted Odds Ratios for AIS 1+ and AIS 3+ spinal injuries

Spine AIS 1+						
Parameter	**Group**	**Referent**	**OR**	**P**	**95^{th}% CI**	
					Lower	**Upper**
Collision partner	Pole	Vehicle	0.85	0.35	0.62	1.19
Side airbag	Deployed	Not fitted/deployed	0.85	0.60	0.46	1.57
Occupant position	Front	Rear	1.47	0.11	0.92	2.36
Spine AIS 3+						
Parameter	**Group**	**Referent**	**OR**	**P**	**95^{th}% CI**	
					Lower	**Upper**
Collision partner	Pole	Vehicle	2.11	0.29	0.52	8.55
Side airbag	Deployed	Not fitted/deployed	2.58	0.38	0.31	21.17
Occupant position	Front	Rear	Excluded (nil rear seat occupants sustained AIS 3+, 9 in front row)			

Upper extremity injury models: Occupants involved in PSI were twice as likely to sustain an upper extremity injury (including shoulder injuries) as occupants involved in vehicle-to-vehicle side impact crashes. Neither airbag deployment nor seating position was associated with upper extremity injuries. Due to the finding that none of the occupants involved in vehicle-to-vehicle impacts sustain an AIS 3 upper extremity injury, it was not possible to perform logistic regression modelling.

Table 6.9 Adjusted Odds Ratios for AIS 1+ upper extremity injuries

Upper Extremity AIS 1+						
Parameter	**Group**	**Referent**	**OR**	**P**	**95th% CI**	
					Lower	**Upper**
Collision partner	Pole	Vehicle	**1.99**	<0.001	1.47	2.70
Side airbag	Deployed	Not fitted/deployed	1.33	0.3	0.75	2.36
Occupant position	Front	Rear	1.27	0.3	0.82	1.99

Lower extremity injury models: PSI was associated with a 1.4 times higher odds of sustaining an AIS 1+ and a 7.3 times higher odds of AIS 3+ lower extremity injury relative to occupants involved in vehicle-to-vehicle side impact crashes (Table 6.9). There was no association between front and rear seat occupants, irrespective of collision partner in the risk of injury.

Table 6.10 Adjusted Odds Ratios for AIS 1+ and AIS 3+ lower extremity injuries

Lower Extremity AIS 1+						
Parameter	**Group**	**Referent**	**OR**	**P**	**95th% CI**	
					Lower	**Upper**
Collision partner	Pole	Vehicle	**1.42**	0.04	1.03	1.98
Side airbag	Deployed	Not fitted/deployed	1.62	0.1	0.90	2.93
Occupant position	Front	Rear	0.98	0.9	0.61	1.57
Lower Extremity AIS 3+						
Parameter	**Group**	**Referent**	**OR**	**P**	**95th% CI**	
					Lower	**Upper**
Collision partner	Pole	Vehicle	**7.27**	<0.001	3.37	15.66
Side airbag	Deployed	Not fitted/deployed	1.75	0.5	0.39	7.88
Occupant position	Front	Rear	0.62	0.4	0.21	1.87

Probabilities of Injury and differences between PSI and vehicle-to-vehicle side impact crashes

In addition to the Odds Ratio analysis, a simple extension is the presentation of the average predicted probabilities using the STATA V.12 MP 'margins' command.[49, 50] This permits the absolute difference in the probability to be derived and also a statement can be made about the percent difference in the probability of injury between the two groups of interest (Table 6.11).

The probability values further demonstrate the aggressive nature of pole side impact crashes, with significant increases in the probability of injury across the body regions and severities. For instance, there was a 54.5% higher probability of an AIS 3+ head injury in PSI crashes than vehicle-to-vehicle side impact crashes; this is an absolute difference of 6% in risk.

Table 6.11 Summary of probability of injury for occupants of M1 passenger cars

Region / Severity	***Pole / tree***	***Vehicle***	***Absolute difference in Pr(Injury, pole) to Pr(Injury, vehicle)***	
	Adj. Prob. (95th% CI)	***Adj. Prob. (95th% CI)***	***Adj. Prob. diff. (95th% CI)***	**P**
AIS 1+				
Head	0.57 (0.50-0.64)	0.37 (0.34-0.40)	**0.19** (0.12-0.27)	<0.001
Face	0.21 (0.16-0.26)	0.08 (0.06-0.10)	**0.13** (0.07-0.18)	<0.001
Neck	*Cannot calculate*			
Thorax	0.36 (0.29-0.42)	0.32 (0.29-0.35)	0.04 (-0.03–0.11)	0.2
Abdomen-Pelvis	0.38 (0.31-0.45)	0.32 (0.29-0.36)	0.05 (-0.22-0.12)	0.1
Spine	0.30 (0.24-0.36)	0.33 (0.30-0.36)	-0.03 (-0.10-0.3)	0.3
Upper extremity	0.51 (0.44-0.57)	0.34 (0.31-0.37)	**0.17** (0.09-0.24)	<0.001
Lower extremity	0.32 (0.25-0.38)	0.25 (0.22-0.27)	**0.07** (0.002-0.14)	0.04
AIS 3+				
Head	0.11 (0.07-0.16)	0.05 (0.04-0.07)	**0.06** (0.01-0.11)	0.008
Face	Nil injuries	Nil injuries	N/A	
Neck	Nil injuries	Nil injuries	N/A	
Thorax	0.21 (0.16-0.27)	0.08 (0.07-0.10)	**0.13** (0.07-0.18)	0.001
Abdomen-Pelvis	0.07 (0.03-0.10)	0.02 (0.01-0.03)	**0.04** (0.01-0.08)	0.009
Spine	0.02 (0.00-0.03)	0.01 (0.00-0.01)	0.008 (-0.01-0.02)	0.4
Upper extremity	*Cannot calculate*	Nil injuries		
Lower extremity	0.08 (0.05-0.12)	0.01 (0.005-0.02)	**0.07** (0.03-0.11)	<0.001

Adjusted Probabilities of Injury and differences between occupants exposed to side impact airbags and those not

In the models presented above, the influence of the availability of side impact airbags on injury outcomes was examined, irrespective of the collision partner. Table 6.12 presents the probabilities of injury for occupants exposed and not exposed to airbags, and the absolute difference in probability between the two groups.

As would be anticipated, the presence of a side impact airbag had a significant benefit in mitigating AIS 3+ head injuries, with the absolute probability difference being 5%.

Table 6.12 Summary of probability of injury for occupants of M1 passenger cars based on airbag status

Region / Severity	***No airbag***	***Airbag available, deployed***	***Absolute difference in Pr(injury, airbag) to Pr(injury, no airbag)***	
	Adj. Prob. (95th% CI)	***Adj. Prob. (95th% CI)***	***Adj. Prob. diff. (95th% CI)***	**P**
AIS 1+				
Head	0.41 (0.38-0.44)	0.30 (0.18-0.43)	-0.11 (-0.24 to 0.01)	0.09
Face	0.11 (0.09-0.13)	0.02 (-0.02-0.06)	**-0.09** (-0.13 to -0.04)	<0.001
Neck	*Cannot calculate*			
Thorax	0.32 (0.29-0.35)	0.41 (0.28-0.54)	-0.09 (-0.04 to 0.22)	0.2
Abdomen-Pelvis	0.33 (0.33-0.36)	0.35 (-0.11-0.16)	0.02 (-0.11 to 0.15)	0.7
Spine	0.33 (0.30-0.35)	0.29 (0.17-0.41)	-0.04 (-0.16 to 0.09)	0.6
Upper extremity	0.37 (0.34-0.40)	0.44 (0.30-0.57)	0.07 (-0.07 to 0.21)	0.3
Lower extremity	0.25 (0.23-0.28)	0.35 (0.22-0.49)	0.10 (-0.03 to 0.23)	0.1
AIS 3+				
Head	0.07 (0.05-0.08)	0.02 (-0.02-0.06)	**-0.05** (-0.09 to -0.007)	0.02
Face	Nil injuries	Nil injuries	N/A	
Neck	Nil injuries	Nil injuries	N/A	
Thorax	0.11 (0.09-0.13)	0.08 (0.006-0.16)	-0.03 (-0.11 to 0.05)	0.4
Abdomen-Pelvis	0.03 (0.02-0.04)	0.04 (-0.01-0.10)	0.01 (-0.04 to 0.07)	0.6
Spine	0.01 (0.00-0.01)	0.02 (-0.02-0.06)	0.01 (-0.03-0.05)	0.5
Upper extremity	*Cannot calculate*	Nil injuries		
Lower extremity	0.03 (0.01-0.03)	0.04 (-0.01-0.10)	0.02 (-0.04 to 0.07)	0.5

6.3.2 Regression modelling of injury risk – Fully Adjusted Models

The analysis of injuries presented in Section 6.3.1 provides estimates controlling only for side impact airbag availability and front – rear seat position. This is an appropriate approach due to the data source being a census of crashes in Victoria. This is particularly important in this analysis as these estimates provide the basis of our understanding of the differential injury risk in PSI compared to vehicle-to-vehicle side impact crashes *as they happen;* that is, given the persons involved and their types of crashes that occur on public roads. This is important as the PSI GTR will in and of itself not change the type of crash or those involved; rather, it seeks to protect involved occupants, hence it is critical to understand the difference in injury probability between the two impact types.

Given the development of the PSI GTR and the setting of performance criteria, there is also interest in understanding injury risk based on a range of other characteristics. This shifts the focus of the question slightly to, *what is the effect of PSI impacts on occupant injury* <u>*controlling for all other influential parameters.*</u> These estimates therefore indicate the average injury probabilities, given all other factors.

Despite the strength of TAC claims data as a 'census' database, there is no direct estimation of collision severity, such as Equivalent Barrier Speed and thus speed zone is used as a surrogate of crash severity. Like the analysis presented above, logistic regression[37] is used to estimate the relative odds of sustaining each injury for occupants involved in PSI compared to occupants involved in vehicle-to-vehicle side impact crashes, adjusted for age, gender, seat position (row), side impact airbag deployment, speed zone of crash, and collision partner (pole vs. vehicle).

While the injury probability for all regions is presented; only the key body regions of the head, thorax, abdomen-pelvis and lower extremity are discussed in detail.

Head Injury – Table 6.13 presents the adjusted Odds Ratio for sustaining an injury to the head (AIS 1+) and serious head injuries (AIS 3+).

The analysis demonstrates the significantly higher odds of occupants involved in PSI crashes sustaining a head injury, with the o*dds of sustaining an AIS 1+ head injury in a pole impact being 1.93 times greater than a vehicle-to-vehicle near side impact crash (OR: 1.93, 95th% CI: 1.37-2.70, p < 0.001).* The o*dds of AIS 3+ head injury in a pole impact was 1.36 times greater than a vehicle-to-vehicle near side impact, although this was not statistically significant (OR: 1.36, 95th% CI: 0.76-0.42, p = 0.3).*

Occupant gender had a strong association with head injury outcomes, such that males had significantly higher odds of sustaining an AIS 1+ and AIS 3+ head injury. <u>This is an important result in the interpretation of the collision partner odds ratio values</u>. In short however, it is more than likely that the 'gender effect' washes out the collision partner and this occurs for two reasons: first, there is a relatively low number of females in the sample and few sustained an AIS 3+ head injury compared to males (F: 6 of 27, 22%; M: 19 of 27, 70.3%; Unknown: 2), and second, speed zone is likely to be a poor indicator of pre-impact speed as it assumes vehicles were travelling at similar speeds pre-impact, and additionally that males and females will be the same in terms of speed choice. We present these models for the sake of completeness, however, as argued above, given the sample is a population-based sample of injured occupants and the interest is in the differential injury risk associated with pole impacts *as they occur in the fleet* we rely on the unadjusted estimates.

Notably, side airbag availability showed some indicative benefit, albeit not statistically significant but in the direction of a reduction, while occupant position and age were not shown to have a statistically significant association with head injury outcome (regardless of collision partner). There was some evidence for higher odds of AIS 3+ head injury in the 100 km/h speed zone relative to the 50 km/h speed zone.

Table 6.13 Adjusted Odds Ratios for AIS 1+ and AIS 3+ head injury

Head AIS 1+						
Parameter	**Group**	**Referent**	**OR**	**P**	**95th% CI**	
					Lower	**Upper**
Collision partner	Pole	Vehicle	**1.93**	<0.001	1.37	2.70
Sex	Male	Female	**1.44**	0.01	1.11	1.87
Age	years		1.00	0.3	0.99	1.00
Speed zone	60-75	<= 50	0.74	0.07	0.54	1.02
	80-90	<= 50	0.77	0.2	0.51	1.17
	>=100	<= 50	0.80	0.3	0.52	1.21
Side airbag	Deployed	Not fitted/deployed	0.62	0.1	0.33	1.16
Occupant position	Front	Rear	0.77	0.2	0.49	1.19
Head AIS 3+						
Parameter	**Group**	**Referent**	**OR**	**P**	**95th% CI**	
					Lower	**Upper**
Collision partner	Pole	Vehicle	1.36	0.3	0.76	2.42
Sex	Male	Female	**2.54**	<0.001	1.52	4.25
Age	years		0.99	0.4	0.98	1.01
Speed zone	60-75	<= 50	0.87	0.7	0.44	1.73
	80-90	<= 50	1.20	0.7	0.53	2.73
	>=100	<= 50	1.97	0.08	0.93	4.16
Side airbag	Deployed	Not fitted/deployed	0.27	0.2	0.04	2.00
Occupant position	Front	Rear	1.46	0.4	0.54	3.90

Thorax Injury – Table 6.14 presents the adjusted Odds Ratio for sustaining an injury to the thorax (AIS 1+) and serious thorax injuries (AIS 3+). There was a significant difference in the odds of injury between PSI involved occupants and vehicle-to-vehicle side impact involved occupants at the AIS 1+ level (OR: 1.62, 95th% CI: 1.12-2.34, p = 0.01). The analysis also demonstrated a significantly higher odds of occupants involved in PSI crashes sustaining an AIS 3+ thorax injury compared to occupants involved in vehicle-to-vehicle side impact crashes (OR: 3.14, 95% CI: 1.94-5.09, p ≤0.01).

At the AIS 3+ injury severity, being male and increasing age (and at AIS 1+) were associated with increased odds of injury. Speed zone was an important variable in the model with evidence of higher odds of injury at the high-end speed zones. Side airbag availability showed an indicative reduction in AIS 3+ thorax injury risk, but this was not statistically significant (OR: 0.60, 95% CI: 0.21-1.74, p = 0.3). There was no difference in injury according to seating position.

Table 6.14 Adjusted Odds Ratios for AIS 1+ and AIS 3+ thorax injury

Thorax AIS 1+						
Parameter	**Group**	**Referent**	**OR**	**P**	**95th% CI**	
					Lower	**Upper**
Collision partner	Pole	Vehicle	**1.62**	0.01	1.12	2.34
Sex	Male	Female	1.26	0.10	0.96	1.67
Age	years		**1.03**	<0.001	1.02	1.04
Speed zone	60-75	<= 50	1.03	0.8	0.73	1.46
	80-90	<= 50	1.04	0.8	0.66	1.62
	>=100	<= 50	1.09	0.7	0.70	1.70
Side airbag	Deployed	Not fitted/deployed	1.32	0.4	0.72	2.40
Occupant position	Front	Rear	0.85	0.5	0.52	1.41
Thorax AIS 3+						
Parameter	**Group**	**Referent**	**OR**	**P**	**95th% CI**	
					Lower	**Upper**
Collision partner	Pole	Vehicle	**3.14**	<0.001	1.94	5.09
Sex	Male	Female	**1.81**	<0.001	1.20	2.73
Age	years		**1.03**	<0.001	1.01	1.04
Speed zone	60-75	<= 50	1.46	0.2	0.81	2.63
	80-90	<= 50	1.92	0.06	0.97	3.82
	>=100	<= 50	1.90	0.06	0.98	3.69
Side airbag	Deployed	Not fitted/deployed	0.60	0.3	0.21	1.74
Occupant position	Front	Rear	0.64	0.2	0.32	1.29

Abdominal-pelvis Injury – Table 6.15 presents the adjusted Odds Ratio for sustaining an injury to the abdomen-pelvis at the AIS 1+ and AIS 3+ severity level. At the AIS 1+ level, there was an indicative higher odds of injury for occupants involved in PSI relative to vehicle impacts (p = 0.08).

In contrast, occupants involved in PSI crashes had a 4.59 times higher odds of sustaining an AIS 3+ abdominal – pelvis injury than those involved in vehicle-to-vehicle side impact crashes (OR: 4.59, 95% CI: 1.95-10.77, p ≤0.01).

Occupant age, sex, side airbag deployment and seat position were not associated with abdominal-pelvis injuries.

Table 6.15 Adjusted Odds Ratios for AIS 1+ and AIS 3+ abdominal-pelvis injury

Abdomen and Pelvis AIS 1+						
Parameter	**Group**	**Referent**	**OR**	**P**	**95th% CI**	
					Lower	**Upper**
Collision partner	Pole	Vehicle	1.37	0.08	0.97	1.95
Sex	Male	Female	0.77	0.07	0.59	1.02
Age	years		1.00	0.2	1.00	1.01
Speed zone	60-75	<= 50	1.13	0.5	0.81	1.59
	80-90	<= 50	1.58	0.04	1.03	2.42
	>=100	<= 50	1.39	0.1	0.91	2.13
Side airbag	Deployed	Not fitted/deployed	1.09	0.8	0.60	1.97
Occupant position	Front	Rear	1.13	0.6	0.71	1.80
Abdomen and Pelvis AIS 3+						
Parameter	**Group**	**Referent**	**OR**	**P**	**95th% CI**	
					Lower	**Upper**
Collision partner	Pole	Vehicle	**4.59**	<0.001	1.95	10.77
Sex	Male	Female	0.91	0.8	0.42	1.97
Age	years		1.01	0.2	0.99	1.03
Speed zone	60-75	<= 50	1.49	0.4	0.53	4.16
	80-90	<= 50	1.08	0.9	0.28	4.14
	>=100	<= 50	1.03	0.9	0.30	3.61
Side airbag	Deployed	Not fitted/deployed	1.44	0.6	0.33	6.34
Occupant position	Front	Rear	0.45	0.1	0.16	1.25

Spine Injury – Table 6.16 presents the adjusted Odds Ratio for sustaining an injury to the spine at the AIS 1+ and AIS 3+ severity level. At the AIS 1+ level, there was no difference in the odds of injury between a PSI and a V2V impact. However, males had lower odds of injury than females, or alternatively females had a 47% higher odds of sustaining an injury to the spine than their male counterparts (p = 0.01). In addition, front seat occupants had 67% higher odds than rear seat occupants of an injury to the spine, adjusted for all other factors.

At the AIS 3+ injury severity, occupants involved on PSI crashes had a 5.5 times higher odds of sustaining an AIS 3+ spine injury than those involved in vehicle-to-vehicle side impact crashes (OR: 5.49, 95% CI: 1.04-28.86, p=0.04). An effect of sex was evident (p = 0.06), indicating males at a lower odds of injury than female occupants, or alternatively expressed as an 87% lower odds of injury.

Table 6.16 Adjusted Odds Ratios for AIS 1+ and AIS 3+ spine injury

Spine AIS 1+						
Parameter	**Group**	**Referent**	**OR**	**P**	**95th% CI**	
					Lower	**Upper**
Collision partner	Pole	Vehicle	0.91	0.6	0.63	1.31
Sex	Male	Female	**0.68**	0.01	0.52	0.90
Age	years		0.99	0.1	0.99	1.00
Speed zone	60-75	<= 50	1.07	0.7	0.76	1.49
	80-90	<= 50	1.00	1.0	0.65	1.55
	>=100	<= 50	1.03	0.9	0.66	1.59
Side airbag	Deployed	Not fitted/deployed	0.86	0.6	0.46	1.61
Occupant position	Front	Rear	**1.67**	0.04	1.02	2.73
Spine AIS 3+						
Parameter	**Group**	**Referent**	**OR**	**P**	**95th% CI**	
					Lower	**Upper**
Collision partner	Pole	Vehicle	**5.49**	0.04	1.04	28.86
Sex	Male	Female	0.13	0.06	0.01	1.11
Age	years		1.02	0.4	0.98	1.05
Speed zone	60-75	<= 50	0.69	0.6	0.15	3.15
	80+	<= 50	0.36	0.3	0.05	2.43
Side airbag	Deployed	Not fitted/deployed	2.77	0.3	0.33	23.22
Occupant position	Front	Rear	Not fitted in model			

Upper Extremity Injury – Table 6.17 presents the adjusted Odds Ratio for AIS 1+ upper extremity injuries.

Occupants involved in PSI crashes had a 1.78 times higher odds of sustaining AIS 1+ injuries (OR: 1.78, 95% CI: 1.27-2.50, p<0.001) than occupants involved in vehicle-to-vehicle side impact crashes.

As there were no AIS 3 injuries among the vehicle-to-vehicle side impact crash group, it is not possible to calculate an odds ratio, although it is worth noting that two occupants of PSI crashes sustained an AIS 3 upper extremity injury.

Table 6.17 Adjusted Odds Ratios for AIS 1+ upper extremity injury

Upper Extemity AIS 1+						
Parameter	**Group**	**Referent**	**OR**	**P**	**95th% CI**	
					Lower	**Upper**
Collision partner	Pole	Vehicle	**1.78**	<0.001	1.27	2.50
Sex	Male	Female	1.11	0.4	0.85	1.45
Age	years		1.00	0.9	0.99	1.01
Speed zone						
	60-75	<= 50	1.16	0.4	0.84	1.62
	80-90	<= 50	1.10	0.7	0.71	1.68
	>=100	<= 50	1.54	0.04	1.01	2.34
Side airbag	Deployed	Not fitted/deployed	1.32	0.3	0.74	2.34
Occupant position	Front	Rear	1.28	0.3	0.81	2.02
Upper Extemity AIS 3						
Parameter	**Group**	**Referent**	**OR**	**P**	**95th% CI**	
					Lower	**Upper**
Collision partner	Pole	Vehicle	Cannot be calculated due to no AIS3 injuires in vehicle-to-vehicle impacts, although 2 in PSI.			
Sex	Male	Female				
Age	years					
Speed zone						
	60-75	<= 50				
	80-90	<= 50				
	>=100	<= 50				
Side airbag	Deployed	Not fitted/deployed				
Occupant position	Front	Rear				

Lower Extremity Injury – Table 6.18 presents the adjusted Odds Ratio for AIS 1+ and AIS 3+ lower extremity injuries.

Occupants involved in PSI crashes had a 1.56 times higher odds of sustaining AIS 1+ injuries (OR: 1.56, 95% CI: 1.08-2.25, p = 0.02) than occupants involved in vehicle-to-vehicle side impact crashes. At the AIS 3+ injury severity, there was a marked elevation in the odds of injury in the PSI occupant group, with a 6.1 times higher odds of sustaining a lower extremity injury than those involved in vehicle-to-vehicle side impact crashes (OR: 6.15, 95^{th}% CI: 2.53-14.92, p<0.001).

None of the covariates were associated with lower extremity injuries, although there was an indicative effect of sex with males having lower odds of AIS 1+ injuries than females (OR: 0.76, 95^{th}%CI: 0.56-1.02, p=0.07).

Table 6.18 Adjusted Odds Ratios for AIS 1+ and AIS 3+ lower extremity injury

Lower Extemity AIS 1+						
Parameter	**Group**	**Referent**	**OR**	**P**	**95^{th}% CI**	
					Lower	**Upper**
Collision partner	Pole	Vehicle	**1.56**	0.02	1.08	2.25
Sex	Male	Female	0.76	0.07	0.56	1.02
Age	years		1.00	0.9	0.99	1.01
Speed zone						
	60-75	<= 50	0.97	0.9	0.68	1.39
	80-90	<= 50	0.77	0.3	0.48	1.25
	>=100	<= 50	0.98	0.9	0.62	1.55
Side airbag	Deployed	Not fitted/deployed	1.61	0.1	0.89	2.93
Occupant position	Front	Rear	1.00	1.0	0.61	1.63
Lower Extemity AIS 3+						
Parameter	**Group**	**Referent**	**OR**	**P**	**95^{th}% CI**	
					Lower	**Upper**
Collision partner	Pole	Vehicle	**6.15**	<0.001	2.53	14.92
Sex	Male	Female	1.57	0.3	0.69	3.57
Age	years		1.00	0.7	0.97	1.02
Speed zone						
	60-75	<= 50	1.67	0.4	0.54	5.18
	80-90	<= 50	0.94	0.9	0.20	4.35
	>=100	<= 50	1.37	0.6	0.38	5.00
Side airbag	Deployed	Not fitted/deployed	1.76	0.5	0.39	7.97
Occupant position	Front	Rear	0.61	0.4	0.19	1.93

Adjusted Probabilities of Injury and differences between PSI and vehicle-to-vehicle side impact crashes (fully adjusted models)

In addition to the Odds Ratio analysis, a simple extension is the presentation of the average predicted probabilities using the STATA V.12 MP 'margins' command.[49, 50] This permits the absolute difference in the probability to be derived and also a statement can be made about the percent difference in the probability of injury between the two groups of interest (Table 6.19).

Following the Odds Ratio analysis, the adjusted probabilities indicate a higher risk of injury for occupants striking a pole or other narrow object compared to those being struck by vehicles. The percent increase in the probability of injury for occupants involved in PSI compared to those involved in vehicle-to-vehicle impacts is also presented, with percentage increases commonly being from 33% higher to more than six times the probability risk for AIS 3+ injuries. It is again worth noting the 33% increase in the risk of AIS 3+ head injuries, despite this not being statistically significant for reasons elaborated upon above. Nonetheless, these probabilities give an indication of the injurious effects of PSI relative to vehicle-to-vehicle side impacts, adjusted for a range of factors.

Table 6.19 Summary of probability of injury for occupants of M1 passenger cars

Region / Severity	***Pole / tree***	***Vehicle***	***Absolute difference in Pr(injury, pole) to Pr(injury, vehicle)***		***% relative difference pole: vehicle***
	Adj. Prob.	***Adj. Prob.***	***Adj. Prob. diff.***	**P**	
AIS 1+					
Head	0.54 (0.46-0.61)	0.38 (0.35-0.41)	**0.15** (0.07-0.24)	<0.001	+42.1%
Face	0.18 (0.12-0.23)	0.08 (0.06-0.10)	**0.09** (0.03-0.15)	0.002	+125%
Neck	*Cannot calculate*				
Thorax	0.41 (0.31-0.48)	0.31 (0.28-0.34)	**0.10** (0.02-0.18)	0.01	+32.2%
Abdomen-Pelvis	0.39 (0.32-0.46)	0.32 (0.29-0.35)	0.07 (-0.009-0.15)	0.08	+21.8%
Spine	0.31 (0.24-0.38)	0.33 (0.30-0.36)	-0.02 (-0.10-0.06)	0.6	-6.1%
Upper extremity	0.48 (0.41-0.56)	0.34 (0.31-0.38)	**0.14** (0.06-0.22)	0.001	+41%
Lower extremity	0.33 (0.26-0.40)	0.24 (0.21-0.27)	**0.09** (0.01-0.17)	0.02	+37.5%
AIS 3+					
Head	0.08 (0.05-0.12)	0.06 (0.04-0.08)	0.02 (-0.02-0.06)	0.3	+33%
Face	Nil injuries	Nil injuries	N/A		
Neck	Nil injuries	Nil injuries	N/A		
Thorax	0.22 (0.15-0.28)	0.08 (0.07-0.10)	**0.13** (0.07-0.19)	<0.001	+175%
Abdomen-Pelvis	0.08 (0.03-0.13)	0.02 (0.009-0.03)	**0.06** (0.01-0.11)	0.01	+33%
Spine	0.03 (-0.01-0.07)	0.006 (0.001-0.01)	0.02 (-0.01-0.07)	0.2	+400%
Upper extremity	*Cannot calculate*	Nil injuries			
Lower extremity	0.07 (0.03-0.11)	0.01 (0.005-0.02)	**0.06** (0.02-0.10)	0.004	+600%

Adjusted Probabilities of injury and differences between occupants exposed to side impact airbags and those not (fully adjusted models)

In the models presented above, the influence of the availability of side impact airbags on injury outcomes was examined. Table 6.20 presents the probabilities for injury for occupants exposed and not exposed to airbags, the absolute difference in probability and the percent difference.

At the AIS1+ level, the average predicted probability of head injury for occupants without side airbags was 0.42 compared to 0.31 for those exposed to an airbag, translating to a 26.2% lower head injury risk, although this was not statistically significant. *The key finding is a 71% reduction in the probability of an AIS 3+ head injury for occupants exposed to a side airbag deployment compared to those without.*

Reductions in injuiries to the face were also observed (-81%), and while not statistically significant, there was a 36% reduction in AIS 3+ thorax injuries (p=0.2).

Table 6.20 Summary of probability of injury for occupants of M1 passenger cars based on airbag status

Region / Severity	***No airbag***	***Airbag available, deployed***	***Absolute difference in Pr(injury, airbag) to Pr(injury, no airbag)***		***Relative risk difference***
	Adj. Prob.	***Adj. Prob.***	***Adj. Prob. diff.***	**P**	
AIS 1+					
Head	0.42 (0.39-0.44)	0.31 (0.018-0.44)	-0.11 (-0.23 to 0.02)	0.1	-26.2%
Face	**0.11 (0.09-0.12)**	**0.02 (-0.02-0.06)**	**-0.09 (-0.13 to -0.04)**	**<0.001**	**-81.1%**
Neck	*Cannot calculate*				
Thorax	0.32 (0.29-0.35)	0.38 (0.25-0.61)	0.06 (-0.07 to 0.19)	0.4	+18.7%
Abdomen-Pelvis	0.33 (0.30-0.36)	0.35 (0.22-0.48)	0.02 (-0.11 to 0.15)	0.8	+6.1%
Spine	0.33 (0.30-0.35)	0.29 (0.17-0.42)	-0.03 (-0.16 to 0.09)	0.6	-12.1%
Upper extremity	0.36 (0.34-0.40)	0.43 (0.29-0.57)	0.06 (-0.07 to -0.20)	0.4	+19.4%
Lower extremity	0.25 (0.23-0.28)	0.35 (0.22-0.48)	0.10 (-0.03 to 0.23)	0.1	+40%
AIS 3+					
Head	**0.07 (0.05-0.08)**	**0.02 (-0.02-0.06)**	**-0.05 (-0.09 to -0.007)**	**0.02**	**-71.4%**
Face	Nil injuries	Nil injuries	N/A		
Neck	Nil injuries	Nil injuries	N/A		
Thorax	0.11 (0.09-0.13)	0.07 (0.005-0.14)	-0.04 (-0.11 to 0.03)	0.2	-36.4%
Abdomen-Pelvis	0.03 (0.02-0.04)	0.06 (-0.01-0.09)	0.03 (-0.04 to 0.06)	0.6	+100%
Spine	0.01 (0.002 -0.01)	0.02 (-0.02 to 0.06)	0.01 (-0.03 to 0.05)	0.5	+100%
Upper extremity	*Cannot calculate*	Nil injuries			
Lower extremity	0.03 (0.02-0.03)	0.04 (-0.01-0.10)	0.01 (-0.04 to 0.76)	0.5	+33.3

6.4 Key findings and Summary

The analysis of the TAC Claims Data highlights the severe nature of PSI crashes in particular. This is demonstrated by occupants of Model Year 2000 and later M1 passenger cars involved in pole side impact crashes being at significantly higher risk of serious head, thorax, abdominal-pelvic injuries, and lower extremity injuries. Across these body regions, the odds of serious injury (or worse) in a PSI impact were *at least twice* that of occupants involved in vehicle-to-vehicle side impact crashes.

A critical finding was the protective benefits of head protecting side impact airbags. Specifically, the probability of AIS 3+ head injuries among occupants of vehicles equipped with side impact protection was 71.4% lower than for occupants without exposure to a head protecting side airbag. This result clearly demonstrates the importance of protecting the head in side impact crashes, and the effectiveness of side impact, head protecting airbags in doing so. This result is comparable to the finding of a 73% reduction in the odds of sustaining a head injury (AIS 1+) given exposure to a curtain plus thorax side airbag combination, as reported in the UK CCIS analysis (see Table 4.17). These are important findings as none of the studies reviewed in Section 2 was able to document any statistically significant head injury benefit associated with side airbags.

Finally, it is imperative to note that two estimates were presented. The first, adjusted only for side impact airbag status, provides estimates of the differential injury effects of pole side impact crashes relative to vehicle-to-vehicle side impact crashes regardless of other crash and occupant characteristics but accounting for seat position and side airbag availability. This approach is preferable in the sense that the data source is a population-based setting and in this sense represents a 'census' of side impact crashes. This gives an understanding of injury estimates based on '*crashes as they occur on the road'* which is ultimately the primary prevention focus.

The presentation of fully adjusted models, including occupant and speed zone characteristics, is useful as it can guide countermeasure opportunities. For instance, older adults are at significantly higher risk of serious thorax injuries, regardless of collision partner. The observation that males were at higher risk of injury than females, irrespective of collision partner, means that there is a role for other prevention strategies and not necessarily limited to passive safety systems. In this context it is worth noting the weakness of using speed zone as a method for controlling for collision severity as it assumes all crashes, regardless of gender, occur at similar speeds – and they occur at or close to that speed limit. These estimates are however useful as they provide an indication of where prevention countermeasures need to be directed, and are particularly useful in examining the protective effects of side airbags irrespective of occupant gender and age.

6.5 A note on the role of NCAP Star Ratings on side impact risk

The project was tasked with examining the relationship between the NCAP 5-star rating and injury risk. The principal question was whether occupants of 5-star NCAP vehicles striking narrow objects and those involved in vehicle-to-vehicle crashes in the side impact configuration had a differential injury risk to those in lower rating vehicles. In seeking to address this question, a database of all published EuroNCAP and ANCAP tests was created, and where possible linked to the TAC Claims dataset. This included details of 238 vehicles tested by both programs, including full test outcomes for 178 vehicles. It is worth noting that not all NCAP test regimes include a pole side impact test (e.g., Japan-NCAP; J-NCAP), and thus only EuroNCAP and ANCAP test results were used.

After linking the details of the star rating of each vehicle to the TAC Claims Dataset only 2 vehicles involved in PSI impacts and 34 in vehicle side impact crashes held a NCAP 5-star rating. Due to the small number of occupants in 5-star vehicles it was not possible to examine the question of whether occupants in 5-star vehicles had a differential injury risk in each of the body regions relative to those in lower star rating vehicles.

Figure 6.6 presents for the sake only of interest and thoroughness the percent distribution of injuries by body region for occupants in 5-star vs. 4-star and lower rated vehicles by collision partner. Some differences in the injury patterns is evident, particularly when comparing 4-star and lower rated vehicles across collision object, and also within the vehicle-to-vehicle side impact configurations; the data suggests lower risk of injury in 5-star rated vehicles. Using the cost of injury structures reported in Section 8 of this report, the mean cost of injury for occupants in 4-star rated vehicles and lower was $AU 673,951 (95th% CI: 477,815 – 740,275) compared to $AU 346,829 (95th% CI: 190,749 – 502,909) in 5-star vehicles. These findings should be interpreted with caution, although they do present a positive picture of lower injury risk and thus associated injury costs in 5-star vehicles, irrespective of collision partner.

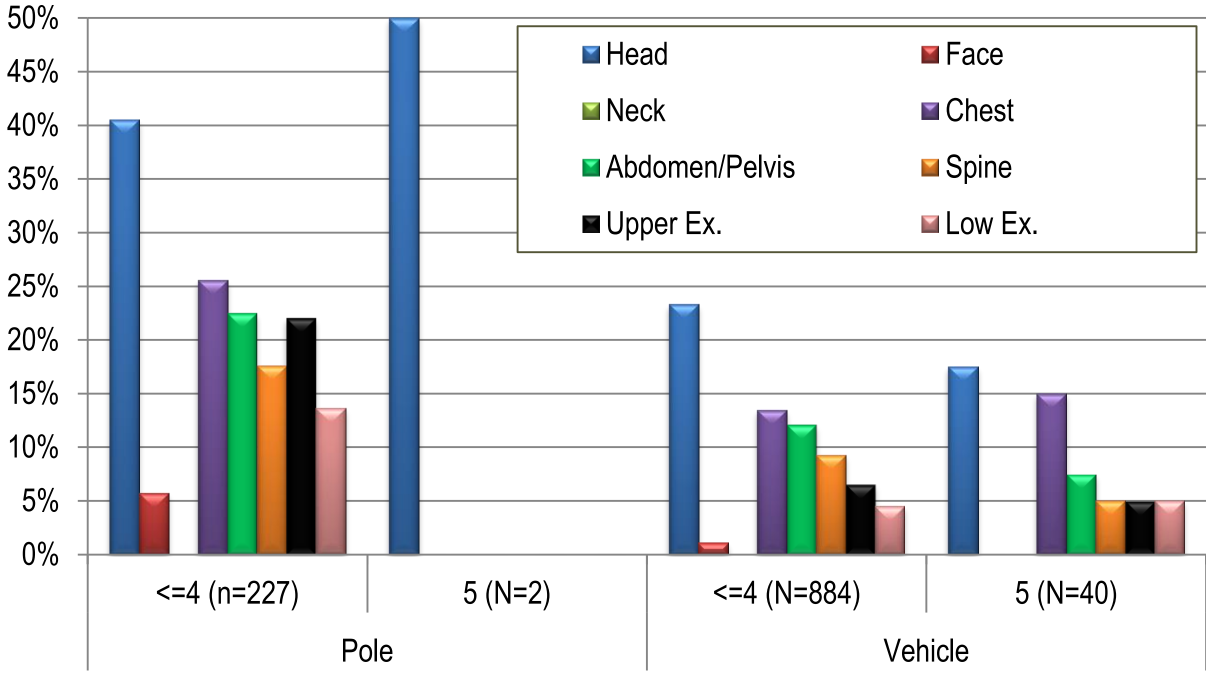


Figure 6.6 Percent of occupants with AIS2+ injuries, by body region, NCAP star rating and collision object

7 INJURY RISK IN SIDE IMPACT CRASHES: ANALYSIS OF AUSTRALIAN IN-DEPTH CRASH DATA

The analysis of Australian In-depth Data provides further context in establishing the safety need and countermeasure priorities for vehicles involved in side impact crashes generally, and pole side impact crashes specifically. By following the same analytic approach as per the analysis of the UK CCIS in-depth data (as reported in Chapter 4), the Australian in-depth data forms a suitable point of comparison, albeit from a different vehicle market and road safety context.

As with the analysis of the UK CCIS in-depth study, the principal research questions are: what are the types of injuries sustained by occupants involved in side impact crashes?, and further, what differences, if any, are there in the injury patterns among occupants of vehicles involved in pole side impact crashes compared to occupants involved in vehicle-to-vehicle side impact crashes?

7.1 The Australian National Crash In-depth Study (ANCIS)

Established in 2000 with the support of government and industry, ANCIS includes data on a random sample of crashes occurring in Victoria and New South Wales in which at least one occupant was sufficiently injured to be admitted to hospital for a minimum of 24 hours. ANCIS is housed at the Monash University Accident Research Centre, Victoria, and since 2010 has had a formal relationship with Neuroscience Research Australia (NeuRA, Sydney) at the University of New South Wales prior to which all NSW cases were collected by Monash contracted staff.

The ANCIS study includes drivers and passengers of four-wheeled passenger cars (M1) and light commercial vehicles (N1) where the vehicle was not more than seven years of age at the time of the crash. Participants are those that provide informed consent directly, or via a next-of-kin or guardian if the injured occupant is unable to provide informed consent due to the nature of their injuries, such as severe brain injury, or fatality. Data is collected through structured in-depth interviews with the injured person and other persons where appropriate.

In addition to occupant interviews (where possible), information is obtained from police, coroners, emergency services and hospital sources, including the medical report and any imaging reports (i.e., X-ray, CT, MRI) in order to validate injuries sustained. In addition, a detailed inspection of the crash site and involved vehicles is performed according to accepted protocols.

ANCIS is currently the most detailed source of crash injury data in Australia and collects data consistent with the UK CCIS, the US NASS CDS, and Germany's GIDAS study.

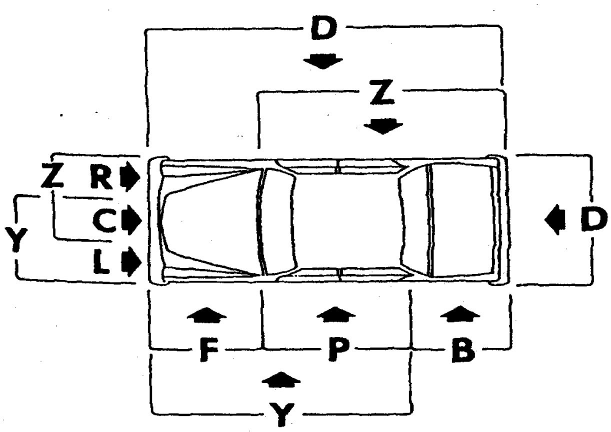
In addition to questions of injury biomechanics, the ANCIS data has examined driver distraction, fatigue and medication use among others.

For full details on the establishment and methodology of ANCIS, the reader is referred to MUARC Report No. 207, ANCIS – The First Three Years (Fildes, Logan, Fitzharris, Scully, & Burton, 2003)[51].

7.2 Method: case selection criteria

At the time of analysis, ANCIS held details of 974 injured occupants for crashes that occurred in the period 2000 – 2011. In selecting the side impact cases for analysis, the following inclusion criteria were applied to the available dataset:

1. Single impact crashes, (also excluding vehicle rollovers);
2. Model Year (MY) 2000 onwards, *as all new model M1 vehicles were required to meet ECE R95 (implemented in Australia as Australian Design Rule [ADR] 72)*[35] from 1 January 2000, MY 2000 onward vehicles were selected as a surrogate for ECE R95 compliance; this constraint partly constrains the potential influence of structural design differences on injury risk*;*
3. Front-row occupants only;
4. Seat-belt known to have been used;
5. Struck-side occupants;
6. Direct loading to the occupant as defined by the Collision Deformation Classification (CDC) damage profile[11] with the principal damage occuing in zones D, Z, P and Y and hence excluding cases where the damage was exclusively in Zones F and B on the side of the vehicle (refer Figure 47.1), and
7. Injury data was known.



Location	Classification
Distributed—side or end	D
Left—front or rear	L
Center—front or rear	C
Right—front or rear	R
Side front—left or right	F
Side center section—left or right	P
Side rear—left or right	B
Side or end—F + P or L + C	Y
Side or end—B + P or R + C	Z

Figure 7.1 Collision Deformation Classification (CDC) system[11]

7.3 Results

After application of the case selection criteria, 58 occupants were available for analysis with 16 being pole / tree side impact crashes and 42 being vehicle-to-vehicle (V2V) side impact crashes (Table 7.1). Of the 42 V2V occupants, 54% sustained an AIS 3+ injury compared to 69% of PSI involved occupants; these are presented separately in the Tables below.

7.3.1 Sample characteristics

The demographic characteristics of occupants injured in PSI and V2V side impact crashes are presented in Table 7.1. The principal differences between the two impact groups were: 50% of PSI occupants were drivers compared to 74% for vehicle-to-vehicle side impact crashes ($X^2(1)=2.9$, $p = 0.08$); occupants involved in PSI were younger (M: 32.8, *SD*: 15.1 years) than those in vehicle-to-vehicle impacts (M: 46.8, *SD*: 16.4 years) (t(56)

= 2.98, p <0.01); most PSI occupants were male (87.5%) compared to 50% of V2V occupants ($X^2(1)=6.8$, $p < 0.01$), and PSI occupants were on average taller ($t(56) = 2.68$, $p = 0.01$) though occupant weight was similar.[11]

Table 7.1 Demographic characteristics of occupants injured and involved in pole side impact and vehicle-to-vehicle side impact crashes

Characteristic	Injured (AIS 1+)		AIS 3+	
	Vehicle (n=42)	**Pole (n=16)**	**Vehicle (n=22)**	**Pole (n=11)**
Position				
Driver	31 (73.8%)	8 (50%)	17 (77.3%)	6 (54.5%)
Front left passenger	11 (26.2%)	8 (50%)	5 (22.7%)	5 (45.5%)
Number of occupants	*42 (100%)*	*16 (100%)*	*22 (100%)*	*11*
Age*				
Mean (SD), years	46.8 (16.4)	32.8 (15.1)	53.8 (14.4)	30.3 (15.8)
Mean - 95th% CL	41.71-51.96	24.70 - 40.8	47.4-60.2	19.6-40.9
Median, years	46	28.5	51.5	24
Min/Max	13-84	16-64	34-84	16-64
Sex [Male, n=50, 62%)				
Male	21 (50%)	14 (87.5%)	12 (54.5%)	10 (91%)
Female	21 (50%)	2 (12.5%)	10 (45.5%)	1 (9%)
Weight[12]				
Mean (SD), kg	72.7 (18.6)	77.6 (17.6)	72.6 (15.9)	73.9 (10.1)
Mean - 95th% CL	66.7-78.6	68.2-87.0	65.5-79.5	67.1-80.7
Median, kg	67.5	75	67	75
Min/Max	51-140	50-115	51-103	50-85
Height[10]				
Mean (SD), cm	170.7 (10.4)	178.9 (10.2)	170.4 (9.7)	181.3 (9.6)
Mean - 95th% CL	167.5-174.0	173.43-184.3	166.1-174.7	174.8-187.7
Median (cm)	172	182	170	183
Min/Max	150-191	158-200	155-191	160-200
BMI				
Mean (SD), years	24.7 (4.6)	24.2 (5.1)	24.8 (3.6)	22.5 (2.6)
Mean - 95th% CL	23.3-26.2	21.5-26.9	23.2-26.4	20.7-24.2
Median (cm)	24	23.8	24.5	23
Min/Max	16.1-40.9	18.2-37.0	19.0-30.1	18.2-25.8
BMI - CATEGORY				
<20, underweight	6 (14.3%)	3 (18.8%)	2 (9.1%)	3 (27.3%)
20-25, normal weight	19 (45.2%)	8 (50%)	11 (50%)	6 (54.5%)
>25 overweight	17 (40.5%)	5 (31.3%)	9 (40.9%)	2 (18.2%)

11 Age and anthropometric characteristics of all ANCIS front row occupants, irrespective of vehicle model year is presented in Appendix 7a

12 As a reference, the WorldSID 50th percentile adult male has a mass of 77.3 kg and a theoretical standing height of 1753 mm

7.3.2 Vehicle characteristics and associated damage

The polarised nature of the Australian fleet is reflected in the distribution of occupants given vehicle class, with large vehicles (PSI: 62.5% cf. V2V: 52.4%) being most common. Few occupants were exposed to side impact airbags in both groups, and the EBS distribution between the two impact groups was similar ($p < 0.05$). With reference to the damage profile of the impact, the mean crush (mm) was significantly greater for PSI involved vehicles (*M: 560, SD: 123.2 mm)* than V2V side impact involved vehicles (M: 331.6, SD: 109.5 mm), reflecting the concentrated energy path of narrow object impacts ($t(17.6) = 3.8$, $p < 0.001$). In addition, 75% of PSI impacts directly engaged the passenger compartment in the door space compared to 45% of vehicle-to-vehicle side impact crashes.

Table 7.2 Vehicle and crash characteristics of occupants injured and involved in pole side impact and vehicle-to-vehicle side impact crashes

Characteristic	Injured (AIS 1+)			AIS 3+	
	Vehicle (n=42)	**Pole (n=16)**		**Vehicle (n=22)**	**Pole (n=11)**
Vehicle Class					
Small	16 (38.1%)	3 (18.8%)		11 (50%)	2 (18.2%)
Medium	4 (9.5%)	3 (18.8%)		2 (9.1%)	2 (18.2%)
Large	22 (52.4%)	10 (62.5%)		9 (40.9%)	7 (63.6%)
Side airbag - exposed					
No side airbag	33 (78.6%)	15 (93.8%)		17 (77.3%)	11 (100%)
Side airbag - deployed	9 (21.4%)	1 (6.3%)		5 (22.7%)	-
EBS					
Mean (SD) km/h	25.4 (7.4)	33.1 (11.8)		26.6 (7.4)	34.9 (11.9)
Mean - 95th% CI	23.1-27.7	26.8-39.4		23.3-29.9	26.9-42.9
Median, km/h	26	29.5		26.8	31.1
Min/Max	12.2-40.0	18-57.0		13-39	23-57
Impact distribution					
Distributed (D)	3 (7.1%)	-		3 (13.6%)	
Side, centre (left/right) (P)	19 (45.2%)	12 (75%)		10 (45.5%)	9 (81.8%)
Y = F+P	17 (40.5%)	4 (25%)		8 (36.4%)	2 (18.2%)
Z =B+P	3 (7.1%)	-		1 (4.5%)	
Crush – maximum					
Mean (SD) mm	331.6 (109.5)	560 (231.5)		329.1 (123.2)	621.82 (245.5)
Mean - 95th% CL	297.5-365.8	436.6-683.4)		274.4-383.7	456.8-786.8)
Median, mm	330	520		320	560
Min/Max	140-600	290-1010		140-600	300-1010
Speed limit (km/h)					
40				-	-
50	8 (19%)			2 (9.1%)	-
60	22 (52.4%)	6 (37.5%)		14 (63.6%)	3 (27.3%)
70	2 (4.8%)			1 (4.5%)	-
80	7 (16.7%)	4 (25%)		3 (13.6%)	4 (36.4%)
90		1 (6.3%)		-	1 (9.1%)
100/110	3 (7.1%)	5 (31.3%)		2 (9.1%)	3 (27.3%)

7.3.3 Injury outcomes of occupants

The principal research question is whether there is a difference in the type and severity of injuries sustained by occupants involved in PSI crashes relative to those involved in V2V side impact crashes. Table 7.3 presents the percent of occupants in each impact category by the highest AIS severity score sustained. It is evident that a higher proportion of PSI crash involved occupants sustained AIS 3 (serious) and higher severity injuries (75%) compared to occupants involved in V2V side impact crashes (54.7%) ($X^2(4)=5.2$, $p = 0.7$). While the mean ISS score was higher for PSI occupants (*M: 21.0, SD: 16.7)* compared to V2V occupants (*M: 13.6, SD:* 13.2), this was not statistically significant, likely due to the small sample size ($t(56) = 1.75$, $p = 0.08$), and there was no difference in the percent of occupants classified as major trauma as indexed by an ISS of > 15.

Table 7.3 Injury severity of occupants involved in vehicle-to-vehicle and pole side impact crashes

Characteristic	Injured (AIS 1+)		AIS 3+	
	Vehicle (n=42)	**Pole (n=16)**	**Vehicle (n=22)**	**Pole (n=11)**
MAIS – max				
1- Minor	13 (31%)	1 (6.3%)		
2- Moderate	6 (14.3%)	3 (18.8%)		
3- Serious	10 (23.8%)	7 (43.8%)	10 (45.5%)	7 (63.6%)
4- Severe	10 (23.8%)	3 (18.8%)	9 (40.9%)	3 (27.3%)
5- Critical	3 (7.1%)	2 (12.5%)	3 (13.6%)	1 (9.1%)
6 - Maximum	-	-	-	-
Injury Severity Score				
Mean (SD)	13.6 (13.2)	21.0 (16.7)	22.3 (11.7)	23.1 (13.1)
Mean - 95th% CL	9.5-17.8	12.1-29.9	17.1-27.6	14.2-31.9
Median	11	15	18	21
Min/Max	1.0 - 51.0	1.0 - 59.0	9.0 to 51.0	10 to 50.0
ISS category				
Minor (<15)	25 (59.5%)	8 (50%)	6 (27.3%)	4 (36.4%)
Major (>15)	17 (40.5%)	8 (50%)	16 (72.7%)	7 (63.6%)

The distribution of injuries sustained by AIS severity level (AIS 1+; AIS 3+) is presented in Table 7.4 and represented in Figure 7.2 (AIS 1+) and Figure 7.3 (AIS 3+). Overall, there are few apparent differences at the AIS 1+ level; however the regions of the head, thorax, abdomen-pelvis, spine and upper and lower extremity are key regions where a higher proportion of PSI crash involved occupants sustained AIS 3+ injuries than did occupants involved in V2V side impact crashes.

Table 7.4 Percent of occupants with AIS 1+ and AIS 3+ injuries

Characteristic	Injured (AIS 1+)		AIS 3+	
	Vehicle (n=42)	**Pole (n=16)**	**Vehicle (n=22)**	**Pole (n=11)**
Head	31.0%	37.5%	11.9%	25.0%
Face	28.6%	31.3%	Nil	Nil
Neck	2.4%	6.3%	Nil	Nil
Thorax	59.5%	62.5%	38.1%	50.0%
Abdomen-pelvis	35.7%	43.8%	7.1%	18.8%
Spine	21.4%	56.3%	Nil	6.3%
Upper extremity	71.4%	56.3%	2.4%	6.3%
Lower extremity	59.5%	62.5%	19.0%	31.3%

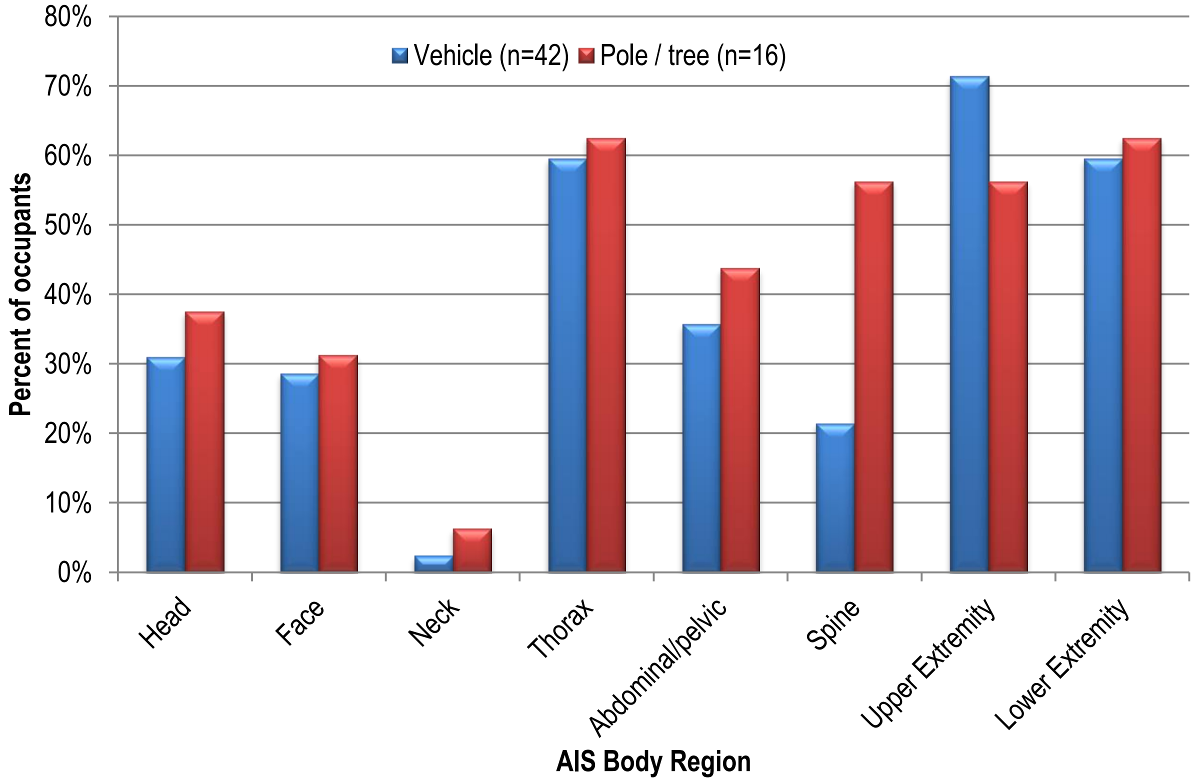


Figure 7.2 Percent of Class MA occupants injured (AIS1+) in near side PSI and vehicle-to-vehicle crashes, by body region

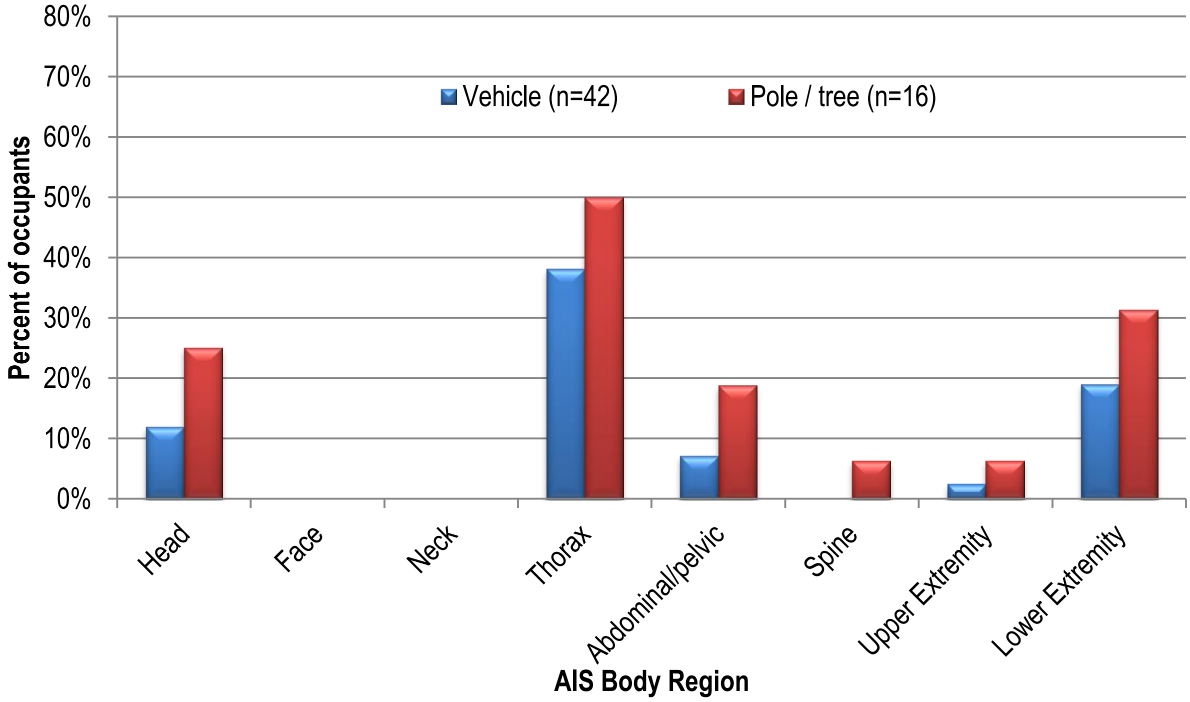


Figure 7.3 Percent of Class MA occupants sustaning an AIS3+ injury near side PSI and vehicle-to-vehicle crashes, by body region

7.3.4 Estimation of differences in injury risk

As noted above, there were few differences in the univariate examination of injuries sustained by occupants of PSI and V2V side impact crashes. There were however some differences in the occupant characteristics between the two impact groups, specifically there were fewer drivers, they were younger, more likely to be male and were taller than their V2V impact counterparts. Notwithstanding the small sample size, statistical models that adjust for key parameters, such as collision severity indexed by EBS (km/h), are important as they permit an unbiased examination of the injury risks associated with each impact configuration.

7.3.4.1 Mortality and Major Trauma Outcomes

Occupants were classified according to their injuries as being a major trauma case if their ISS score exceeded 15, i.e., ISS 15. While the Odds Ratio suggests occupants of PSI were more likely to be classified as a major trauma patient, this was not statistically significant. Occupant age and collision severity indexed by EBS were associated with major trauma case status, with a 6% and 10% increase in the odds of sustaining sufficient injuries to be a major trauma case for every 1 year and 1 km/h increase respectively, regardless of collision partner.

Table 7.5 Adjusted Odds Ratios for major trauma outcomes for occupants involved in PSI crashes relative to vehicle-to-vehicle side impact crashes

Minor / Major Trauma						
Parameter	**Group**	**Referent**	**OR**	**P**	**95th% CI**	
					Lower	**Upper**
Collision partner	Pole	Vehicle	2.02	0.35	0.46	8.87
Side airbag	Deployed	Not fitted/deployed	1.62	0.55	0.33	7.86
EBS (km/h)			1.10	0.01	1.02	1.19
Age (years)			1.06	0.01	1.02	1.11

7.3.4.2 Body region specific injury outcomes

For consistency with the UK CCIS In-depth analysis, logistic regression models examining the differences, if any, in the odds of injury to occupants involved in PSI and V2V side impact crashes are examined in the following pages.

Head injury outcomes: The analysis indicates no difference in the odds of head injury or AIS 3+ head injuries between side impact collision groups. Moreover, side airbag availability and EBS were also unrelated to injury status. Ultimately, the small number of cases precludes any effects to be observed.

Table 7.6 Adjusted Odds Ratios for head injury and AIS 3+ head injury for occupants involved in PSI crashes relative to vehicle-to-vehicle side impact crashes

Head AIS 1+						
Parameter	**Group**	**Referent**	**OR**	**P**	**95th% CI**	
					Lower	**Upper**
Collision partner	Pole	Vehicle	1.09	0.9	0.29	4.12
Side airbag	Deployed	Not fitted/deployed	0.89	0.8	0.20	4.03
EBS (km/h)			1.02	0.4	0.96	1.09
Head AIS 3+						
Parameter	**Group**	**Referent**	**OR**	**P**	**95th% CI**	
					Lower	**Upper**
Collision partner	Pole	Vehicle	1.41	0.71	0.24	8.39
Side airbag	Deployed	Not fitted/deployed	1.92	0.49	0.30	12.36
EBS (km/h)			1.08	0.07	0.99	1.18

Thorax injury outcomes: At the AIS 1+ injury severity level, none of the key parameters were associated with sustaining a thorax injury. At the AIS 3+ injury level, there was some indication of an increased odds of thorax injury, however this was not statistically significant; both EBS (km/h) and age were associated with an increased odds of sustaining a serious thorax injury, irrespective of the collision partner.

Table 7.7 Adjusted Odds Ratios for thorax AIS 1+ and AIS 3+ injury for occupants involved in PSI crashes relative to vehicle-to-vehicle side impact crashes

Thorax AIS 1+						
Parameter	**Group**	**Referent**	**OR**	**P**	**95th% CI**	
					Lower	**Upper**
Collision partner	Pole	Vehicle	0.73	0.6	0.20	2.70
Side airbag	Deployed	Not fitted/deployed	0.56	0.4	0.14	2.33
EBS (km/h)			1.05	0.1	0.98	1.13
Thorax AIS 3+						
Parameter	**Group**	**Referent**	**OR**	**P**	**95th% CI**	
					Lower	**Upper**
Collision partner	Pole	Vehicle	2.13	0.3	0.50	9.05
Side airbag	Deployed	Not fitted/deployed	0.98	0.8	0.21	4.62
EBS (km/h)			**1.08**	0.03	1.01	1.16
Age (years)			**1.06**	0.01	1.01	1.10

Abdomen-pelvis injury outcomes: There was no association between the collision partner and the odds of sustaining an AIS 1+ or AIS 3+ abdominal-pelvic injury. As with the thorax injury model, increasing EBS (km/h) was associated with increased odds of injury, but only at the AIS 1+ level. Interestingly, being male was protective, or conversely, females were at significantly higher risk of injury than males, irrespective of collision partner, but again, this was evident only at the AIS 1+ level.

Table 7.8 Adjusted Odds Ratios for Abdomen-pelvis AIS 1+ and AIS 3+ for occupants involved in a PSI crash relative to vehicle-to-vehicle side impact crashes

Abdomen and Pelvis AIS 1+						
Parameter	**Group**	**Referent**	**OR**	**P**	**95th% CI**	
					Lower	**Upper**
Collision partner	Pole	Vehicle	1.46	0.6	0.34	6.34
Side airbag	Deployed	Not fitted/deployed	1.56	0.6	0.35	7.00
EBS (km/h)			**1.07**	0.04	1.00	1.15
Sex	Male	Female	**0.27**	0.05	0.07	1.02
Abdomen and Pelvis AIS 3+						
Parameter	**Group**	**Referent**	**OR**	**P**	**95th% CI**	
					Lower	**Upper**
Collision partner	Pole	Vehicle	1.88	0.6	0.19	18.35
Side airbag	Deployed	Not fitted/deployed	1.54	0.7	0.13	18.72
EBS (km/h)			1.09	0.1	0.98	1.20
Sex	Male	Female	0.59	0.6	0.06	5.38

Spine injury outcomes: The spine AIS region was the only region in the analysis where an effect of collision partner was found. Specifically, occupants involved in PSI crashes had a 5 times higher odds of sustaining an injury to the spine region (OR: 5.17, 95% CI: 1.05-25.43, p = 0.04). None of the other parameters such as airbag deployment, EBS, age or sex were associated with an injury to the spine.

Due to the small number of cases in the sample and the rare occurrence generally of AIS 3+ spine injuries, it was not possible to perform a logistic regression model at the AIS 3+ level, as none of the occupants in V2V side impact crashes sustained an AIS 3+ spine injury.

Table 7.9 Adjusted Odds Ratios for Spine AIS 1+ and AIS 3+ for occupants involved in a PSI crash relative to vehicle-to-vehicle side impact crashes

Spine AIS 1+						
Parameter	**Group**	**Referent**	**OR**	**P**	**95th% CI**	
					Lower	**Upper**
Collision partner	Pole	Vehicle	5.17	0.04	1.05	25.43
Side airbag	Deployed	Not fitted/deployed	2.44	0.3	0.49	12.20
EBS (km/h)			1.05	0.2	0.97	1.14
Sex	Male	Female	1.52	0.6	0.36	6.44
Age (years)			1.03	0.2	0.98	1.07
Spine AIS 3+						
Parameter	**Group**	**Referent**	**OR**	**P**	**95th% CI**	
					Lower	**Upper**
Collision partner	Pole	Vehicle	Cannot calculate – no spine injuries in vehicle-to-vehicle side impact crashes			
Side airbag	Deployed	Not fitted/deployed				
EBS (km/h)						
Sex	Male	Female				

Injuries to the upper extremity: None of the factors of collision partner, side airbag deployment, or EBS were associated with upper extremity injuries at either the AIS 1+ or AIS 3+ injury severity level. The impact of the small number of cases can be seen in the indicatively higher odds of AIS 1+ upper extremity injuries (OR: 4.88) but the very wide confidence interval. This is confirmed to be an issue as the side airbag deployment variable was 'dropped' from the analytical model due to co-linearity (i.e., no cases in one group).

Table 7.10 Adjusted Odds Ratios for upper extremity AIS 1+ and AIS 3+ for occupants involved in a PSI crash relative to vehicle-to-vehicle side impact crashes

Upper Extremity AIS 1+						
Parameter	**Group**	**Referent**	**OR**	**P**	**95th% CI**	
					Lower	**Upper**
Collision partner	Pole	Vehicle	0.61	0.5	0.16	2.28
Side airbag	Deployed	Not fitted/deployed	4.88	0.1	0.56	42.50
EBS (km/h)			1.00	0.9	0.94	1.06
Upper Extremity AIS 3+						
Parameter	**Group**	**Referent**	**OR**	**P**	**95th% CI**	
					Lower	**Upper**
Collision partner	Pole	Vehicle	2.39	0.6	0.11	49.89
Side airbag	Deployed	Not fitted/deployed	*Excluded from analysis*			
EBS (km/h)			0.99	0.9	0.86	1.15

Injuries to the lower extremity: Similar to all models examining the odds of injury – with the exception of the spine, there was no association between collision partner and injury occurrence. Collision severity, indexed as EBS, and being female was associated with a significant increase in the odds of injury.

Table 7.11 Adjusted Odds Ratios for lower extremity AIS 1+ and AIS 3+ for occupants involved in PSI crash relative to vehicle-to-vehicle side impact crashes

Lower Extremity AIS 1+						
Parameter	**Group**	**Referent**	**OR**	**P**	**95th% CI**	
					Lower	**Upper**
Collision partner	Pole	Vehicle	1.23	0.8	0.28	5.50
Side airbag	Deployed	Not fitted/deployed	1.24	0.8	0.27	5.76
EBS (km/h)			1.11	0.02	1.02	1.21
Sex	Male	Female	**0.12**	<0.001	0.03	0.52
Lower Extremity AIS 3+						
Parameter	**Group**	**Referent**	**OR**	**P**	**95th% CI**	
					Lower	**Upper**
Collision partner	Pole	Vehicle	1.81	0.48	0.35	9.37
Side airbag	Deployed	Not fitted/deployed	1.22	0.83	0.20	7.38
EBS (km/h)			1.06	0.11	0.99	1.14
Sex	Male	Female	0.39	0.22	0.09	1.75

7.3.4.3 Summary of injury outcomes

For each statistical model, in addition to the odds ratio the average probability of injury can be derived as can the absolute difference in the probability of injury[50] and from this the percent increase or reduction in the probability of injury between the two collision groups. Table 7.12 presents a summary of the probability of injury for PSI and V2V crash involved occupants. While the percent increase in the probability of injury appears high in some instances, the only statistically significant difference in the probability of injury was for injuries of the spine, with a 1.5 times higher probability of injury associated with PSI. The small number of PSI cases limits the value of the analysis presented here.

Table 7.12 Summary of probability of injury for occupants of MA vehicles involved in PSI crashes relative to vehicle-to-vehicle side impact crashes

Region / Severity	***Pole / tree***	***Vehicle***	***Absolute difference in Pr(Head, pole) to Pr(Head, vehicle)***		***% relative difference pole to vehicle***
	Adj. Prob. (95th% CI)	***Adj. Prob. (95th% CI)***	***Adj. Prob. diff. (95th% CI)***	**P**	
Severity indicator					
Major Trauma	0.53 (0.30-0.76)	0.39 (0.26-0.53)	0.14 (-0.14-0.41)	0.3	+35.8%
AIS 1+					
Head	0.34 (0.10-0.58)	0.32 (0.18-0.47)	0.02 (-0.28-0.31)	0.9	+6.25%
Face	0.30 (0.07-0.54)	0.29 (0.15-0.43)	0.02 (-0.27-0.30)	0.9	+3.4%
Neck	0.03 (-0.04-0.11)	0.04 (-0.04-0.11)	-0.002 (-0.12-0.11)	0.9	-25%
Thorax	0.55 (0.29-0.81)	0.62 (0.48-0.76)	-0.07 (-0.37-0.23)	0.6	-11.2%
Abdomen-Pelvis	0.44 (0.18-0.70)	0.36 (0.22-0.50)	-0.08 (-0.23-0.39)	0.6	+22%
Spine	0.55 (0.28-0.82)	0.22 (0.09-0.34)	0.33 (0.01-0.65)	0.01	+50%
Upper extremity	0.70 (0.56-0.84)	0.60 (0.36-0.84)	-0.11 (-0.40-0.18)	0.4	+16%
Lower extremity	0.63 (0.40-0.86)	0.59 (0.46-0.73)	0.04 (-0.24-0.31)	0.8	+6.7%
AIS 3+					
Head	0.18 (0.00-0.37)	0.14 (0.03-0.25)	0.04 (0.19-0.27)	0.7	+28.5%
Face					
Neck					
Thorax	0.52 (0.29-0.76)	0.37 (0.23-0.51)	0.15 (-0.14-0.44)	0.3	+40.5%
Abdomen-Pelvis	0.14 (-0.04-0.33)	0.08 (-0.01-0.18)	0.06 (-0.17-0.28)	0.6	+75%
Spine					
Upper extremity	0.07 (-0.07-0.20)	0.02 (-0.02-0.07)	0.04 (-0.10-0.18)	0.6	+250%
Lower extremity	0.30 (0.05-0.55)	0.20 (0.07-0.32)	0.10 (-0.19-0.40)	0.5	+150%

Adjusted Probabilities of Injury and differences between occupants exposed to side impact airbags and those not

In the models presented above, the influence of the availability of side impact airbags on injury outcomes was examined and 'forced' into each model given its importance to the research question at hand. Table 7.13 presents the probabilities for injury for occupants exposed and not exposed to airbags, the absolute difference in probability and the percent difference.

The single notable result was the increased probability of sustaining an AIS 1+ upper extremity injury, with a 41% higher probability of injury and this is irrespective of collision partner or EBS; this is consistent with some of the earlier reported literature. There were no other effects of the side impact airbag evident.

Table 7.13 Summary of probability of injury for occupants of MA vehicles based on airbag status

Region / Severity	***No airbag***	***Airbag available, deployed***	***Absolute difference in Pr(Head, airbag) to Pr(Head, no airbag)***		***% relative difference airbag to no-airbag***
	Adj. Prob. (95th% CI)	***Adj. Prob. (95th% CI)***	***Adj. Prob. diff. (95th% CI)***	**P**	
Severity indicator					
Major Trauma	0.42 (0.29-0.54)	0.51 (0.23-0.54)	0.09 (-0.21-0.39)	0.6	+21.4%
AIS 1+					
Head	0.33 (0.20-0.46)	0.31 (0.02-0.60)	-0.02 (-0.34-0.29)	0.8	-6.1%
Face	0.25 (0.13-0.37)	0.51 (0.20-0.82)	0.02 (-0.27-0.30)	0.9	+104%
Neck †	Not included in model				
Thorax	0.63 (0.49-0.76)	0.49 (0.19-0.80)	-0.13 (-0.47-0.20)	0.4	-22.2%
Abdomen-Pelvis	0.36 (0.23-0.49)	0.46 (0.17-0.74)	0.09 (-0.22-0.41)	0.5	+27.7%
Spine	0.28 (0.17-0.40)	0.45 (0.17-0.73)	0.16 (-0.14-0.47)	0.3	+61%
Upper extremity	0.63 (0.49-0.77)	0.89 (0.69-1.09)	0.26 (0.02-0.51)	0.04	+41%
Lower extremity	0.60 (0.47-0.72)	0.63 (0.39-0.88)	0.04 (-0.24-0.32)	0.8	+5%
AIS 3+					
Head	0.14 (0.05-0.23)	0.23 (-0.02-0.47)	0.26 (-0.08-0.59)	0.1	+64%
Face					
Neck					
Thorax	0.41 (0.29-0.54)	0.56 (0.13-0.69)	0.15 (-0.14-0.44)	0.3	+36.5%
Abdomen-Pelvis	0.10 (0.02-0.18)	0.14 (-0.09-0.37)	0.06 (-0.17-0.28)	0.6	+40%
Spine					
Upper extremity					
Lower extremity	0.22 (0.11-0.33)	0.25 (-0.03-0.53)	0.03 (-0.27-0.33)	0.8	+13.6%

†side airbag dropped from analysis due to co-linearity

7.4 Key findings and Summary

The primary objective of the analysis of the Australian in-depth dataset was to determine the type of injuries sustained by occupants in Model Year 2000 and newer vehicles. A further goal was to examine the nature of differences, if any, in the injury outcomes of occupants involved in pole side impact crashes compared to those involved in vehicle-to-vehicle side impact crashes, as well as influential factors such as age and airbag availability on injury risk.

At the outset it is essential to state that the small number of occupants (i.e., 42 vehicle-to-vehicle and 16 PSI) constrains the analysis immensely. Nonetheless, the analysis of the ANCIS dataset was useful for a number of reasons, including as a point of comparison with the analysis of the UK CCIS dataset and the analysis of the GIDAS in-depth dataset[13] where similar results were obtained with respect to AIS 3+ injuries of the head, thorax, abdomen-pelvis and lower extremity.

While there were some differences evident in the percent of occupants sustaining AIS 1+ and AIS 3+ injuries in particular, once these apparent differences were examined in logistic regression models adjusting for EBS (km/h), side airbag deployment status and in some instances age and gender, the only difference to emerge was for AIS 1+ spine injuries where those in PSI crashes were at higher risk.

While EBS was consistently – but not always, associated with injury outcomes, increased age was associated with a higher likelihood of multiple serious injuries and thus classification of the occupant as a major trauma case, and also serious thorax injuries. Similarly, the injury risk for females was significantly greater for AIS 1+ injuries of the abdomen-pelvis and AIS 1+ lower extremity injuries.

Consolidation and summary of AIS 3+ injury analysis

Of interest was the degree of similarity in the risk of serious injuries to M1 and N1 vehicle occupants involved in side impact crashes across the *Contracting Parties.* The present report analysed two in-depth data sources, these being the UK CCIS data and the Australian ANCIS system while an analysis of GIDAS data was undertaken by BASt in Germany and presented to the WP. 29 Informal Group. An analysis of the Victorian Transport Accident Commission Claims data was also performed for this project.

Table 7.14 presents the percent of side-impact crash-involved occupants in the CCIS, ANCIS and TAC Claims datasets that sustained an AIS 1+ injury according to specific body regions. As evident, the percent of occupants involved in pole side impact crashes sustaining an AIS 1+ injury was consistently higher in each body region across the datasets. At the AIS 3+ (serious) injury severity level, a higher proportion of occupants involved in pole side impact crashes sustained head, thorax, abdomen-pelvis, and upper and lower extremity injuries than their counterparts involved in vehicle-to-vehicle side impact crashes.

There were however some differences in the frequency of injury; for instance, the percent of PSI crash involved occupants sustaining a thorax injury was 27.8% in the UK in-depth data and 21.2% in the TAC Claims data but 50% of those in the ANCIS dataset sustained an AIS 3+ thorax injury. Interestingly, this pattern is evident for the thorax body region for occupant's involved in vehicle-to-vehicle side impact crashes. In contrast, there were similarities among the in-depth datasets for the frequency of head injury for pole side impact crashes, although this did not hold for vehicle-to-vehicle occupants.

In comparing the findings of the three datasets, it is important to remain cognisant of differences in data coverage and data capture methods; these issues are discussed in full in the respective sections of this report. However what is strongly evident is the frequency of sustaining a serious AIS 3+ injury is considerably higher in pole side impact crashes than in vehicle-to-vehicle side impact crashes.

13 WP.29 Informal Document, PSI-05-04 - (BAST) Pole Side Impact Accidents in Germany; http://www.unece.org/fileadmin/DAM/trans/doc/2012/wp29grsp/PSI-05-04.pdf),

Table 7.14 Percent of injured occupants involved in side impact crashes represented in the UK in-depth data (CCIS), Australian in- depth data (ANCIS) and Victorian (TAC) Claims mass data

	Pole side impact			**Vehicle-to-vehicle side impact**		
	CCIS (n=36)	**TAC** (n=212)	**ANCIS** (n = 16)	**CCIS** (n-263)	**TAC** (n = 865)	**ANCIS** (n = 42)
Head	47.2%	57.1%	37.5%	21.7%	37.1%	31.0%
Face	44.4%	21.2%	31.3%	18.3%	8.1%	28.6%
Neck	19.4%	0.9%	6.3%	40.7%	0.3%	2.4%
Thorax*	41.7%	35.8%	62.5%	36.5%	31.9%	59.5%
Abdomen-pelvis	41.7%	37.7%	43.8%	33.1%	32.5%	35.7%
Spine	(a)	29.7%	56.3%	(a)	33.1%	21.4%
Upper extremity	55.6%	50.5%	56.3%	32.3%	34.0%	71.4%
Lower extremity	41.7%	31.6%	62.5%	27.0%	24.6%	59.5%

(a) spine injuries distributed into region (i.e., C-spine: neck; Thoracic-spine: thorax; Lumbar/sacrum: Abdomen-pelvis

Table 7.15 Percent of occupants involved in side impact crashes sustaining an AIS 3+ injury represented in the UK in-depth data (CCIS), Australian in- depth data (ANCIS) and Victorian (TAC) Claims mass data

IS body region	**AIS 3 + (serious) injury**			**AIS 3 + (serious) injury**		
	Pole			**Vehicle**		
	CCIS (n=36)	**TAC** (n=212)	**ANCIS** (n = 16)	**CCIS** (n-263)	**TAC** (n = 865)	**ANCIS** (n = 42)
Head	27.8%	11.8%	25.0%	4.9%	5.5%	11.9%
Face	Nil	Nil	Nil	Nil	Nil	Nil
Neck	Nil	Nil	Nil	0.4%	Nil	Nil
Thorax*	27.8%	21.2%	50.0%	8.0%	8.7%	38.1%
Abdomen-pelvis	11.1%	6.6%	18.8%	5.3%	2.0%	7.1%
Spine	(a)	1.4%	6.3%	(a)	0.7%	Nil
Upper extremity	Nil	0.9%	6.3%	Nil	Nil	2.4%
Lower extremity	19.4%	8.5%	31.3%	3.0%	1.3%	19.0%

(a) spine injuries distributed into region (i.e., C-spine: neck; Thoracic-spine: thorax; Lumbar/sacrum: Abdomen-pelvis

Table 7.16 presents a snap-shot summary of the analysis of AIS 3+ injuries and the associated odds ratios across the UK CCIS in-depth data, the ANCIS data, the TAC Claims data and the GIDAS dataset. It is evident from Table 7.16 that PSI crashes were associated with higher odds of injury relative to vehicle-to-vehicle side impact crashes. In most instances, the odds of injury for occupants involved in PSI are at least twice that for occupants of vehicle-to-vehicle side impact crashes. Moreover, the pattern of increased risk is consistent across the four datasets.

The impact of sample size is clear in the analysis of the Australian in-depth data through the ANCIS study, where there were only 16 PSI occupants. It is notable that while there were 15 PSI occupants in the GIDAS dataset, the odds of sustaining an AIS 3+ thorax injury was three times higher in PSI relative to vehicle-to-vehicle side impact crashes.

The analysis of multiple datasets across multiple jurisdictions highlights the universal nature of the increased severity of injury associated with pole side impact crashes. There would be considerable value in future analysis combining the in-depth datasets to determine the joint pattern of injuries and injury risk. Such an approach would capitalise on the consistency of data collected, permit adjustment for confounding variables and differences across the datasets, whilst providing increased statistical power afforded due to a larger sample size.

Table 7.16 Odds ratios for AIS 3+ injuries for select regions for UK in-depth data, Australian in-depth and mass data, and German in-depth data

AIS 3+, body region	United Kingdom			Australia						Germany[d]		
	CCIS[a]			TAC Mass Claims data[b]			ANCIS[c]			GIDAS[d]		
	PSI (n=36) relative to V2V (n=263)			PSI (n=212) relative to V2V (n=865)			PSI (n=16) relative to V2V (n=42)			PSI (n=15) relative to V2V (n=88)		
	OR	**95th % CI**	**P**	**OR**	**95th % CI**	**P**	**OR**	**95th % CI**	**P**	**OR**	**95th % CI**	**P**
Head	5.15	1.74-15.29	0.03	2.26	1.36-3.76	<0.001	1.41	0.24-8.39	0.7	3.10	*Not reported*	0.1
Thorax	3.87	1.31-11.42	0.01	2.83	1.89-4.24	<0.001	2.13	0.21-4.62	0.3	3.09	*Not reported*	0.04
Ab-Pelvis	0.93	0.19-4.44	0.9	3.55	1.72-7.33	<0.001	1.88	0.19-18.35	0.6	2.20	*Not reported*	0.4
Lower Extremity	4.79	1.22-18.79	0.02	7.27	3.37-15.66	<0.001	1.81	0.09-1.75	0.2	-		

[a] Chapter 4
[b] Chapter 6
[c] Chapter 7
[d] Claus Pastor, BASt, http://www.unece.org/fileadmin/DAM/trans/doc/2012/wp29grsp/PSI-05-04.pdf

7.5 Appendix 7a – Age and anthropometric characteristics of front row occupants involved in side impact crashes

To further understand the occupant characteristics of occupants injured in side impact crashes, the age, weight and height cumulative distribution of side impact cases in the ANCIS dataset are presented below. It is important to note that no exclusions were made on the basis of vehicle model year or the damage profile other than it occurred to the left or the right side of the vehicle. Only front row occupants are included in the analysis. In total, there were 304 side impact cases (struck side and non-struck side), with 102 being PSI and 202 being vehicle-to-vehicle side impact crashes. The information is presented with a view to informing the choice of the ATD in the proposed GTR.

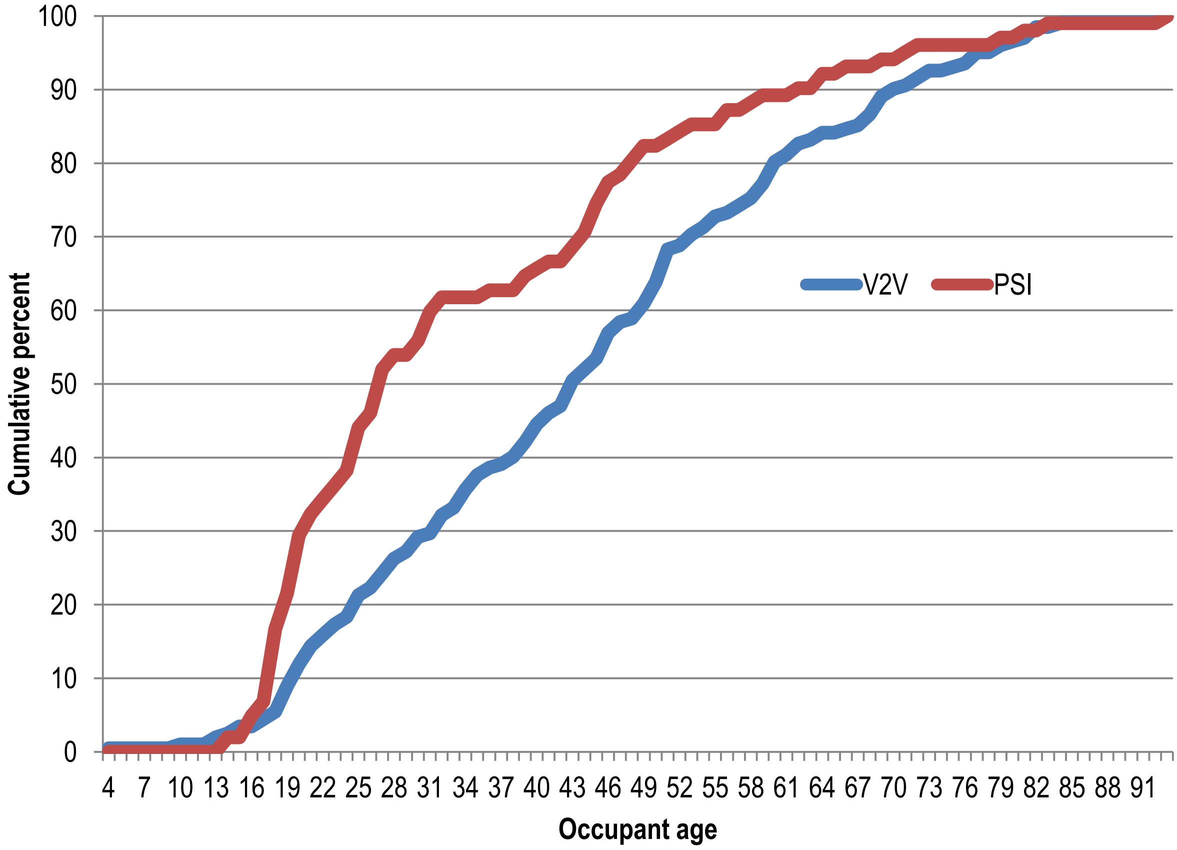


Figure A7.1 Cumulative age distribution of front row occupants involved in struck-side and non struck-side impact crashes

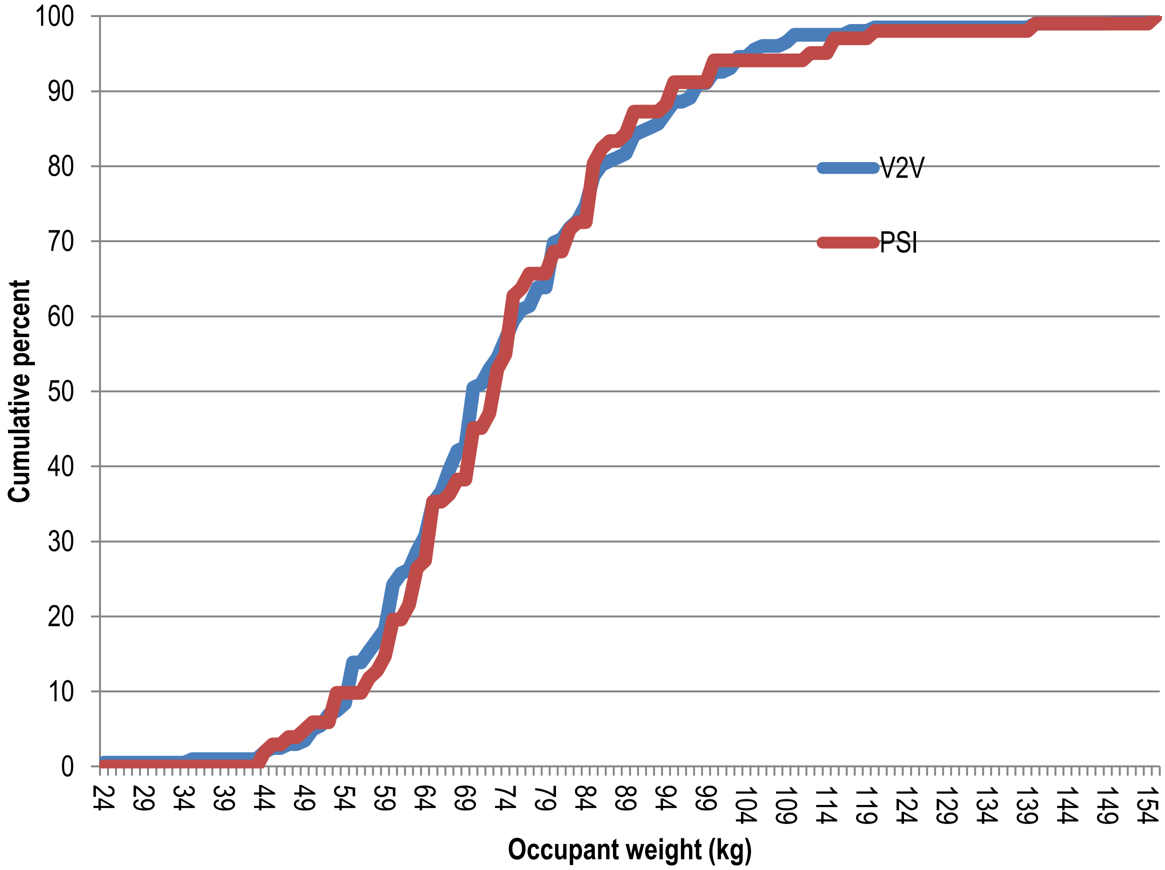


Figure A7.2 Cumulative weight distribution of front row occupants involved in struck-side and non struck-side impact crashes

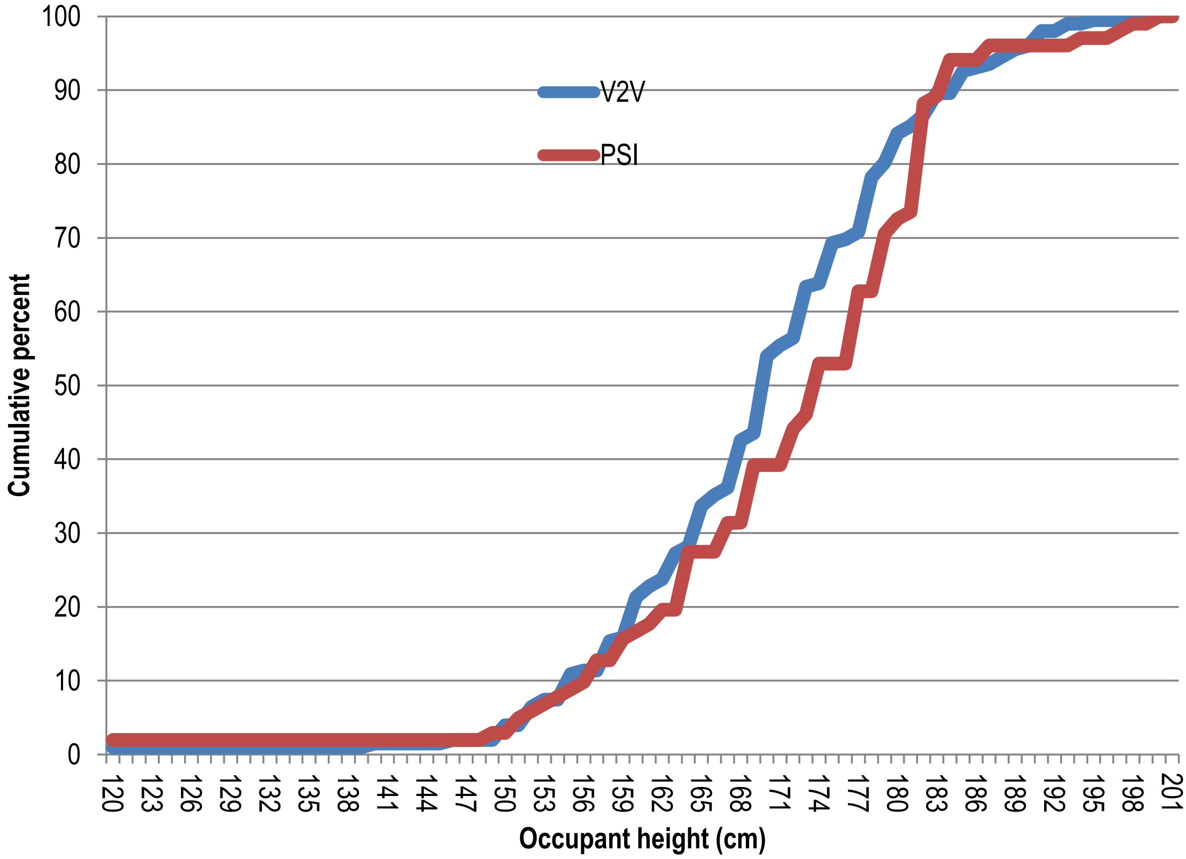


Figure A7.3 Cumulative height distribution of front row occupants involved in struck-side and non struck-side impact crashes

8 ASSESSMENT OF LIKELY BENEFITS OF A POLE SIDE IMPACT GTR AND ASSOCIATED COSTS

This report set out to examine the need for, and the likely benefits associated with, the introduction of a pole side impact GTR. The previous chapters have presented significant evidence for the differential injury outcomes for occupants of M1 and N1 category vehicles involved in pole side impact crashes and vehicle-to-vehicle side impact crashes. Specifically, pole side impact crashes are associated with higher mortality and a higher likelihood of sustaining serious injury. In particular, the head and the thorax are at significantly higher risk in pole side impact crashes than vehicle-to-vehicle crashes. There is also considerable research evidence pointing to the benefits of side curtain airbags and our analysis of mass crash data and in-depth data supports this research. This chapter therefore assesses whether the proposed PSI GTR is likely to be cost-effective.

8.1 Rationale - Modelling the benefits of a proposed PSI GTR

The principal question of this chapter is:

> **What is the incremental benefit of the GTR in terms of lives saved, injuries avoided, and the cost-benefit, given ESC fitment, over and above the current safety implementation process?**

To address this question, a number of accurate data sources are required in order for the necessary inputs to be derived. The chapter steps through each of the required inputs and culminates in a summary of the incremental benefits – both in person and financial terms, and the associated incremental costs of implementation of the GTR. The key steps in the analysis are as follows:

1. Project the future number of crashes given the population estimates;
2. Account for the likely influence of ESC in reducing side impact crashes;
3. Account for the rate of penetration of side impact airbags though the fleet and their effectiveness in mitigating fatalities and injuries;
4. Determine the benefits afforded by the proposed PSI GTR, by injury severity;
5. Convert 'benefits' into financial estimates, by applying known injury distributions and associated cost of injury values, and
6. Apply the incremental cost of meeting the GTR for M1 vehicles and appropriate costs for N1 vehicles, whilst accounting for the current side curtain airbag fitment rate and penetration through the fleet.

Due to the nature of the data required, we use the Australian State of Victoria as the basis of estimation. Victoria accounts for approximately 19% of all driver and passenger fatalities[32] , represents 25.7% of registered M1 and N1 vehicles[13], and 24.8% of the national population. Data from Victoria is also the most robust in terms of providing all necessary inputs required for the analysis. The final step is the extrapolation of the person-based benefits to national values based on population and registration census statistics.

8.2 Current crashes and projections of future crashes, the influence of ESC and the impact of the GTR

The key end point for this sub-section is the estimation of the number of fatalities and injuries avoided due to the implementation of the PSI GTR. Following regulatory analysis guidelines, a 30 year period is examined, with benefits and costs accrued over the entire period determined.

To arrive at this end-point, a number of key sub-tasks must be performed, these being:

1. Project the future number of crashes using future population projections and the historical relationship between crashes (by type) and the number of registered vehicles;

2. Account for the likely influence of ESC in reducing side impact crashes using known ESC effectiveness values, and

3. Determine the benefits afforded by the proposed PSI GTR, by using published estimates of side impact airbags and incorporating an incremental benefit.

Each of these steps and the data used is described below.

8.2.1 Projecting the future number of vehicles in the fleet and future crashes

We use actuarial methods to determine the future number of crashes using projected population, 30 years into the future (Australian Bureau of Statistics) and also historical patterns in the number of registered vehicles and known crash numbers.

The **first step** is to determine the number of vehicles for each year in the future. This requires two inputs:

1. Projected population by the Australian Bureau of Statistics[12], and

2. The historical vehicle ownership ratio, expressed as the number of registered vehicles[13, 52] per persons aged 15 years and older in the population.

Using the above two inputs, the number of registered vehicles can be derived for each year, 2016 – 2045. The GTR is modelled as commencing in 2016.

The **second step** is to determine the number of expected fatalities and injuries for each year in the future. To do so, we use the historical vehicle involvement rate in side impact fatalities to establish the 'fatalities per registered vehicle' and 'serious injuries per registered vehicle.

The inputs here are:

1. The number of registered vehicles for each year of available crash data;[13, 52]

2. Number of persons killed and injured[10, 32, 53] (see Section 8.2.2; also Chapter 5), and

3. From Step 1, we use the number of registered vehicles, for each year.

The end result of Step 1 and Step 2 is the number of fatalities and persons injured for every future year.

The basis of the fatalities and injuries per registered vehicle are those specific to side impact crashes (Step 2, data input 2). Hence, there is no need to apply any proportion to segment the future number of fatalities and injuries into their constituent parts, for instance, frontal, side impact, or rollover.

The crashes in this analysis relate to side impact crashes where the damage profile engaged the occupant compartment, and where there was only one impact; that is, crashes with two or more impacts were excluded.

8.2.2 Establishment of base-year crash rates

With knowledge of the future population and the vehicle: person ratio, the number of registered vehicles into the future can also be projected. Using the 'base-year' number of fatalities and injuries sustained in side impact crashes, the future number of side impact fatalities and injuries can be determined. This is done on the basis of the number of known fatalities and serious injuries per registered vehicle in the 'base year'.

The latest available full year of road data at the time of writing the report was the 2010 Victorian Police Reported Casualty data. Due to data availability and data quality constraints, Victorian data is used as the basis of estimating the likely benefit of the proposed PSI GTR.

Table 8.1a Number of fatalities, injuries and uninjured occupants of M1 and N1 vehicles by side impact collision partner, Victoria 2010

	Side impact collision partner			
M1 / N1 occupants	**Vehicle**	**Pole**	**Other fixed**	**Total**
Fatal injury	25 (0.9%)	29 (8.1%)	1 (1.7%)	55 (1.7%)
Admitted to hospital	331 (11.8%)	127 (35.3%)	1 (25.0%)	473 (14.7%)
Injured – not admitted	949 (33.8%)	137 (38.1%)	15 (41.7%)	1111 (34.4%)
Non-injury	1502 (53.5%)	67 (18.6%)	25 (31.7%)	1588 (49.25)
Total	2807 (100%)	360 (100%)	60 (100%)	3227 (100%)

The data presented in Table 8.1a is the number of occupants of M1 and N1 vehicles involved in side impact crashes. For the purposes of determining the likely benefits of the PSI GTR, consideration is given only to those killed and injured, and it is necessary to perform the analysis for occupants of M1 and N1 vehicles separately.

Table 8.1b and Table 8.1c disaggregate the fatality and injury data presented in Table 8.1a for use in the benefits estimation process presented in the following sections. For the benefits analysis, only front and rear outboard occupants will be used (refer Table 8.1c).

Table 8.1b Number of fatalities, injuries and uninjured occupants for M1 and N1 vehicles by side impact collision partner, Victoria 2010

	Side impact collision partner			
M1 occupants	**Vehicle**	**Pole**	**Other fixed**	**Total**
Fatal injury	23 (0.9%)	27 (8.8%)	1 (2.0%)	51 (1.8%)
Admitted to hospital	309 (12.3%)	110 (35.7%)	10 (20.0%)	429 (14.9%)
Injured – not admitted	851 (33.8%)	112 (36.4%)	22 (44.0%)	985 (34.2%)
Non-injury	1337 (53.1%)	59 (19.2%)	17 (34.0%)	1413 (49.1%)
Total	2520 (100%)	308 (100%)	50 (100%)	2878 (100%)
N1 occupants	**Vehicle**	**Pole**	**Other fixed**	**Total**
Fatal injury	2 (0.7%)	2 (3.8%)	0 (nil)	4 (1.1%)
Admitted to hospital	22 (7.7%)	17 (32.7%)	5 (50%)	44 (12.6%)
Injured – not admitted	98 (34.1%)	25 (48.1%)	3 (30%)	126 (36.1%)
Non-injury	165 (57.5%)	8 (15.4%)	2 (20%)	175 (50.1%)
Total	287 (100%)	52 (100%)	10 (100%)	349 (100%)

Table 8.1c Number of fatalities, injuries and uninjured occupants by seating position for M1 and N1 vehicles by side impact collision partner, Victoria 2010

			Collision Partner			
Class	**Seating position**	**Injury severity**	**Vehicle**	**Pole**	**Fixed - other**	**Total**
M1	Front	Fatal injury	19 (0.9%)	25 (9.9%)	1 (2.6%)	45 (1.9%)
		Admitted to hospital	259 (12.1%)	94 (37.2%)	10 (25.6%)	363 (15%)
		Injured – not admitted	750 (35.2%)	94 (37.2%)	19 (48.7%)	863 (35.6%)
		Non-injury	1104 (51.8%)	40 (15.8%)	9 (23.1%)	1153 (47.6%)
		Total	2312 (100%)	253 (100%)	39 (100%)	2464 (100%)
	Rear (outboard)	Fatal injury	4 (1.2%)	2 (4.3%)	0 (-)	6 (1.5%)
		Admitted to hospital	45 (13.5%)	12 (25.5%)	0 (-)	57 (14.7%)
		Injured – not admitted	83 (24.9%)	15 (31.9%)	3 (37.5%)	101 (26%)
		Non-injury	202 (60.5%)	18 (38.3%)	5 (62.5%)	22 (57.8%)
		Total	334 (100%)	47 (100%)	8 (100%)	389 (100%)
	Rear (centre)	Fatal injury	- (-)	-(-)	- (-)	- (-)
		Admitted to hospital	5 (9.3%)	4 (50%)	0 (-)	9 (13.8%)
		Injured – not admitted	18 (33.3%)	3 (37.5%)	0 (-)	21 (32.3%)
		Non-injury	31 (57.4%)	1 (12.5%)	3 (100%)	35 (53.8%)
		Total	54 (100%)	8 (100%)	3 (100%)	65 (100%)
	All	Fatal injury	23 (0.9%)	27 (8.8%)	1 (2%)	51 (1.8%)
		Admitted to hospital	309 (12.3%)	110 (35.7%)	10 (20%)	429 (14.9%)
		Injured – not admitted	851 (33.85)	112 (36.4%)	22 (44%)	985 (34.2%)
		Non-injury	1337 (53.1%)	59 (19.2%)	17 (34%)	1413 (49.1%)
		Total	2520 (100%)	308 (100%)	50 (100%)	2878 (100%)
N1†	**Seating position**	**Injury severity**	**Vehicle**	**Pole**	**Fixed - other**	**Total**
	Front	Fatal injury	2 (0.8%)	2 (4.4%)	- (0)	4 (1.3%)
		Admitted to hospital	20 (7.6%)	13 (28.9%)	5 (55.6%)	38 (12%)
		Injured – not admitted	92 (35.1%)	23 (51.1%)	2 (22.2%)	117 (37%)
		Non-injury	148 (56.5%)	7 (15.6%)	2 (22.2%)	157 (49.7%)
		Total	262 (100%)	45 (100%)	9 (100%)	316 (1005)
	Rear (outboard)	Fatal injury	-	-	-	-
		Admitted to hospital	2 (8.7%)	4 (57.1%)	(-)	6 (19.4%)
		Injured – not admitted	6 (26%)	2 (28.6%)	1 (100%)	9 (29%)
		Non-injury	15 (65%)	1 (14.3%)	0 (-)	16 (51.6%)
		Total	23 (100%)	7 (100%)	1 (100%)	31 (100%)
	All	Fatal injury	2 (0.7%)	2 (3.8%)	(-)	4 (1.1%)
		Admitted to hospital	22 (7.7%)	17 (32.7%)	5 (50%)	44 (12.6%)
		Injured – not admitted	98 (34%)	25 (48%)	3 (30%)	126 (36.1%)
		Non-injury	165 (57.5%)	8 (15.4%)	2 (20%)	175 (50.1%)
		Total	287 (100%)	52 (100%)	10 (100%)	349 (100%)

† 2 non-injured rear-centre occupants not presented in table

8.2.3 Establishment of the GTR increment effectivenes value

In considering the need for a pole side impact regulatory test, it is critical to remain cognisant of the high frequency of serious head injuries sustained in all side impact crashes. As noted by Meyerson[54], the current Moving Deformable Barrier used in existing side impact regulatory tests fails to address head injury risk. Based on the analysis of multiple crash databases (i.e., CCIS, ANCIS, and TAC Claims Data), serious head, thorax and abdomen-pelvis injuries remain a pressing concern, even among recently designed and manufactured vehicles that comply with the current UN ECE R95 side impact protocol.

The logic behind the introduction of a pole test is that in order to meet the test requirements specific countermeasures designed to protect the head, thorax, and the abdomen-pelvis regions would need to be improved. For information, a schematic of the pole test is represented graphically below (Figure 8.1).

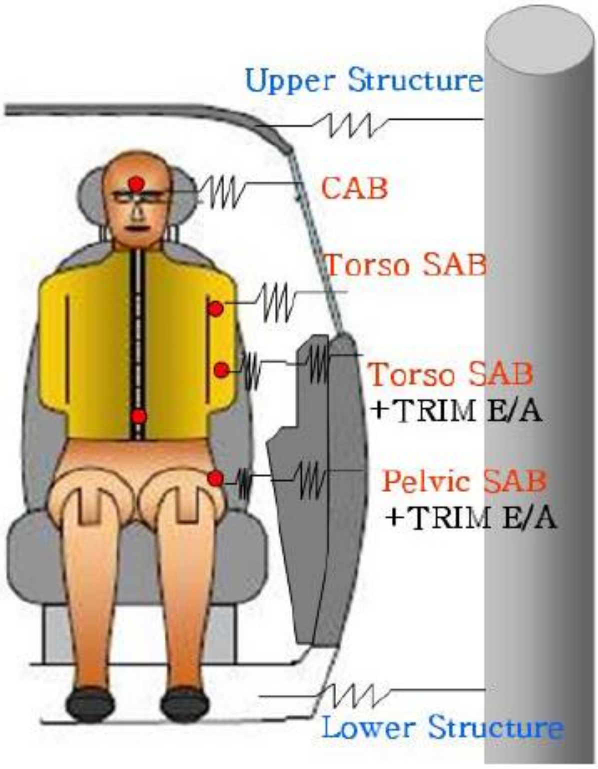


Figure 8.1 The oblique pole side impact test with enegy absorption (E/A) types shown[55]

Research presented to the Informal Group by the US NHTSA representative[54] and associated discussions highlighted the modifications required to meet the requirements of an oblique pole side impact test. These modifications to current vehicles include:

1. Installation of head protecting side airbags;
2. Installation of thorax protecting side airbags; and / or
3. Structural changes to the lateral aspect of the vehicle.

In their assessment of the potential benefits of introducing an oblique PSI test, vehicle rollovers, complete ejection cases, children, occupants in the rear seat and low and high delta-V crashes were excluded. The US NHTSA evaluation estimated that 311 lives and 361 serious injuries would be prevented when all light vehicles meet the test requirements using two sensors with curtain and thorax side airbags (see p. E-3[15]). Within the FMVSS 214 Amending report a 46.9% reduction in struck-side and non-struck side occupant (front and rear) fatalities was estimated to be achievable given implementation of the oblique side impact test.[15] This reduction percent was established on the basis of data presented by NHTSA. Specifically, NHTSA established the target population of killed occupants (n = 2853) and estimated that 1029 lives would be saved due to current SAB systems. NHTSA then estimated that an additional 311 lives would be saved due to the oblique test, for a total reduction of 1340 lives; hence 1513 occupants would be killed. In percentage reduction terms, current SAB systems would deliver a 36% fatality benefit and the oblique test would add an additional 10.9% fatality reduction benefit; the net fatality reduction is therefore 46.9%. The addition of the oblique test represents 23.2% of the net fatality benefit (i.e., 10.9% of 46.9%).

The enhanced protection of the oblique test has as its basis that to meet the test requirements key changes to the design of current airbag and airbag sensor systems would be required. Collectively, these changes would be expected to improve the effectiveness of side airbag systems by providing improved coverage for a broader range of occupants, and therefore would provide improved protection across a larger range of impact angles experienced in real-world crashes. Specifically, it is likely that the oblique test using a 50th percentile male ATD will require larger seat-mounted side airbags to account for the pole impacting the vehicle in a more forward location relative to the vehicle seat and ATD thorax than current side impact tests. This is due to the fact that in the oblique impact configuration that the ATD will move forward and toward the impacting and intruding pole. In making the thorax airbag larger, greater protection will be afforded to other body regions and may actually serve as a mechanism to channel the load path more evenly and thus avoid concentrated loading of the thorax; this will be necessary to reduce the energy absorbed through the ATD rib deflection. The larger airbag systems can be seen in the images below where a vehicle from the North American market compliant with FMVSS-214 (Figure 8.2: top right panel) is compared to the same vehicle sold in the Australian market (Figure 8.2: top left panel). Notably, the Australian market vehicle was an ANCAP 5 star rated vehicle.

Australian model	North American model

Figure 8.2 Comparison of curtain and thorax side airbags (below) fitted to the same vehicle model in the Australian and North American market (supplied by T. Belcher)

A further source of increased protection is that the oblique test performance requirements will likely demand improved impact detection systems to be developed and installed. This has important implications for the 'tuning' of the airbag deployment in the event of a crash. More reliable sensors, that is, sensors with an improved ability to detect a side impact crash which then leads to optimised side airbag deployment, would be expected to have benefits across the full range of real-world side impact crashes.

The use of the WorldSID 50th Male ATD would be expected to more accurately capture the risk of injuries to occupants by being of higher biofidelity and more accurate anthropometry than earlier generation ATDs. A high correlation between the ATD measured responses and the occupant in the field is critical to ensure the validity of the crash test itself. The anthropometry of the WorldSID 50th Male ATD offers improved opportunities to align the seating position and airbag design more appropriately, leading to improved head injury protection in particular.

The addition of the 5th Female ATD to the oblique pole side impact test specification is important to mention. As stated, the 5th Female at 150 cm in height is regarded to best represent drivers under 163 cm in height. Hence, with the combination of the 50th percentile male at 175 cm, the addition of the 5th Female ATD provides broader coverage for the full range of occupants and seating positions, particularly through design modifications to the head protecting curtain airbag itself (i.e., larger, longer reach, great volume). The importance of incorporating the 5th Female ATD to the test protocol is seen in Figure 8.3. It is evident that in meeting the test requirements of the PSI GTR, a broader range of occupants would be protected. This is pertinent to the overall assessment of the PSI GTR, as it is proposed that the WorldSID 5th female be incorporated as part of Phase 2 of the GTR implementation. It is considered that further gains will be achieved through the addition of the 5th Female to the test battery as it will be necessary to provide coverage for a broader spectrum of real-world crash configurations, particularly as some manufacturers may elect to install a 4-sensor deployment system.

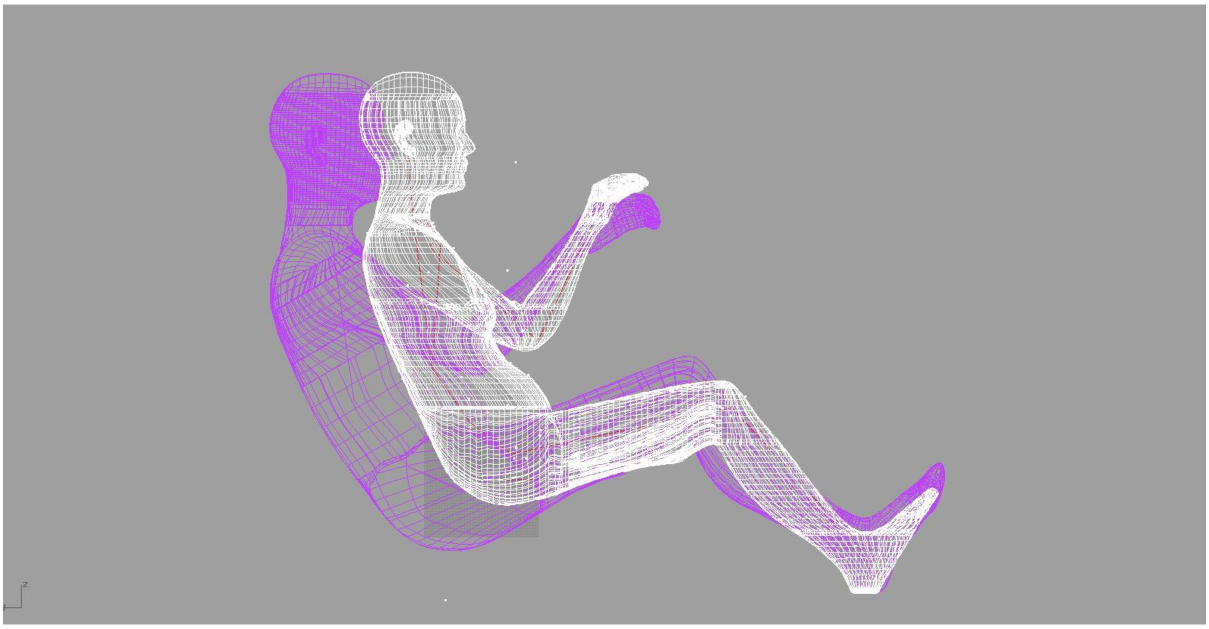


Figure 8.3 Seating position of the 5th percentile female relative to the 50th percentile male occupant (image supplied by T.Belcher; original from UMTRI).

For the estimation of GTR effectiveness, based on the scope and number of modifications and innovations required for vehicles to meet the proposed PSI GTR test specification – and on the basis of the US NHTSA evaluation, it is reasonable to assume that the PSI GTR would deliver a 30% incremental benefit over and above existing side impact protection levels.

Based on the current observed fatality and serious injury reduction benefits associated with side impact airbags (and their associated structural modifications) of 32% and 34% respectively, the GTR increment or added benefit of 30% represents an added 9.6% (i.e., 0.3 of 32%) and 10.2% for fatality and injury benefits.

8.2.4 Accounting for ESC in reducing the crashes a GTR can influence

As determined in Section 8.2.1, we determined the number of expected fatalities and persons injured for each year, 2016 to 2045.

The next step **(Step 3)** in the estimation process is to account for the number of crashes that ESC is likely to prevent based on known effectiveness values. These 'prevented' crashes are then *removed* from the pool of crashes that side impact airbag systems are likely to influence.

In determining the number of crashes ESC will prevent two assumptions are required:

1. Determine the proportion of PSI and other side impact crashes ESC will influence, and
2. Determine a crash reduction value for ESC; that is, specification of the percent of crashes relevant to ESC that will be avoided.

Crashes influenced by ESC – based on the specification of ESC and past research[56-58], two assumptions are made in the analysis here:

a. Assume that **all** single vehicle crashes are amenable to ESC as they departed the road as single vehicle accidents; this is relevant for pole side impact crashes and 'other fixed object impacts'.

b. Assume that **none** of the vehicle-to-vehicle impacts are amenable to ESC as they are intersection crashes in most instances

8.2.4.1 Research into the effectiveness of ESC from Monash University

Monash University Accident Research Centre undertook an evaluation on ESC using police-reported crash data from five Australian states and NZ as part of the Used Car Safety Ratings program. The research examined the crash involvement of 27,915 1998 model year (MY) and newer vehicles with ESC fitted and 439,543 vehicles without ESC fitted. Table 8.2 presents the key findings with respect to single and multiple vehicle crashes for M1 and N1 vehicles.

For M1 vehicles: ESC was associated with an 18.6% reduction in single vehicle passenger car crashes, while a higher benefit was evident for single vehicle SUVs crashes (56%).

For multiple vehicle side impact crashes no ESC benefit was apparent. This is as expected as ESC is purported only to mitigate loss of stability which are characteristic of run-off-road and rollover crashes.

For N1 vehicles: This category includes 4 x 2 pick-ups, 4 x 4 pickups and vans, known collectively as 'light commercial vehicles'. In the analysis conducted, there were insufficient cases of 'commercial vehicles' to show a statistically significant effect for ESC on 'commercial' vehicle crash rates, with the point reduction estimate being approximately 10%. There was no effect of ESC, as expected on multiple vehicle impact crashes.

Previous research has demonstrated a range of benefits for light commercial vehicles, and Fitzharris et al[59] in a cost-effectiveness study of ESC adopted a 32% crash reduction value of ESC, with crash reduction values of 16% - 45% used for sensitivity analysis.

Table 8.2 MUARC estimated values of the crash reduction effect of ESC for M1 and N1 vehicles[58]

M1 VEHICLES						
		% Crash reduction		**Stat. sig.**	**95% CL**	
Single vehicle accident	***# vehicles with ESC***	***Unadjusted***	***Adjusted***[14]		***Lower***	***Upper***
Passenger cars	9,354	23.60	18.60	<.0001	13.06	23.78
4WD	2091	53.58	56.21	<0.001	49.49	62.04
Multiple vehicle side impact						
Passenger cars	12,053	1.59	-3.56	0.1	-8.53	1.17
4WD	3899	2.14	-0.76	0.5	-9.06	6.91
N1 VEHICLES						
Single vehicle accident						
Commercials	198	17.56	10.43	0.5	-25.81	36.73
Multiple vehicle accident						
Commercials	320	9.62	10.94	0.3	-11.85	29.10

8.2.4.2 Research into the effectiveness of ESC from the USA, Germany and elsewhere

The effectiveness of ESC in reducing crashes is now well understood with a number of evaluation studies having been undertaken.

A meta-analysis of 12 studies demonstrated that ESC prevents about 40% of all crashes involving loss of control, with the largest reductions found for rollover crashes (approx. 50%), followed by run-off-road (approx. 40%) and other single vehicle crashes (approx. 25%), while no effect was demonstrated for multiple vehicle or rear-end crashes.[60] ESC had a larger crash reduction benefit for SUVs than for passenger cars. In considering the findings, Høye suggested that these reduction values are '...likely to be somewhat overestimated, especially for non-fatal crashes'.

In an assessment of the likely benefits of ESC in light commercial vehicles, Fitzharris et al.[59] conducted a review of the published literature on ESC effectiveness; these are Category N1 vehicles. In six of the eight studies, the ESC crash reduction benefit was approximately 32%, with one study pointing to a 16% benefit and another reporting a 45% crash reduction benefit.

As part of the Informal Group on Pole Side Impact GTR (PSI), Meyerson[54] cited an ESC crash reduction value of 35% for passenger cars and 67% for SUVs in calculating the likely benefits of an oblique pole side impact test. After adjusting for the composition of the fleet, ESC benefit values of 41% and 35% were used for fatality crashes and serious injury crashes.

At the same Informal Group meeting, Gail, Pöppel-Decker and Lorig presented a safety evaluation of vehicle stability control for passenger cars involved in rural crashes. Using national, police reported data for the period 2000 to 2005 inclusive, Gail et al estimated that vehicle stability control was responsible for a 40% reduction in the number of fatalities and severely injured drivers.

In summary, the ESC benefit values reported by Monash University are consistent with international studies on ESC effectiveness. As such, we can have considerable confidence in applying the ESC effectiveness values presented in Table 8.2.

---

14 The adjusted ESC effectiveness analysis accounts for driver factors (sex and age) and crash characteristics (year of crash, speed zone and jurisdiction of crash location, the number of vehicles involved and year of crash). By doing so the estimates of ESC are 'adjusted' for the effect of non-vehicle factors on injury outcomes.

8.2.4.3 ESC effectiveness values used in this report

The evaluations of ESC effectiveness reported above provide the basis for selecting an appropriate ESC benefit value for use in the estimation of the likely benefits associated with the PSI GTR.

- For M1 vehicles:
    - For single vehicle PSI crashes, a 20.74% ESC crash reduction value is used[15]. This value reflects the composition of this class of vehicles involved in injury crashes and the differential effectiveness of ESC between passenger cars and SUVs. Analysis of the crash data indicates that 94.3% of persons injured in PSI crashes were occupants of passenger cars compared to 5.7% who were occupants in SUVs.
    - For vehicle-to-vehicle crashes, ESC will have no effect.[16]
- For N1 vehicles:
    - For single vehicle PSI crashes, a 45% ESC crash reduction value is used based on previous research and the composition of the Victorian/Australian light commercial vehicle fleet (i.e. 4 x 2 pick-up, 4 x 4 pick-up and van registrations as a proportion of light commercial vehicle registrations).
    - For vehicle-to-vehicle crashes, ESC will have no effect.

8.2.4.4 Accounting for ESC fitment rates and penetration through the fleet

Having established the future number of vehicles and hence crashes, and of these the number of occupants killed and injured in side impact crashes (see Section 8.2.1), we apply the specified crash reduction values of ESC for M1 pole side impact crashes involving front seat occupants (i.e. single vehicle effectiveness values of 20.74% for M1 and 45% for N1) to determine the influence of ESC. However, we must also consider the implementation schedule of ESC as ESC will not reach 100% of the fleet until some time in the future.

To ensure we account for fleet penetration of ESC, we use the number of new vehicles sold with ESC and the total number of vehicles registered (see Appendix 8b for detail). This process accounts for the fact ESC will not reach its full 20.7% per annum benefit (i.e., for M1 vehicles) in PSI and other fixed object crashes (and 45% for N1 vehicles) until 100% saturation of ESC into the fleet is reached. Application of the multiplier and the crash reduction value of ESC results in the number of PSI fatalities saved due to ESC; hence, the balance between the projected number of crashes for each future year is the number amenable to enhanced side impact protection. This process is presented below.

The method described above is presented in Table 8.3a for fatalities and Table 8.3b for injury crashes. The following interpretation can be given to each column:

Column A_f The number of fatalities due to side impact crashes for every year; this is based on the population and known vehicle ownership ratios, and the number of fatalities per vehicle registered.

Column B_f This is a 'multiplier' value that reflects ESC penetration into the fleet, and reflects historic fitment rates, as well as the profile of the vehicle fleet in Victoria; this states that in 2016 76% of all registered passenger vehicles will have ESC fitted.

15 The 20.74% ESC effectiveness value is the sum of the product of the ESC vehicle effectiveness by the proportion of occupants in the vehicle types, i.e., [20.74% = (0.943*0.186)+(0.057+0.5621)]

16 Passenger car occupants represent 92.6% of injured occupants cf. 7.4% for SUVs

Column C_f A second multiplier that is the product of ESC penetration by the nominated crash reduction benefit of ESC for pole side impact crashes.

Column D_f The product of Column A (PSI fatalities) x Column C (multiplier 2); this is the number of fatalities 'saved' by the introduction of ESC, and this is determined for every year.

Column E_f This is the 'balance' of pole side impact fatalities that remain, and consequently are 'amenable' to side impact protection via other means.

By way of example, for the year 2016, 27 PSI fatalities are predicted to occur (A_f), however the safety benefit of ESC will result in the reduction of 4 fatalities (D_f). Hence, 23 fatalities are expected to remain (E_f), and would be amenable to improved side impact protection demanded by the GTR.

By 2044, when all M1 vehicles are expected to have ESC fitted, 8 lives would be saved due to ESC. This means that despite ESC having by this stage been fitted to 100% of vehicles in the fleet, 32 pole side impact fatalities will remain, having initially estimated 40 fatalities for that year. Over the 30 year period, ESC is estimated to result in the reduction of 202 driver and front passenger fatalities where a pole would otherwise have impacted the side of the vehicle. Despite this, 805 fatalities remain and are amenable to improved side impact protection

Table 8.3a Pole/tree side impact M1 front seat occupant fatalities amenable to improved side impact protection based on applying ESC crash reduction benefits given its known implementation, estimated effectiveness and the predicted number of future fatalities

Year	**Side impact fatalities (Predicted)**	**ESC penetration into the fleet (prop of fleet with ESC)**	**ESC effectiveness (20.74% reduction multiplied by ESC penetration)**	**ESC benefit per annum (PSI lives saved)**	**Amenable to Improved Side Impact Protection**
	A_f	**B_f**	**C_f**	**D_f**	**E_f**
2016	27	76.6%	0.158	4	23
2017	28	80.5%	0.163	5	23
...					
2044	40	100%	0.207	8	32
2045	40	100%	0.207	8	32
TOTAL	**1007**	**-**	**-**	**202**	**805**

Following the above, Table 8.3b presents the same process for injuries sustained.

For the sake of being thorough, the following interpretation can be given to each column:

Column A_i The number of injuries due to side impact crashes for every year; this is based on the population and known vehicle ownership ratios, and the number of injuries per vehicle registered.

Column B_i This is a 'multiplier' value that reflects ESC penetration into the fleet, and reflects historic fitment rates, as well as the profile of the vehicle fleet in Victoria.

Column C_i A second multiplier that is the product of ESC penetration by the nominated crash reduction benefit of ESC for pole side impact crashes.

Column D_i The product of Column A (PSI injured) x Column C (multiplier 2); this is the number of injuries 'saved' by the introduction of ESC, and this is determined for every year.

Column E_i This is the 'balance' of pole side impact injuries that remain, and consequently are 'amenable' to side impact protection via other means.

Table 8.3b Number of M1 front seat occupants <u>injured</u> in pole/tree side impact crashes amenable to improved side impact protection, based on applying ESC crash reduction benefits

Year	Predicted number of persons injured	ESC penetration into the fleet (prop of fleet with ESC)	ESC effectiveness (20.74% reduction multiplied by ESC penetration)	ESC benefit per annum (PSI injuries saved)	Amenable to Improved Side Impact Protection
	A_i	B_i	C_i	D_i	E_i
2016	204	76.4%	0.158	32	172
2017	207	80.5%	0.163	35	172
...					
2044	300	100%	0.207	62	238
2045	304	100%	0.207	63	241
TOTAL	**7574**	**-**	**-**	**1521**	**6053**

The above two tables present the number of front row occupants killed and injured in PSI after accounting for the effects of ESC. As stated above, ESC is not expected to have any influence on multiple vehicle side impact crashes and hence require alternative side impact protection countermeasures.

8.2.5 Accounting for the penetration of side impact airbags through the fleet

The previous section described the process by which the number of fatalities and injuries in the future that remain open to influence by other safety means - as they still occur despite the benefits of ESC, was derived.

A primary safety feature directly targeting side impact crashes are curtain side impact airbags. In arriving at the incremental benefits of an enhanced side impact standard in the form of a GTR, it is first necessary to account for the fatality and injury reduction benefits associated with side curtain airbags by accounting for their penetration into the fleet.

While somewhat out of order for our direct purpose here, the fitment rates for both ESC and curtain side airbags in new vehicle sales are presented in the following section. Using the historic fitment rates and the distribution of vehicle age, the movement of curtain side airbags through the fleet until 100% penetration is achieved are modelled and a 'multiplier' term derived. This step determines the number of fatalities and injuries that can be positively influenced by the reduction benefits associated with side impact airbags, and after the application of a side airbag benefit forms the comparator for additional savings associated with the GTR increment.

Table 8.4a restates the number of fatalities (Table 8.3a, Column E_f) and injuries (Table 8.3b, Column Ei) that are amenable to influence by alternative side impact protection strategies. In the next step the injury reduction benefit of current side impact airbags is modelled, accounting for penetration rates through the fleet. By accounting for curtain side airbag fleet penetration time (Column G), the number of pole side impact fatalities (Column H) and injuries (Column I) that occur and can be influenced by a side airbag system are determined. The last step is to model the protective benefit of a side airbag system.

This can be summarised as:

Column F_f — Restated from E_f - This is the 'balance' of pole side impact fatalities that remain, and consequently are 'amenable' to side impact protection via other means.

Column F_i — Restated from E_i - This is the 'balance' of pole side impact injuries that remain, and consequently are 'amenable' to side impact protection via other means.

Column G — Side curtain airbag penetration into the vehicle fleet, accounting for historic fitment and the total size of the fleet (see Appendix 8b).

Column H — The product of Column F_f x Column G (SAB penetration); this is the number of fatalities that can be reduced by side curtain airbags.

Column I The product of Column F_i x Column G (SAB penetration); this is the number of injuries that can be reduced by side curtain airbags.

Column J The number of fatalities avoided under a business-as-usual (BAU) side airbag fitment schedule, assuming a 32% reduction benefit (i.e., Column H * 0.32).

Column K The number of injuries avoided under a BAU side airbag fitment schedule, assuming a 34% reduction benefit (i.e., Column I * 0.34).

Table 8.4a M1 front seat occupant fatalities and injuries avoided under a business-as-usual side airbag implementation scenario

	Side impact fatalities and injuries post-ESC benefit (amenable to SAB)		**% of occupants in fleet under BAU not exposed to side airbags**	**Open to influence from SAB / exposed given SAB fitment**		**BAU reduction benefit**	
	$\mathbf{F_f}$	$\mathbf{F_i}$	**G**	**H**	**I**	**J**	**K**
Year	Fatalities	Injuries	SAB penetration multiplier	Fatalities	Injuries	Fatalities avoided @ 32% SAB	Injuries avoided @ 34% SAB benefit
2016	23	172	0.552	13	95	4.0	32.3
2017	23	173	0.60	14	104	4.4	35.2
...							
2044	32	238	0.967	31	230	9.8	78
2045	32	241	0.967	31	233	9.9	79
Total	**805**	**6053**		**720**	**5417**	**231**	**1842**

8.2.6 Modelling current improvements in vehicle safety on PSI fatalities and injuries and the GTR effect

The end-result at the previous section was the number of pole side impact fatalities (Table 8.4a, Column J) and injuries (Table 8.4a, Column K) that current side impact airbags under a business-as-usual (BAU) fitment of side curtain airbags would prevent.

The effect of the GTR would be two-fold: 1) side curtain airbag fitment to all new vehicles would be assured, and 2) the protective value of side airbags would offer an incrementally higher level of protection.

The practical effect of the fitment of side airbags to all vehicles would be a small acceleration in the fleet penetration, but it would importantly guarantee that fitment reaches 100%. Following the same method described above, the number of fatalities and serious injuries avoided can be determined. This step is necessary as the incremental effectiveness of the GTR is modelled as a percent increase on the base fatality and injury reduction benefit of side airbags (Table 8.4b).

For M1 vehicles, to arrive at the additional savings due to all new vehicles sold from 2016 fitted with SAB, it is first necessary to derive the number of front seat occupants not previously exposed to a SAB under the BAU scenario. For this, we take the complement of the SAB fleet penetration multiplier (L_1) and using the new vehicle fleet penetration values (L_2), which results in the number of occupants that would now be exposed and who would benefit from the fitment of SAB (M, N), under a mandate; for this, we assume a SAB effectiveness value of 32% for fatalities and 34% for injuries, as described above, following which the number of lives saved and injuries avoided due to a mandate ensuring the fitment of SAB is determined (column O, P). Hence, at the current SAB effectiveness, 10 lives and 80 occupants would avoid injury if all new vehicles were fitted with SAB from 2016 inclusive, onwards.

For N1 vehicles, a single multiplier was used as the proportion of vehicles in the fleet with SAB was estimated for vans, 4 by 2 and 4 by 4 vehicles under BAU, a mandate and the GTR scenario. This is shown in Appendix 8.11.

Table 8.4b M1 front seat occupant fatalities and injuries avoided due to the fitment of side airbags as standard equipment from 2016

	Side impact fatalities and injuries post-ESC benefit (SAB amenable)		**% of occupants in fleet under BAU not exposed to side airbags**	**SAB new vehicle fitment into fleet multiplier**	**Additional fatalities exposed to SAB due to mandate**		**Reduction benefit due to 100% fitment of side airbags, over and above BAU fitment ('the mandate effect')**	
	F_f	**F_i**	**L_1**	**L_2**	**M**	**N**	**O**	**P**
Year	Fatalities	Injuries	[1-SAB penetration multiplier]		Fatalities ($F_f * L_1 * L_2$)	Injuries ($F_i * L_1 * L_2$)	Fatalities avoided @ 32% SAB	Injuries avoided @ 34% SAB benefit
2016	23	172	0.448 [1-0.552]	0.021	0.2	1.6	0.07	0.55
2017	23	173	0.40 [1-0.60]	0.07	0.6	4.8	0.21	1.65
...								
2044	32	238	0.033 [1-0.967]	0.991	1.0	7.8	0.33	2.65
2045	32	241	0.033 [1-0.967]	0.993	1.1	7.9	0.34	2.69
Total	**805**	**6053**			**31.1**	**234**	**10**	**80**

The next step in the estimation of the GTR effect on fatalities and injuries is to model the 'incremental' or added benefit of improved side airbags and other side impact countermeasure systems over and above existing side impact protection levels (Table 8.4c). The increment commences at year 1 with all new vehicles sold meeting the requirement. This is expressed as the e-SAB fleet penetration multiplier (i.e., enhanced SAB; Column Q).

As described earlier (Section 8.2.3, p.125), it is estimated the GTR would deliver a 30% improvement in the safety performance of vehicles involved in side impact crashes. This translates to an increment (or added benefit) of 9.6% and 10.2% for fatalities and injuries respectively; hence the total net safety benefit of SAB in GTR compliant vehicles is a **41.6%** fatality reduction while the injury reduction benefit would be **44.2%** once 100% fleet penetration is achieved. Following application of the GTR increment, the number of fatalities and serious injuries avoided due to the improved side impact protection demanded by the GTR is presented in column T (fatalities) and column U (injuries).

Table 8.4c M1 front seat occupant fatalities and injuries avoided due to the incremental effectiveness of the GTR

	Side impact fatalities and injuries post-ESC benefit (amenable to SAB)		**% fleet with side airbags**	**Open to influence from SAB / exposed given SAB fitment**		**Reduction benefit due to the GTR incremental effectiveness estimate of 30% of current SAB**	
	F_f	**F_i**	**Q**	**R**	**S**	**T**	**U**
Year	Fatalities	Injuries	SAB penetration multiplier	Fatalities	Injuries	Fatalities avoided due to a 30% GTR increment (i.e., 0.096)	Injuries avoided due to a 30% GTR increment (i.e., 0.102)
2016	23	172	0.02	0.48	3.6	0.05	0.4
2017	23	173	0.07	1.60	12.1	0.15	1.2
...							
2044	32	238	1.0	31.4	236	3.0	24.1
2045	32	241	1.0	31.9	239.6	3.1	24.4
Total	**805**	**6053**		**548**	**4120**	**52.6**	**420**

To determine the number of fatalities and injuries avoided due to the GTR, the reduction benefit due to 100% fitment of side airbags and the incremental 30% improvement over and above existing levels of side impact protection are considered. For ease of reference, the relevant number of fatalities and injuries avoided from Table 8.4a, Table 8.4b and Table 8.4c are restated in Table 8.4d.

The calculation of GTR benefit is as follows: **NET GTR fatality benefit (column V) =**

> (Reduction benefit due to 100% fitment of side airbags, over and above BAU fitment) + Reduction benefit due to the GTR incremental effectiveness estimate of 30% of current SAB).
>
> *Alternatively:*
>
> Column V = (Column O + Column T) – Column J.

The GTR injury reduction benefit is calculated in the same manner (W = (P+U))

Table 8.4d M1 front seat occupant fatalities and injuries avoided by the GTR, over and above business-as-usual fitment of SAB

	BAU reduction benefit		**Reduction benefit due to 100% fitment of side airbags, over and above BAU fitment**		**Reduction benefit due to the GTR incremental effectiveness estimate of 30% of current SAB**		**NET GTR benefit**	
	J	**K**	**O**	**P**	**T**	**U**	**V**	**W**
Year	Fatalities avoided @ 32% SAB	Injuries avoided @ 34% SAB benefit	Fatalities avoided @ 32% SAB	Injuries avoided @ 34% SAB benefit	Fatalities avoided due to a 30% GTR increment (i.e., 0.096)	Injuries avoided due to a 30% GTR increment (i.e., 0.102)	**Fatalities avoided**	**Injuries avoided**
2016	4.0	32.3	0.07	0.55	0.05	0.4	0.11	0.92
2017	4.4	35.2	0.21	1.65	0.15	1.2	0.36	2.88
...								
2044	9.8	78	0.33	2.65	3.0	24.1	3.34	26.71
2045	9.9	79	0.34	2.69	3.1	24.4	3.34	27.12
Total	**231**	**1842**	**10**	**80**	**52.6**	**420**	**63**	**500**

The process described above relates to M1 pole side impact and other fixed object side impact crashes, and while computationally identical it was assumed that ESC would not be effective in mitigating vehicle-to-vehicle side impact crashes. It is highly reasonable to assume that any additional benefits attributable to the PSI GTR would flow directly to occupants involved in vehicle-to-vehicle side impact crashes, particularly given the prevalence of fatal head injuries for both M1 and N1 vehicle occupants killed in other side impact crashes (see Chapter 5).

Following application of this method, it can be determined that over the first 30 years post-implementation, there will be 63 fewer M1 occupants killed and 500 fewer occupants injured in pole side impact crashes.

The analysis method for N1 occupants is similar to that used for M1 occupants, with the exception being that a single multiplier was used (see above for detail) to determine savings due to accelerated fitment of SAB associated with a mandate, while the increment calculation follows that for M1 vehicles. Hence, for N1 occupants, the Net GTR benefit is: [(Benefit due to 100% fitment of side airbags from 2016 above BAU fitment + Benefit due to the GTR incremental effectiveness estimate of 30% of current SAB) – BAU savings].

In the next steps, we assume occupants previously killed or seriously injured will sustain minor injuries. The analysis also disaggregates the serious injury savings into appropriate injury types, such as severe and moderate traumatic brain injury (TBI), paraplegia and serious injuries to other body regions. The number of minor injuries avoided is determined from the 2010 minor injury rate in Victoria using population projections and the 44.2% injury reduction estimate for GTR compliant systems determined above (see Section 8.3 below for detailed discussion).

8.3 Cost of injury and application to fatalities and injuries avoided

The translation of the additional lives saved and injuries avoided requires application of accepted cost of injury values. These costs of injury 'reduction' benefits form the basis of the BCR analysis and for fatality reductions the application of cost is straightforward but more complex for injury cases. For the process of placing dollar values on the impact of the GTR (i.e., monetise the impact), three sources are available that permit an accurate translation of per person counts into financial terms.

Fatality values: The Australian Government *Office of Best Practice Regulation (OBPR)* offers guidance on the societal cost of a fatality which is used as the basis of all regulatory analysis[40, 42] with the most recent (2012) value used in vehicle safety related regulatory impact analyses being $AU 4,938,964 per incident case. This value represents an amalgam of the *Value of a Statistical Life* as published by the OBPR (2007) – to reflect willingness to pay terms, combined with broader crash costs as published in the Bureau of Transport Economics (BTE), *Road Crash Costs in Australia* with appropriate Consumer Price Index (CPI) inflation values used to arrive at 2012 values.

Injury values: Cost of injury values for 'serious' and 'minor' injuries were derived using the proportional relationship with the BTE serious and minor injury values against that for a fatality. To reflect willingness-to-pay terms, these relative proportions were then multiplied by the OBPR fatality value (see above). After adjustment for inflation (to 2012), the dollar values for 'serious' and 'minor' injuries were $AU 804,618.00 & $AU 29,709 per incident case respectively.[41, 61, 62] These are higher than if inflation alone was applied to the BTE cost of injury values (cf. serious: $AU $615,187; minor: $AU 20,772) though it was considered appropriate to scale these costs so as to ensure consistency with the fatality estimation method.

It is recognised that great acuity is required when placing monetary values on regulatory impacts, particularly in the context of improved information. The third source of cost of injury data is from *Access Economics,* who in their report, *The economic cost of SCI and TBI in Australia*[14], used Victorian TAC claims data in arriving at the societal and lifetime care costs of traumatic brain injury (**TBI**) and spinal cord injury (**SCI**). *Access Economics* placed the following per incident costs (2008 values) on TBI and SCI:

- Severe TBI: $AU 4.8 million per incident case, and taken to be AIS 4+ injuries and / or a Glasgow Coma Score of 3-8;[63]
- Moderate TBI: $AU 2.5 million per incident case, and taken to be AIS 3 and / or GCS 9-11,
- TBI: $AU 3.7 million per incident case (combined severity), and
- SCI - paraplegia: $AU 5 million per incident case.

After applying CPI to inflate these costs to 2012 values, the cost of a severe TBI is $AU 5,261,135, the cost of moderate TBI is $AU 2,740,174, the cost of TBI per case is $AU 4,055,459, and the cost for paraplegia is $AU 5,480,349. For the BCR analysis, the injury costs are discounted using a 7% discount rate per annum.

In applying these injury costs to the Victorian side impact data that is used as the basis for the cost-effectiveness analysis, it is necessary to understand the distribution of these injury types in pole side impact crashes and vehicle-to-vehicle crashes. Using the TAC Claims database (described in Chapter 6), the number and proportion of cases across each of the injury types and severities can be determined for occupants of M1 and N1 vehicles (Table 8.5). The injury categories are those used by the TAC and are consistent with the definitions used in the *Access Economics* report on the cost of TBI and SCI. The data used in Table 8.5 relates to all occupants involved in side impact crashes, irrespective of seating position and side of impact damage.

An important observation is the percentage of occupants of N1 vehicles having sustained a severe TBI, with only a marginal difference between impact types; in contrast, the percentage of M1 occupants sustaining a severe TBI in PSI is 1.67 times higher than M1 occupants involved in V2V side impact crashes. This has important implications for the BCR analysis to follow, particularly given the high financial cost of severe TBI as well as the higher incidence of V2V side impact crashes. Of note is that the proportion of M1 and N1 occupants classified as having sustained a minor injury for PSI and V2V impacts are almost identical. It is clear then that the severity of head injuries is a key point of differentiation across the vehicle types and collision configurations. It is therefore essential that appropriate cost structures are used in estimating the potential cost-effectiveness of the PSI GTR, particularly as the primary countermeasure is focussed on reducing the incidence and severity of head injuries.

Using the proportions presented in Table 8.5, the predicted future number of injuries avoided is disaggregated by type and severity of injury, thereby appropriately capturing the true benefits afforded by the proposed GTR. This step is necessary due to the high differential lifetime care costs associated with TBI and SCI, over and above 'serious' injuries avoided, and the fact that the primary countermeasure is likely to be an optimised airbag system specifically designed to mitigate head injury.

Table 8.5 Injury distribution for application of monetary costs of injury for admitted occupants

	M1		**N1**	
Injury category	**Fixed object impact (n = 193)**	**Vehicle-to-vehicle side impact (n = 538)**	**Fixed object impact (n = 39)**	**Vehicle-to-vehicle side impact (n = 30)**
Severe TBI	10.9%	6.5%	10.3%	13.3%
Moderate TBI	3.1%	5.0%	7.7%	3.3%
Paraplegia	0.5%	0.4%	2.6%	3.3%
Serious injuries, other regions	85.5%	88.1%	79.5%	80.0%
Total	100%	100%	100%	100%

Aside from making an informed assumption concerning the distribution and pattern of injury types, two further assumptions are made with respect to their cost and severity, these being:

1. That an 'avoided' fatality and serious injury occupant would sustain 'minor injuries', and
2. That an 'avoided' minor injury would be uninjured.

8.4 Costs of meeting the GTR, airbag fitment rates and NCAP performance

The cost structures of meeting the proposed PSI GTR requires consideration of the current technology costs, current fitment rates as well as the types of side impact protection systems fitted into new vehicles sold. The following sections explore each of these aspects prior to arriving at overall cost structures directly relevant for the Victorian fleet which serves as the basis of assessing the likely societal benefit of the PSI GTR.

8.4.1 Cost considerations – EEVC, US and Australian incremental costs

A number of sources have been accessed in assessing the cost of meeting the proposed GTR and these are discussed below.

8.4.1.1 EEVC costs

The EEVC report used as its basis 2006/2007 UK crash data to arrive at potential benefits of a range of side impact countermeasures for a single year. The EEVC report stated that for Option C, the introduction of a pole test, would lead to an additional 75 lives saved and 222 serious injuries avoided). These annual savings, expressed as a financial benefit equated to £328 million (€371 million).

The EEVC report also provided three cost estimates, depending on the level of safety performance of the 'vehicle park'. Per vehicle cost estimates were made for upgrading three different types of production vehicle based on current safety performance, these being:

1. Meets ECE R95 and requires upgrade to meet Pole test ('worst case'): €387
2. Meets ECE R95 and achieves 13 points in side impact test, 2008 protocol, with airbags providing thorax protection but not head protection ('baseline vehicle'): €297

3. Meets ECE R95 and achieves maximum score in 2008 NCAP protocol ('best case'): €121

The EEVC report states: 'a baseline vehicle was used to provide a more realistic indication of the total cost of any new requirement and used to scale costs in line with passenger car registration data in Europe. The baseline was set to be representative of a typical vehicle from the UK vehicle park' (EEVC, p.13).

The costs per vehicle represent the financial value of meeting the pole test option, given the vehicle specification. Table 4 of the EEVC report provides the 'annual cost for the proposed regulatory changes by scaling the per car costs', which for the UK translates to €705 million (*note: appears in Table 5, costs as £)*. It must be stated that it is not specified in the EEVC report which vehicle scenario is being modelled (i.e., worst, baseline, best), although the report later states that '*the benefits* (valued at £328 million, Table 5) *have been calculated based on the safety performance level of the range of vehicles in the accident sample. They represent a conservative (or even 'worst case') estimate of the likely benefits that could be achieved due to the assumptions made in the analysis. The costs have been calculated depending on the safety performance level of the vehicle and are full costs.' EEVC, p.15).*

The EEVC report estimates a 10% reduction in fatalities and a 4% reduction in serious injuries. These estimates were based on the reductions if all vehicles on UK roads offered a 'typical' level of protection seen in post-2003 vehicles (p.11). These reductions relate only to side impact crashes where the occupant compartment was engaged at +/- 45 degrees. The EEVC report states that the benefits are 'likely to give a very conservative benefit...' (p.11).

In interpreting the findings, it is not possible to determine any likely cost-effectiveness value, and indeed, the EEVC state, 'hence it is recommended that a comparison of the absolute values of the benefits and costs should not be made because it could well be misleading. However a comparison of the relative values of the benefits and costs should be meaningful because the benefits and costs have been derived in a consistent manner and hence can be used with a reasonable degree of confidence (EEVC, p.16).

Notwithstanding the significant issues with the derivation and comparability of benefits and costs of implementation each proposed test configuration, what remains important is the EEVC cost estimates of meeting the proposed pole side impact regulation. Of particular relevance is the applicability of the 'baseline' and 'best case' vehicle scenario, and especially the distinction between NCAP performance (13 points vs. maximum) and the absence / presence of head protecting side impact airbags; the baseline condition at €297 assumes no head protection and only 13 NCAP points achieved whereas the 'best' case assumes a maximum NCAP score (with no specification of airbag fitment).

With the implementation of the NCAP pole side impact test, the installation of head protecting side airbags has become widespread. Importantly, for this analysis, the EEVC stated that the cost burden associated with meeting Euro-NCAP side impact requirements (of between €258 to €283) 'has been met by many manufacturers to obtain good NCAP scores (EEVC[64], p.15).

The reason why this is of relevance for our analysis is the high penetration of curtain side airbags into the fleet in Victoria (see Figure 8.2), which is used as the basis of calculation. It is necessary only to add an additional cost burden to that proportion and type of vehicles unlikely to have fitted side curtain airbags by phase-in time of any PSI GTR. Indeed, as shown in the following section in Australia, the fitment of head protecting side curtain airbags by 2015 is expected to be 96.7% of M1 vehicles sold, with the remaining vehicles having thorax combination airbags fitted as standard. This brings vehicles into line with the 'best case' and hence the implementation costs of meeting the pole impact requirements to the 'Low' value of €121.00 per vehicle.

In arriving at the cost increment for consideration for use in our analysis, we can inflate the EEVC 'best' cost point from €121 (2007 value) to 2012 values; this being €134.08 per vehicle.[17] Based on a simple exchange rate calculation[18], the per-vehicle cost in Australia would be $AU 170.08 (2012 value); this assumes manufacture and supply costs remain constant.

17 Inflation index relates to Harmonised Indices of Consumer Prices (HICPs): Annual average rate of change (%); see: http://epp.eurostat.ec.europa.eu/

18 Exchange rate as at mid-market rates as of 2012-12-31 17:00 UTC (€ 1.0 = $AU 1.268530185). Accounting for both differences in Purchasing Power Parity (PPP) and Exchange Rates, the 2012 cost would be $AU 265.05; this assumes all manufacturing, supply and fitment costs are incurred exclusively in Australia; it is however known

8.4.1.2 US / NHTSA costs

In its examination of the case for amending FMVSS 214 to add an oblique pole side impact test[15], NHTSA arrived at three cost models depending on the type, number and coverage of side airbags.[19] NHTSA stated that manufacturers would use side airbags for the head and thorax, with current systems made wider, to pass the oblique test (pp. VI-I); these are presented in Table 8.6a as 'current systems'. Through a series of reports and 'tear-down' studies, NHTSA provided detailed costs estimates of current frontal and side impact airbag components, as well as added requirements to meet the oblique side impact test.[20] NHTSA stated that manufacturers would elect to use window curtain and thorax SAB systems to meet the test requirement, and in addition these would be wider to afford great reach to the A-pillar and the C-pillar; as a consequence more fabric and a modified, more powerful inflator would be required[21]. NHTSA also noted that an additional sensor pair might be required to provide adequate coverage and firing for the rear seat, although this would be voluntary.

Table 8.6a shows the component costs of current and oblique pole side impact test requirements, referred to as 'GTR compliant systems'. These airbag component costs reported by NHTSA form the basis of GTR increment costs.

As a matter of interest, implementation costs for the oblique test used by NHTSA were based on the level of compliance in the MY 2005 fleet with consideration given to the manufacturers plans in MY 2011 vehicles. NHTSA stated the increment values in meeting the oblique test were $US 25.20 (combination SAB), $US 32.90 (window curtain and thorax SAB, 2 sensors), and $US 66.10 (window curtain and thorax SAB, 4 sensors). These increment values are not used in the current report, rather we use costs 'built-up' from individual components, with consideration given to the Australian market as at end 2015, based on inflated costs to 2012[22] (see Table 8.6b).

Table 8.6a Airbag system fitment costs – current systems (as at 2004) and oblique pole side impact test compliant costs[23]

	System Type	Frontal Airbag Capable Control Module 2004 USD	SAB, Sensors & SAB Control Module Capability 2004 USD	Total 2004 USD
Current Systems	Current combination head / thorax in the front seat, 2 Sensors	$177.31	$115.68	$292.99
	Current window curtain SAB, 2 Sensors	$177.31	$171.10	$348.41
	Current window curtain and thorax SAB, 2 Sensors	$177.31	$234.10	$411.41
GTR Compliant Systems	Wide combination, 4 Sensors (may be used in convertibles)	$177.31	$162.85	$340.16
	Wide curtain and wide thorax, 2 sensors	$177.31	$242.50	$419.81
	Wide curtain and wide thorax, 4 sensors	$177.31	$279.17	$456.48

that vehicle components are sourced from overseas component suppliers and the majority of the Australian new car market are overseas suppliers. For this reason, the exchange rate value was used.

19 FMVSS 214 Regulatory Impact analysis assumed 4 sensors may be necessary to detect two different impact alignments of 50th male and 5th female pole tests.

20 NHTSA used 'tear-down' studies, prior research and market assessments in arriving at airbag component costs. Costs are: current window curtain, $US 130.87; current thorax SAB, $US 63; current combination SAB, $US 75.47; plus detection sensors at $US $36.67 (2 sensors, 1 per side); plus wiring to frontal airbag ECM at $US 3.56 (all 2004 USD)

21 NHTSA estimated that additional fabric and more powerful inflator would cost $US 5.25 for current thorax SAB and $US 10.50 for combination SAB, and the additional fabric for the curtain airbag would be $US 3.15 (all 2004 USD)

22 USD 2004 costs inflated to USD 2012 values, using US CPI at 2.47% (on average per annum)

23 FMVSS 214 Regulatory Impact analysis assumed 4 sensors may be necessary to detect two different impact alignments of 50th male and 5th female pole tests.

Table 8.6b Airbag system fitment costs – current systems (2012 costs) and oblique pole side impact test compliant costs

	System Type	Frontal Airbag Capable Control Module 2012 US Dollars	Side Airbags, Sensors & Side Airbag Control Module Capability 2012 US Dollars	Total 2012 US Dollars
Current Systems	Current combination head / thorax in the front seat, 2 Sensors	$215.51	$140.60	$356.11
	Current window curtain SAB, 2 Sensors	$215.51	$207.96	$423.47
	Current window curtain and thorax SAB, 2 Sensors	$215.51	$284.53	**$500.04**
GTR Compliant Systems	Wide combination, 4 Sensors (may be used in convertibles)	$215.51	$197.93	$413.44
	Wide curtain and wide thorax, 2 sensors	$215.51	$294.74	$510.25
	Wide curtain and wide thorax, 4 sensors	$215.51	$339.31	**$554.82**

Using the cost estimates presented in Table 8.6b, an incremental cost matrix given current side airbag systems can be determined (see Table 8.7a - USD; Table 8.7b - AUD). The incremental cost represents the estimated cost of meeting the GTR over and above current airbag fitment specifications. For instance, where a vehicle is currently fitted with a window curtain and thorax SAB with two sensors ($US 500.04), and is upgraded to a GTR compliant wide curtain and wide thorax with 4 sensors ($US 554.82), the increment is $US54.78 – these values are highlighted in Table 8.6b and Table 8.7a. The same logic is applied to arrive at GTR increment costs for each current and GTR compliant configuration.

Table 8.7a Incremental costs (USD) of meeting the GTR, given current airbag systems

		Incremental Costs ($US 2012)			
		GTR Phase 1 Compliant Vehicles			
		Wide combo + 4 sensors (some convertibles)	Wide curtain + wide thorax + 2 Sensors	Wide curtain + wide thorax + 4 sensors	Weighted GTR compliant passenger (M1) fleet mix†
Current Systems	No airbags (front or side)	$413.44	$510.25	$554.82	$526.96
	No side airbags	$197.93	$294.74	$339.31	$311.45
	Current combo + 2 sensors	$57.33	$154.14	$198.71	$170.85
	Current curtain + 2 sensors		$86.78	$131.35	$103.50
	Current curtain & narrow thorax + 2 sensors		$10.21	**$54.78**	$26.92

†Note: Of 8 North American market vehicles tested 3 had 4 sensors and 5 had 2 sensors, hence the weighted GTR compliant passenger fleet mix refers to this point.

Table 8.7b Incremental costs (AUD) of meeting the GTR, given current airbag systems

		Incremental Costs ($AU 2012)[24]			
		GTR Phase 1 Compliant Vehicles			
		Wide combo + 4 sensors (some convertibles)	Wide curtain + wide thorax + 2 sensors	Wide curtain + wide thorax + 4 sensors	Weighted GTR compliant passenger (M1) fleet mix
Current Systems	No airbags (front or side)	$397.78	$490.92	$533.81	$507.00
	No side airbags	$190.44	$283.58	$326.46	$299.66
	Current combo + 2 sensors	$55.16	$148.30	$191.18	$164.38
	Current curtain + 2 sensors		$83.49	$126.38	$99.58
	Current curtain & narrow thorax + 2 sensors		$9.82	$52.70	$25.90

8.4.1.3 Local Industry Advice

Advice to the researcher undertaking this report from a manufacturing industry expert was that the cost of a current new Australian sold vehicle meeting an enhanced side impact requirement would be 'about $20 for design considerations per vehicle and probably no more than $50 for additional parts and enhancements, like sensors, slightly more forward and rear-ward reaching bags and inflators'. This implies a four sensor system, the total cost of which is **$AU 70 (€55.19; $US 72.75).**[25]

Within the above context the point needs to be made that the design costs for the large majority of M1 passenger vehicles required to meet the proposed PSI GTR are likely to be low given that i) most of the required research and development costs necessary to ensure compliance with the PSI GTR are already occurring in large part – as evidenced by a high proportion of new vehicles having side curtain airbags as standard, and ii) the harmonisation of requirements through the development and implementation of a PSI GTR means the remaining research, design and development costs will be spread across a much larger number of vehicles than those sold in Australia; this latter point represents a significant economy of scale. Given the known vehicle mix and the advice from the industry expert, the weighted GTR fleet mix cost of $AU 25.90 is used for M1 vehicles with SAB fitted as standard equipment; this represents the GTR increment cost for M1 passenger vehicles relevant for Phase 1 of the proposed GTR, which is focussed on front seat occupants.

In contrast to M1 vehicles, it is expected that the design and development costs of meeting the PSI GTR are likely to be higher as many of the current N1 vehicle models have not previously been required – and thus designed, to meet perpendicular or oblique PSI performance requirements. Moreover, the requisite costs will be spread over fewer vehicles (cf. M1) and many N1 vehicles currently sold in Australia are not sold in the US market where there is a requirement to meet a pole side impact standard in the form of FMVSS-214. For this reason, the $20 design considerations cost per vehicle suggested for the Australian market sold passenger vehicle by the industry expert noted above is added to the costs present in Table 8.7b for N1 vehicles.

8.4.1.4 Incremental costs adopted for analysis

The following section articulates the current and expected side airbag fitment status for M1 and N1 vehicles, after which the GTR cost increment is established for the Australian market using the cost matrix presented in Table 8.7b. For the purposes of estimating the likely cost-effectiveness of the GTR, it is assumed that the side airbag component costs for M1 passenger cars are equivalent for N1 vehicles.

24 Exchange rate as at mid-market rates as of 2012-12-31 17:00 UTC ($US 1.0 = $AU 0.9621271257).

25 Exchange rate as at mid-market rates as of 2012-12-31 17:00 UTC ($AU 1.0 = $US 1.0393636904; $AU 1.0 = €0.7883139176).

8.4.2 Cost considerations: curtain side airbag and ESC fitment rates

The assignment of the appropriate costs of meeting the proposed GTR is a critical step in the calculation of the overall benefit-cost ratio of the PSI GTR. In Victoria the fitment rates of various vehicle features in all new vehicles are routinely recorded. Curtain side airbag and ESC fitment data for the period October 2006 to March 2012 was supplied by the *Transport Accident Commission* (Victoria). The fitment data captures the number of new vehicles sold equipped with front and rear occupant curtain airbags and ESC.

While the fitment of side curtain airbags is of primary interest, the standard fitment of ESC into new vehicles is also of interest due to the need to account for the crash prevention safety benefits of ESC, which are specific to run-off-road crashes. It is accepted however that mandating ESC will ensure the technology will be fitted on all new M1 vehicles sold by 2014, and that a similar mandate will be applicable at some point soon thereafter for N1 category vehicles. The rapid uptake of ESC is clear for Class M1 vehicles in Figure 8.4, while exponential growth in ESC fitment in N1 vehicles is expected.

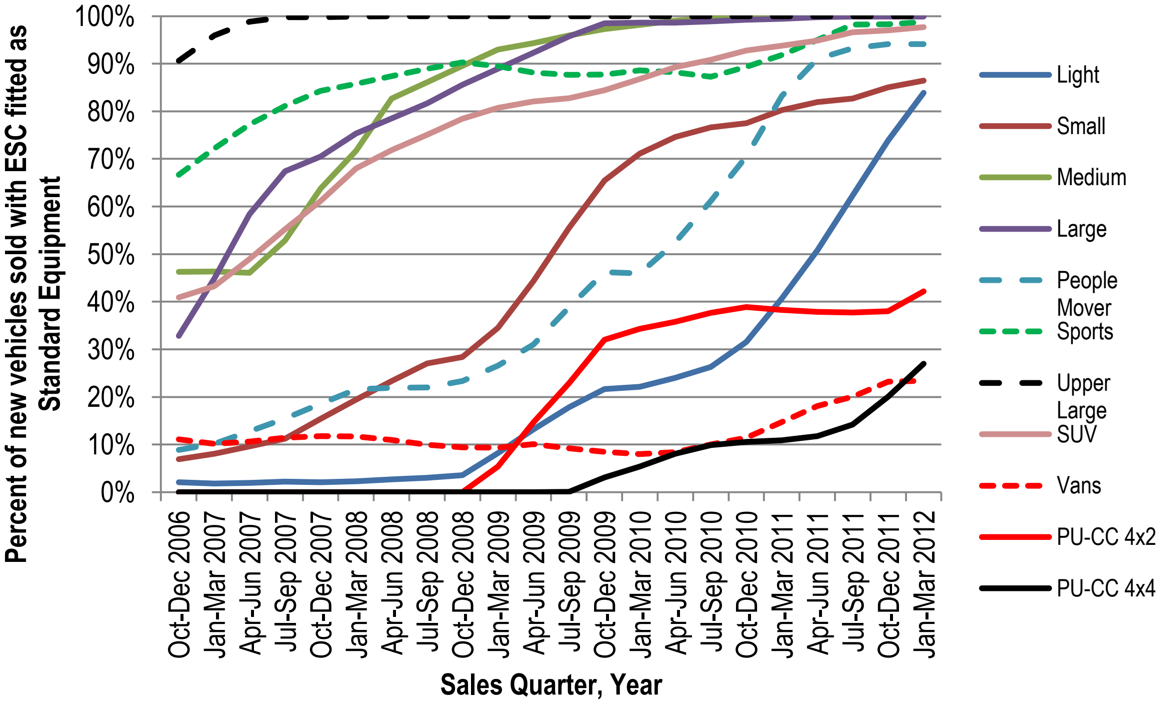


Figure 8.4 Percent of new vehicle sales with ESC fitted as standard equipment, Victora 2006-2012

The rapid acceleration in the fitment of ESC (Figure 8.4) seen in M1 vehicles is in response to a number of factors, principally that from 1 November 2011 under Australian Design Rules all new model M1 vehicles require ESC to be fitted, and in addition, from 1 November 2013 ESC must be fitted to all new vehicles sold. Consequently, 100% of all new M1 vehicles purchased and entering the fleet will be fitted with ESC prior to the application of a pole side impact standard in Australia. Fitment rates in Victoria (as shown in Figure 8.1) were likely also influenced by measures undertaken by the Victorian Government that required all newly registered vehicles be fitted with ESC from 1 January 2011.[65] Finally, fitment of ESC to vehicles would have been influenced by GTR 8 (UN R13H) as well as NCAP 5-star rating requirements.

ESC fitment rates for N1 vehicles lag considerably, with less than 50% of PU-CC 4 x 2 vehicles fitted with ESC when sold and around 25% of 4 X 4 and vans. A national regulation on ESC fitment for N1 vehicles has been shown to be highly cost effective[59] and a mandate is anticipated in the short term, which will effectively result in a similar exponential leap in fitment rates to that seen in M1 vehicles.

Historical and current side curtain airbag fitment rates

The curtain side airbag in combination with a thorax airbag is the primary countermeasure used to improve side impact safety. The fitment of side impact protection airbags is normally accompanied with restraint system (seat-belt, sensors, control module) enhancements and structural changes to the vehicle, which can include side impact anti-intrusion bars, foam within the door space, additional padding as well as changes to the material properties of the vehicle structure itself.

Analysis of side impact airbag fitment trends is a critical step in understanding the current vehicle fleet and what it will look like at the time of implementation of a new side impact test in the form of a PSI GTR (Figure 8.5). This has implications for the implementation costs, but also the safety benefit afforded by side impact airbags as new vehicles move through the fleet until full penetration is achieved. It must be accepted that the full benefit to society of the fitment of any new technology takes considerable time and is a reflection not only of buyer preferences but fleet turnover. Previous research has indicated that it can take up to 25 – 30 years for technology such as airbags, seat-belt reminder systems and ESC to reach full fleet penetration.[59, 66-68] This has clear implications for the point at which full benefits of a new technology – and hence a regulation, will be achieved.

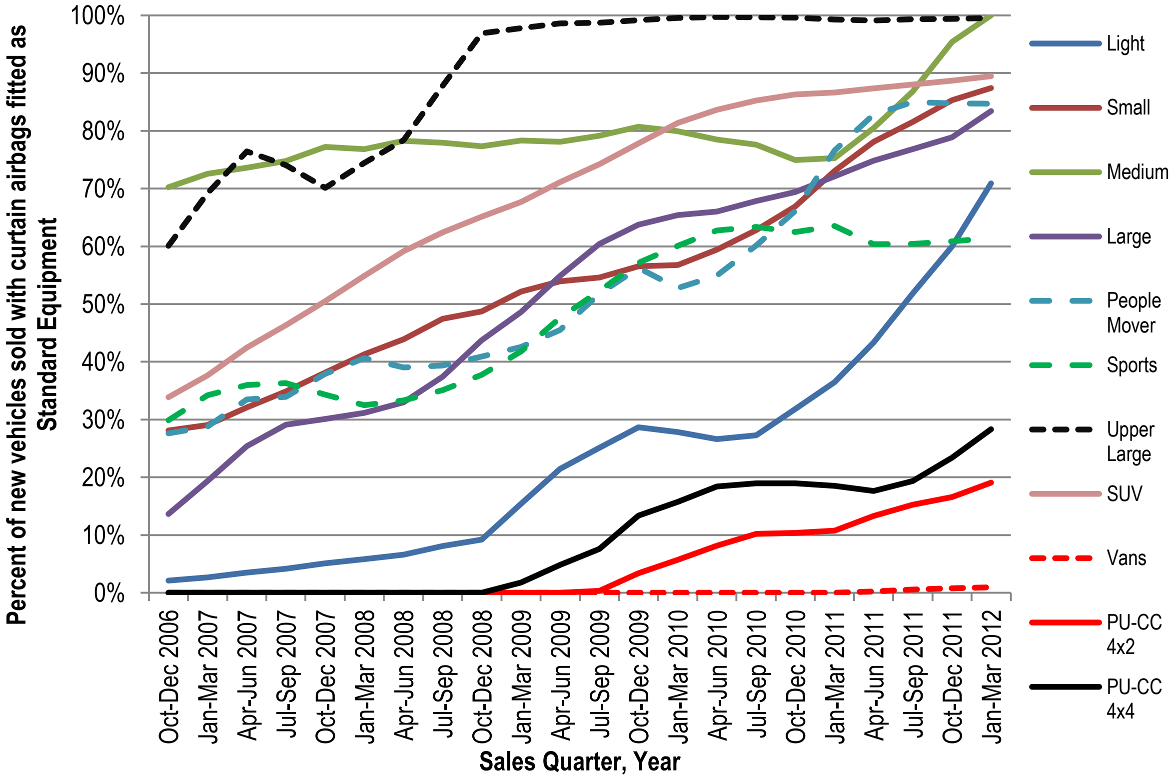


Figure 8.5. Fitment rates for new vehicles sold with curtain side airbags fitted

The fitment rates presented above form the basis for estimating the proportion of vehicles sold, and hence in the fleet in the long run, with ESC and side impact airbags. For the analysis here, it is assumed that all new M1 vehicles sold will have ESC fitted, while modelling is used to estimate future ESC fitment rates for N1 vehicles. For arriving at the cost structures for the PSI GTR, examination of airbag fitment rates follows.

Projections: vehicles without side impact airbags at 2016

M1 vehicles - by end 2015, it is assumed that the percent of vehicles fitted with side impact curtain airbags and thorax airbags as standard equipment is as per Table 8.8. The forward projections are based on an on average, 5.9% increase in the new car sales fitted with curtain side airbags as standard equipment per quarter since 2006, however it is recognised that some segments will fail to reach 100% standard fitment, and the fitment proportion is set to peak at 96.7% of new M1 vehicle sales. This is despite the requirement by ANCAP for head protecting side impact airbags to be fitted for vehicles to achieve a 5-star ANCAP rating in 2012 for the front row and in 2014 for the rear seats. The ANCAP Road Map specifies fitment of head protecting side impact airbags at other star-rating levels in the period 2012-2017.

Table 8.8 Requirements for new M1 vehicles to meet the requirements of the PSI GTR†

M1 vehicle sales class	Percent of M1 new vehicle sales	Side airbag fitment rate at end 2015 in vehicle class	M1 Requirements to meet the PSI GTR	
			Vehicles requiring increment cost only (Year 1)	Vehicles requiring full cost / GTR compliant system (Year 1)
Light	14.6%	90%	33,267	3696
Small	28.1%	95%	67,584	3557
Medium	11.7%	100%	29,621	0
Large	16.6%	100%	42,026	0
People mover	1.6%	95%	3848	203
Sports	2.4%	85%	5165	911
Upper large	0.8%	100%	2025	0
SUV	24.2%	100%	61,267	0
Total	100%		244,803	8367
Weighted percent			96.7%	3.3%

† Based on new passenger vehicles (M1) sold in the State of Victoria, Australia

To arrive at the cost of meeting the GTR for M1 vehicles, three parameters are used:

1. The number of new passenger vehicles sold and buyer preferences across market groups (Table 8.8);
2. The expected fitment / non-fitment rate of side airbags (Table 8.8), and
3. The incremental cost structures as shown in Table 8.7b.

For the purposes of BCR assessment of the proposed GTR, analysis is performed for front seat occupants and 'all occupants' (front plus rear) separately. This aligns with Phase 1 and Phase 2 of the PSI GTR and as a consequence, the cost structures differ depending on whether two sensor or four sensor costs are used in combination with the 'wide' curtain and thorax SAB costs (over and above current SAB systems) (see Section 8.4.1.2 for discussion). Given the very high penetration of side curtain airbags among new M1 vehicles sold (i.e., 96.7%), the full upgrade cost from combination head/thorax SAB is applied in year one only, after which the GTR increment cost is used. The cost structures used are as follows:

<u>Front occupant analysis, weighted two / four sensor cost</u>: For year 1 (2016), the discounted full upgrade cost of $AU 164.18 (2012 dollars) for vehicles without a side curtain airbag system fitted is used (with an assumption the SAB system fitted is a 2 sensor 'combination' system), and $AU 25.90 (2012 dollars) is used as the GTR increment cost for the vast majority of new M1 passenger vehicles that are fitted with current curtain and thorax SAB (see Table 8.7b). From year 2 onwards (2017), the discounted (7% per annum) GTR increment cost of $AU 25.90 is used.

<u>All occupant analysis:</u> The wide curtain / thorax four sensor costs are used; that is in year 1 the full upgrade cost from a current combination system to a GTR compliant four sensor system ($AU 191.18)) is used, with the GTR increment cost being $AU 52.70 (in year 1 for vehicles with side curtain airbags, and year 2 onward for all).

As a sensitivity analysis, BCRs were calculated for front seat occupants using four sensor costs.

For front occupants the weighted costs are as follows: In year 1, the costs are (8367 * $AU 164.38) + (244,803 * $AU 25.90) = $AU 7,715,765; on a per unit basis this equals $AU 30.48 (2012 dollars – not discounted). From year 2 onwards, the GTR increment cost is $AU 25.90 (2012 dollars – not discounted). As implementation commences in 2016, the discounted values (using 2012 as the base year for the analysis of both benefits and costs) are $AU 23.25 for Year 1 and $AU 18.47 for Year 2, per vehicle unit

N1 vehicles: The method for calculating the cost of N1 vehicles meeting the GTR differs from M1 vehicles for a number of reasons:

1. There was a vast difference in the proportion of sales of vans (16%), 4 x 2 (39%) and 4 x 4 vehicles (44%) across the period 2006 to 2012;
2. The fitment rate of side curtain airbags differs considerably between these N1 vehicle types (2012 fitment rate: 0.7% of vans, 38.5% of 4 x 2 and 61% of 4 x 4 vehicles), and
3. The side airbag system required to meet the GTR differs for 4 x 4 vehicles due to a proportion being twin-cab – and thus requiring a four sensor system to protect the rear occupants, while vans and 4 x 2 vehicles were considered to require only two sensor systems.

As a consequence of these considerations, a number of preliminary steps were required before the number of vehicles requiring the full implementation cost or increment only cost could be established. First, using N1 vehicle sales data for the period 2006 to 2012 inclusive as the base, the future number of N1 vehicles (i.e., vans, 4 x 2, 4 x 4) sold for the period 2013 to 2045 was determined. Likewise, the number of new vehicles sold with ESC and side curtain airbags as standard equipment in the 2013 to 2045 period was estimated on the basis of historical fitment rates of these technologies (i.e., 2006 – 2012 sales data) to establish the BAU case.

To establish the BAU case, a 1.5% per annum growth in side curtain airbag installation into vans was assumed while for 4 x 2 and 4 x 4 vehicles a 5.9% increase was used; there was significant volatility in the proportion of 4 x 2 and 4 x 4 vehicles with side curtain airbags fitted from 2011 to 2012, and hence the well-established M1 airbag growth rate was used. In the BAU scenario, fitment within vans reached its peak value of 50.23% in 2045 (the 30th year) with the peak fitment for 4 x 2 and 4 x 4 vehicles being set at 97.5%. In 2016, it was estimated that 38.3% of the registered N1 fleet would have side curtain airbags fitted, and by 2045 this would increase to 89%.

For the purposes of costs, 63.5% of N1 vehicles sold in 2016 would have side curtain airbags fitted as standard equipment, and this increases each successive year to a peak of 89.4% (given the low fitment of vans). Hence, this represents the number of proportion of vehicles requiring the increment-only cost. This calculation represents part one in the application of costs presented in Table 8.7b.

To factor in the additional cost of meeting the PSI GTR, the next step is to determine the number of new vehicles requiring the full SAB implementation cost; these are vehicles assumed to be without any type of side airbag fitted but have dual frontal airbag systems (some may have combination SAB, hence the BCR is likely to be conservative). Using the new vehicle penetration multiplier, the percent (and number) of vehicles entering the fleet requiring the full implementation cost can be determined. This is part two in the application of costs presented in Table 8.7b.

In sum, the above estimation process results in the estimation of the number of new vehicles requiring the GTR increment cost (Part 1) and the full SAB implementation cost (Part 2) each year in the period 2016 to 2045.

Having established the number of vehicles in each year requiring either the full implementation cost or the increment only cost, reference is made to the incremental costs of meeting the GTR given current airbag systems fitted (Table 8.7b).

<u>For front seat occupant BCR calculations,</u> the two sensor costs are used. For vehicles without a SAB system fitted, the full wide curtain / thorax two sensor SAB system ($AU283.58) plus an additional $AU 20 for additional development costs (i.e., $AU 303.58, 2012 dollars). The increment only cost was $29.82 (i.e., $AU 9.82 + $AU 20; 2012 dollars). These costs are applied to the relevant number of vehicles in each successive year, using a 7% discount rate.

<u>For the 'all occupant' BCR calculations,</u> it is assumed all vans and 4 x 2 vehicles would require two sensor systems, with the same costs used for the front occupant BCR analysis. For the 4 x 4 vehicles, 70% were assumed to be single cab, and thus requiring the two sensor costs. For the twin-cab 4 x 4 vehicles where four sensor systems would be required, the full wide SAB implementation cost is $AU 346.46 with $AU 72.70 ($52.70 + $AU 20) adopted for vehicles with current side curtain airbag systems, but requiring additional fabric and

sensors. Given the increasing fitment of side curtain airbags under the BAU scenario, the cost structures were calculated for each individual year, 2016 to 2045 (see Appendix 8.11).

Side impact protection, NCAP and cost choices

In reference to the choice of cost in meeting the PSI GTR, certain assumptions are made concerning the safety performance of new vehicles sold and the likely incremental cost. This is especially pertinent with reference to the EEVC cost estimates of implementation as discussed above. There are two critical points:

1. The EEVC state that the cost of meeting the Euro-NCAP side impact performance criteria, to which all new vehicles are tested from 2009, would be met by the manufacturers, and
2. The EEVC 'low' cost assumes that the vehicle complies with UN R-95 and achieves the maximum Euro-NCAP side impact score (Protocol 2008).

Following point 2, analysis of NCAP side impact test scores was performed by type of side impact protection. Using ANCAP and EuroNCAP test results, a database of 237 vehicles was constructed with the type of side impact airbag system specified. Figure 8.6 presents for each airbag system the percent of vehicles by point score category. For the curtain plus thorax side airbag system (MY 2000 to MY 2008), 60% achieved the full 16 points, with a further 22.3% receiving point 15.0 to 15.9 points, 9% receiving 14 – 14.9 points and 2% receiving between 13 – 13.9 points; none of the 88 vehicles fitted with a curtain plus thorax airbag scored less than 13 points.

The analysis presented here underscores the value of curtain plus thorax airbags, and further, demonstrates that in 2016 – a point at which a PSI GTR could come into force, the 'low' cost perspective of the EEVC is more appropriate than the 'base' or 'high' cost vehicle safety specification. This is the case as all new vehicles sold in 2016 would be expected to exceed the NCAP requirements under the 2008 protocol and receive maximum points.

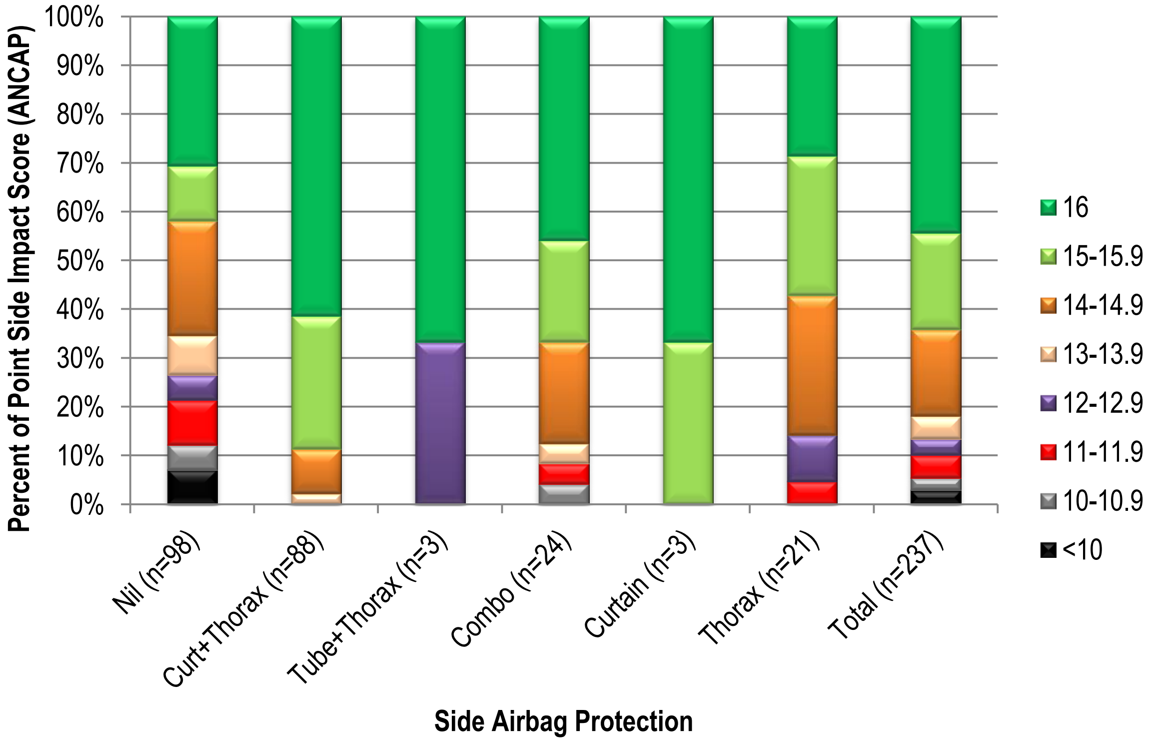


Figure 8.6. Side impact point scores achieved by vehicles tested by ANCAP and Euro-NCAP by side impact protection

8.5 Benefits and Costs associated with the GTR for M1 vehicle front seat occupants

The principal objective in this chapter was to determine the likely benefits and costs associated with the implementation of an enhanced PSI GTR that would deliver improved safety over and above safety performance offered by curtain and thorax side impact airbags.

8.5.1 Processes and key assumptions

At the outset, a key assumption from the incremental cost side is that the safety performance of all new vehicles entering the fleet in 2016 would meet the 2008 NCAP side impact protocol receiving 'maximum points', i.e., 15 and higher, and the GTR would assure an improvement over and above this level.

The fatality and injury basis of savings includes all injured occupants, including those belted, unbelted and ejected. In this context, the safety performance of curtain plus thorax airbags – and other side impact protection features, represents the 'average' safety benefit in the real-world. Likewise, the incremental cost is the 'average' value, as some vehicles will, it is expected, meet the enhanced safety standard, while others will require further engineering, which is reflected in the per unit increment value.

Following a step-by-step approach and using a range of inputs, a full cost-benefit analysis was performed of the additional safety benefit ascribed to the implementation of the GTR. Calculations are presented in detail for front seat occupant fatalities and injuries in M1 vehicles.

At its most basic, using the appropriate costs for fatalities and for each injury severity level, the monetary cost of current and future crashes was calculated in two steps:

- Step 1: current trends in side impact protection were modelled using the Business-As-Usual (BAU) approach, and
- Step 2: an additional safety benefit ascribed to the implementation of the GTR and applied only to the fatalities and injuries that remain *after* accounting for savings afforded due to ESC fitment under the BAU approach; were added to the BAU model.

<u>The expected incremental benefit associated with the GTR was set at 30%.</u>

Computationally, two approaches can be taken however the end result is the same.

Approach A: Determine the benefits and costs associated with both BAU <u>*and*</u> the Increment (i.e., driving airbag fitment to 100% + improved safety), subtracting the difference in the two models to arrive at the incremental benefit. The advantage is that under this approach a BCR analysis of side impact protection under the BAU approach is also derived; however this analysis is interested only in the effect of the proposed GTR, and the monetisation of benefits and regulatory costs is determined by reference to the 'incremental gain' due to the GTR.

On the benefits side, we translate the fatality and injury reductions into dollar values. Using the known injury severity distribution described earlier, savings at each injury severity were determined, such as the proportion of severe traumatic brain injury savings compared to minor injury savings, and costed accordingly.

On the cost side, we use an average unit cost of <u>$AU 30.48</u> (2012 value – not discounted) for the first year, and the increment value of <u>$AU 25.90</u> (2012 value – not discounted) for each following year; this accounts for the full implementation cost for a proportion of vehicles in year 1 due to the introduction of the GTR. These costs reflect the weighted mix of two and four sensor costs assumed for GTR compliant vehicles and relevant for front seat occupant benefits.

As the benefits and costs are projected into the future, we discount both at 7% per annum, to reflect the discounted real value of tomorrow's dollar 'today' (i.e. in 2012). The discounted (2012 base year) average cost for the first year of implementation (2016) is $AU 23.25 per vehicle and the discounted (2012 base year) incremental cost for the second year of implementation (2017) is $AU 18.47 per vehicle. A BCR is derived for every year, and for the entire 30 year period.

8.5.2 Estimated benefits and costs of the GTR for M1 vehicles (front occupants)

The results of the analysis for M1 front seat occupants (2 sensors) are presented below (Table 8.10a, 30 years; Table 8.10b, per annum; *State of Victoria*). The tables present the fatalities and injuries avoided by type, their associated dollar value and the financial cost of implementation of the GTR. The benefits in terms of additional lives saved and injuries avoided over the 30-year term are significant, particularly as benefits would accrue across all side impact configurations. Across the 30-year period, 125 fatalities would be avoided as would 86 cases of severe traumatic brain injury and 52 instances of moderate traumatic brain injury; in addition, a large number of occupants would not sustain 'serious' injuries'. The average per annum savings for Victoria is presented in Table 8.10b.

In dollar terms ($AU, 2012), the implementation of the PSI GTR is seen to be highly cost effective with an overall BCR of 7.40:1 over the 30-year implementation period. The BCR can be decomposed to its constituent parts, specifically pole impacts (BCR 2.24:1), vehicle-to-vehicle side impacts (BCR 4.98:1) and side impacts involving 'other fixed objects (0.17:1).

In the 30th year of implementation, the BCR will reach 12.95:1. By this point 99.3% of vehicles in the fleet would have the enhanced side impact protection demanded by the GTR. The BCR reaches equilibrium once greater than 99% of vehicles in the fleet meet the enhanced safety standard, which occurs in 2044 (year 29). It is expected that 100% of all registered vehicles will meet the proposed GTR by 2047.

Table 8.10a Incremental benefits of the GTR for M1 vehicle front seat occupants (30%), over and above BAU of SAB installation for Victoria, 2016-2045

Incremental benefits	Pole impacts	Vehicle-to-Vehicle	Other fixed object	Total
Additional Fatalities avoided	63	60	3	125
Additional TBI-severe avoided	27	56	3	86
Additional TBI-moderate avoided	8	43	1	52
Additional Paraplegia avoided	1	3	0	5
Additional Serious injuries avoided	214	763	23	999
Additional Minor injuries avoided	250	2508	51	2808
Financial benefits, 2016-2045 ($AU, 2012)	$163,646,580	362733252	12692038	$539,071,870
GTR requirement cost ($AU, 2012)	$72,895,006	72895006	72895006	$72,895,006
BCR (30 year period)	**2.24**	**4.98**	**0.17**	**7.40**
BCR in Yr 30	3.91	8.73	0.30	12.95

Table 8.10b Incremental benefits of the GTR for M1 vehicle front seat occupants (30%), over and above BAU of SAB installation for Victoria, average per annum incremental benefits

Incremental benefits	Pole impacts	Vehicle-to-Vehicle	Other fixed object	Total
Additional Fatalities avoided	2	2	0.1	4
Additional TBI-severe avoided	1	2	0.1	3
Additional TBI-moderate avoided	0.3	1	0.03	2
Additional Paraplegia avoided	0.04	0	0.005	0.155
Additional Serious injuries avoided	7	25	1	33
Additional Minor injuries avoided	8	84	2	94
Financial benefits, 2016-2045 ($AU, 2012)	$5,454,886	$12,091,108	$423,068	$17,969,062
GTR requirement cost ($AU, 2012)	$2,429,834	$2,429,834	$2,429,834	$2,429,834
BCR (30 year period)	**2.24**	**4.98**	**0.17**	**7.40**

The benefits for M1 vehicles were calculated for Victoria as high quality data inputs were available for each analysis step. Using these values as the basis for Australia, the incremental benefits can be determined by using known population data on the 'benefits' side and known vehicle registration data on the 'cost' side [26].

Table 8.11a presents the expected incremental benefits generated by a PSI GTR for Australia over the 30 year period, 2016 to 2045, while Table 8.11b presents the savings and costs on an average per annum basis. The financial benefits to Australia are significant, at $AU 2.6 billion over the 30 year period for an incremental cost of $AU 0.27 billion, for an overall BCR of 9.5:1. On a per annum basis, a GTR would be expected to save the Australian community approximately $AU 87.5 million per annum for an outlay of $AU 9.2 million per annum.

For Australia, on a per annum basis, the analysis estimates 20 additional lives will be saved through the enhanced safety requirements demanded by a GTR, with 14 cases of severe TBI, 8 moderate TBI and 1 case of paraplegia per annum also avoided. In addition, 162 serious injuries and 456 minor injuries would be avoided. It is worth noting that injury shifts from fatality and serious injury to minor injuries were accounted for, both in number and in cost implications.

Table 8.11a Incremental benefits of a GTR for M1 vehicle front seat occupants (30%), over and above BAU of SAB installation for Australia, 2016-2045

Incremental benefits	Pole impacts	Vehicle-to-Vehicle	Other fixed object	Total
Additional Fatalities avoided	305	291	12	608
Additional TBI-severe avoided	132	274	14	421
Additional TBI-moderate avoided	38	212	4	254
Additional Paraplegia avoided	6	16	1	23
Additional Serious injuries avoided	1041	3717	111	4868
Additional Minor injuries avoided	1217	12215	246	13679
Financial benefits, 2016-2045 ($AU, 2012)	$797,111,037	$1,766,848,280	$61,822,030	$2,625,781,346
GTR requirement cost ($AU, 2012)	$276,117,445	$276,117,445	$276,117,445	$276,117,445
BCR (30 year period)	**2.89**	**6.40**	**0.22**	**9.51**
BCR in Yr 30	5.03	11.23	0.39	16.65

Table 8.11b Incremental benefits of a GTR for M1 vehicle front seat occupants (30%), over and above BAU of SAB installation for Australia, average per annum

Incremental benefits	Pole impacts	Vehicle-to-Vehicle	Other fixed object	Total
Additional Fatalities avoided	10	10	0.4	20
Additional TBI-severe avoided	4	9	0	14
Additional TBI-moderate avoided	1	7	0.13	8
Additional Paraplegia avoided	0.2	1	0.02	1
Additional Serious injuries avoided	35	124	4	162
Additional Minor injuries avoided	41	407	8	456
Financial benefits, 2016-2045 ($AU, 2012)	$26,570,368	$58,894,943	$2,060,734	$87,526,045
GTR requirement cost ($AU, 2012)	$9,203,915	$9,203,915	$9,203,915	$9,203,915
BCR (30 year period)	**2.89**	**6.40**	**0.22**	**9.51**

26 Based on 2000 – 2009 Australian population statistics: Victoria comprises 24.76% of the Australian national population, and we use a 4.037 inflation factor to scale up crash statistics to Australia; a secondary inflation factor is also included to account for the differential road safety performance between Victoria and the other jurisdictions (*1.262). The total inflation factor used was 4.87093 on the benefits side and 3.74 on the 'cost' side, accounting for Victorian registrations representing 26.4% of national vehicle sales.

8.5.3 Sensitivity analysis for M1 vehicles, using increment cost as the variable factor (front occupants)

Using the same method as above, sensitivity analysis for Australia was performed using a range of incremental costs, from $AU 20 through to $AU 110 in 2012 dollar values (see Figure 8.7), noting that $AU 25.90 (2012 dollars) was the increment cost (weighted combination of two and four sensor) used in the principal analysis. This analysis also takes into consideration a different cost structure for year 1, given the small percent of M1 vehicles without SAB in 2016, as described above.

This analysis is useful as it highlights the robust nature of the benefits across a range of increment cost values. The break-even increment cost is $AU 250 (2012 dollars), which is 1.5 times greater than the full per vehicle cost of SAB implementation.

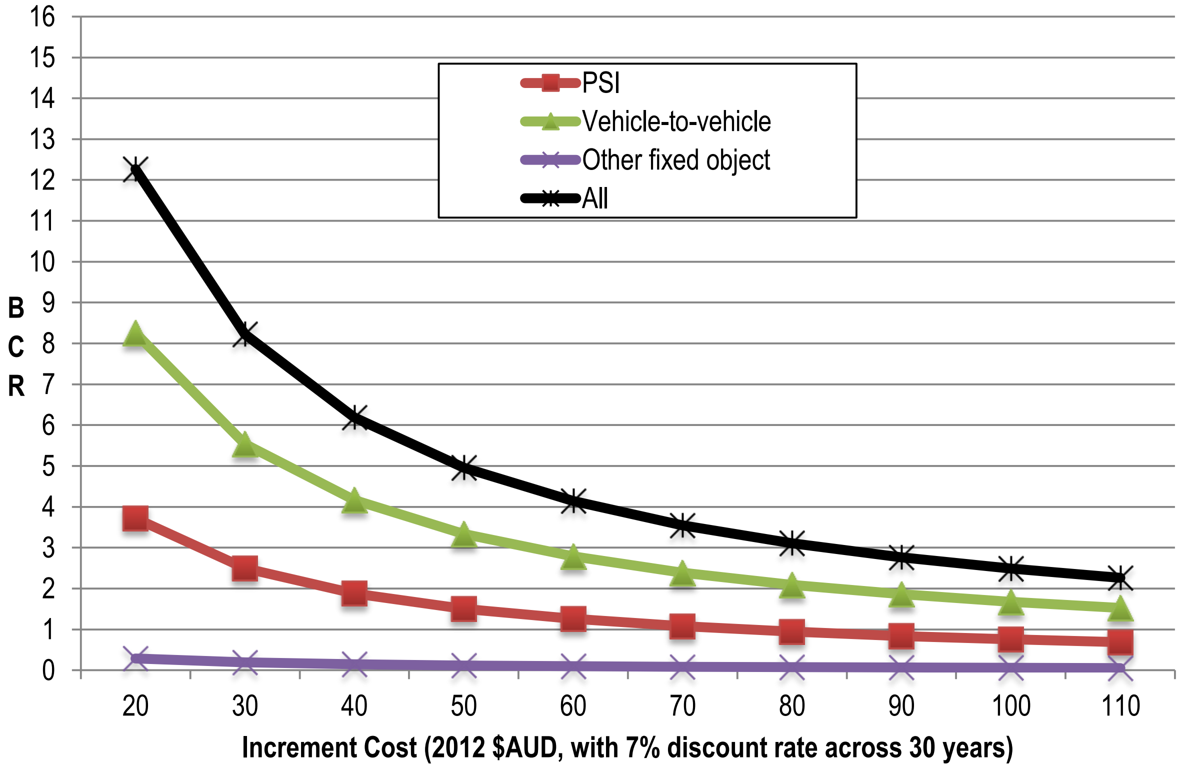


Figure 8.7. BCR values for Australia across the range of increment costs (2012 dollars) for the PSI GTR, Class M1 vehicles for front seat occupants (average BCR) with a GTR increment effectiveness of 30%

8.5.4 Sensitivity analysis for M1 vehicles, using increment percent benefit and cost as the variable factor (front occupants)

In the analysis present above, the expected benefit to occupant protection delivered by the GTR was set at 30% over and above expected safety performance as seen by the literature on side impact airbags. The analysis presented in the following sub-sections examines the effects of a lower (20%) and higher (40%) incremental benefit due to the GTR. This forms the basis of the sensitivity analysis following the expected benefits analysis presented above.

8.5.4.1 20% additional benefit due to GTR for front seat occupants of M1 vehicles

Using a value of 20% as the incremental benefit due to the GTR, rather than the nominated 30% value, implementation of the GTR would remain highly cost effective using a $AU 25.90 two sensor incremental cost, with the overall BCR being 5.46:1 (Table 8.12a; Table 8.12b). Thirty year and per annum savings for Australia are presented in Tables 8.13a and 8.13b, where the 30-year BCR is 5.46 for Victoria and 7.02 for Australia.

A graphical representation of the BCRs over the 30 year period for Australia across incremental costs ranging from $AU 20 to $AU 110 (2012 dollars) is presented in Figure 8.8. The break-even increment cost is $AU 200 (2012 dollars).

Table 8.12a Incremental benefits of a GTR for M1 vehicle front seat occupants, over and above BAU of SAB installation for Victoria, 2016-2045, *assuming 20% increment benefit*

Incremental benefits	Pole impacts	Vehicle-to-Vehicle	Other fixed object	Total
Additional Fatalities avoided	45	43	2	90
Additional TBI-severe avoided	20	41	2	62
Additional TBI-moderate avoided	6	31	1	37
Additional Paraplegia avoided	1	2	0	3
Additional Serious injuries avoided	154	549	16	719
Additional Minor injuries avoided	180	1804	36	2021
Financial benefits, 2016-2045 ($AU, 2012)	$120,805,695	267587644	9369401	$397,762,740
GTR requirement cost ($AU, 2012)	$72,895,006	72895006	72895006	$72,895,006
BCR (30 year period)	**1.66**	**3.67**	**0.13**	**5.46**
BCR in Yr 30	2.74	6.11	0.21	9.06

Table 8.12b Incremental benefits of a GTR for M1 vehicle front seat occupants, over and above BAU of SAB installation for Victoria, average per annum, *assuming 20% increment benefit*

Incremental benefits	Pole impacts	Vehicle-to-Vehicle	Other fixed object	Total
Additional Fatalities avoided	2	1	0.1	3
Additional TBI-severe avoided	1	1	0.1	2
Additional TBI-moderate avoided	0.2	1	0.02	1
Additional Paraplegia avoided	0.03	0	0.003	0.112
Additional Serious injuries avoided	5	18	1	24
Additional Minor injuries avoided	6	60	1	67
Financial benefits, 2016-2045 ($AU, 2012)	$4,026,856	$8,919,588	$312,313	$13,258,758
GTR requirement cost ($AU, 2012)	$2,429,834	$2,429,834	$2,429,834	$2,429,834
BCR (30 year period)	**1.66**	**3.67**	**0.13**	**5.46**

Table 8.13a Incremental benefits of a GTR for M1 vehicle front seat occupants, over and above BAU of SAB installation for Australia, 2016-2045, _assuming 20% increment benefit_

Incremental benefits	Pole impacts	Vehicle-to-Vehicle	Other fixed object	Total
Additional Fatalities avoided	219	210	9	438
Additional TBI-severe avoided	95	197	10	303
Additional TBI-moderate avoided	27	152	3	182
Additional Paraplegia avoided	5	11	0	16
Additional Serious injuries avoided	749	2674	80	3503
Additional Minor injuries avoided	876	8789	177	9842
Financial benefits, 2016-2045 ($AU, 2012)	$588,436,082	$1,303,400,684	$45,637,698	$1,937,474,464
GTR requirement cost ($AU, 2012)	$276,117,445	$276,117,445	$276,117,445	$276,117,445
BCR (30 year period)	**2.13**	**4.72**	**0.17**	**7.02**
BCR in Yr 30	3.52	7.86	0.27	11.65

Table 8.13b Incremental benefits of a GTR for M1 vehicle front seat occupants, over and above BAU of SAB installation for Australia, average per annum, _assuming 20% increment benefit_

Incremental benefits	Pole impacts	Vehicle-to-Vehicle	Other fixed object	Total
Additional Fatalities avoided	7	7	0.3	15
Additional TBI-severe avoided	3	7	0	10
Additional TBI-moderate avoided	1	5	0.10	6
Additional Paraplegia avoided	0.2	0	0.02	1
Additional Serious injuries avoided	25	89	3	117
Additional Minor injuries avoided	29	293	6	328
Financial benefits, 2016-2045 ($AU, 2012)	$19,614,536	$43,446,689	$1,521,257	$64,582,482
GTR requirement cost ($AU, 2012)	$9,203,915	$9,203,915	$9,203,915	$9,203,915
BCR (30 year period)	**2.13**	**4.72**	**0.17**	**7.02**

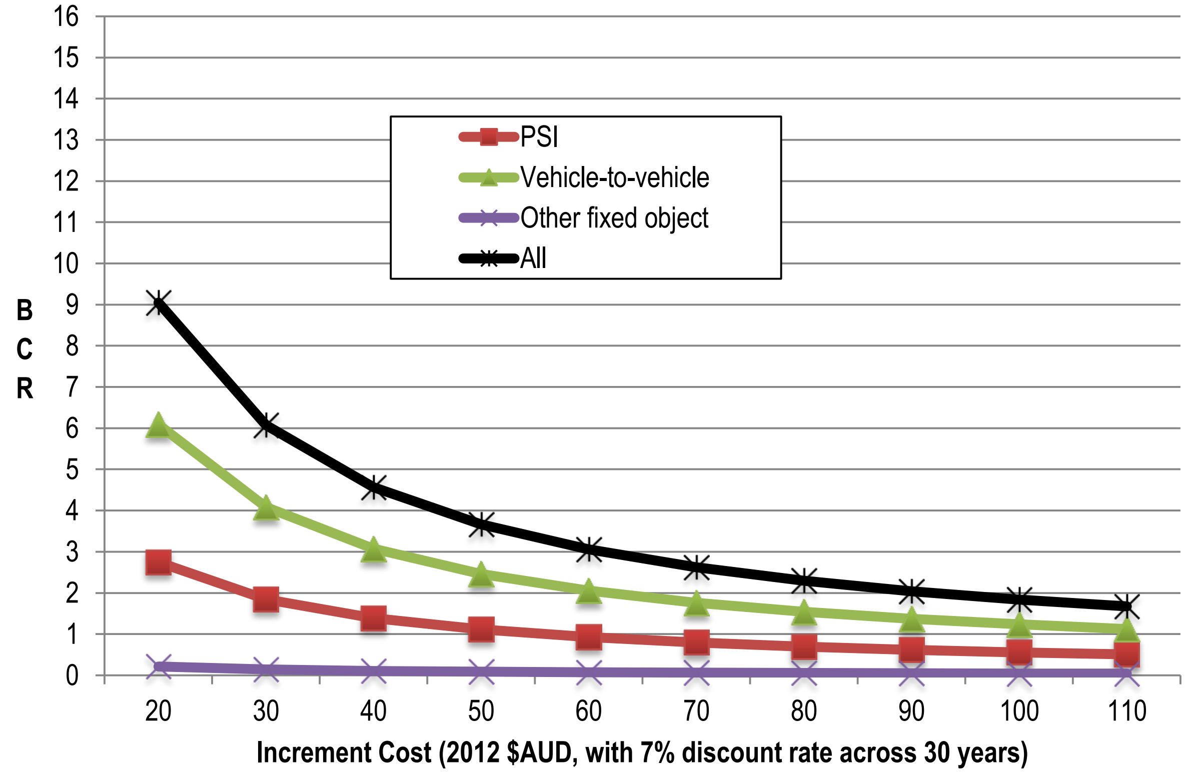


Figure 8.8. BCR values for Australia across the range of increment costs for the PSI GTR, Class M1 vehicle front seat occupants at 20% effectiveness

8.5.4.2 40% additional benefit due to GTR for front seat occupants of M1 vehicles

Using a value of 40% as the added benefit due to the GTR, rather than the nominated 30% value, implementation of the GTR would be highly cost effective using a $AU 25.90 incremental cost (2012 dollars), with the overall BCR being 9.33 for Victoria (Table 8.14a; Table 8.14b) and 12.00 for Australia (Tables 8.15a and 8.15b) for front seat occupants of M1 vehicles, with a two sensor SAB system.

A graphical representation of the BCRs for Australia over the 30 year period across a range of incremental costs is presented in Figure 8.9.

Table 8.14a Incremental benefits of a GTR for M1 vehicle front seat occupants, over and above BAU of SAB installation for Victoria, 2016-2045, *assuming 40% increment benefit*

Incremental benefits	Pole impacts	Vehicle-to-Vehicle	Other fixed object	Total
Additional Fatalities avoided	80	77	3	160
Additional TBI-severe avoided	35	72	4	111
Additional TBI-moderate avoided	10	56	1	67
Additional Paraplegia avoided	2	4	0	6
Additional Serious injuries avoided	274	977	29	1280
Additional Minor injuries avoided	320	3211	65	3596
Financial benefits, 2016-2045 ($AU, 2012)	$206,487,466	457878860	16014675	$680,381,001
GTR requirement cost ($AU, 2012)	$72,895,006	72895006	72895006	$72,895,006
BCR (30 year period)	**2.83**	**6.28**	**0.22**	**9.33**
BCR in Yr 30	5.09	11.36	0.39	16.84

Table 8.14b Incremental benefits of a GTR for M1 vehicle front seat occupants, over and above BAU of SAB installation for Victoria, average per annum, *assuming 40% increment benefit*

Incremental benefits	Pole impacts	Vehicle-to-Vehicle	Other fixed object	Total
Additional Fatalities avoided	3	3	0.1	5
Additional TBI-severe avoided	1	2	0.1	4
Additional TBI-moderate avoided	0.3	2	0.04	2
Additional Paraplegia avoided	0.06	0	0.006	0.199
Additional Serious injuries avoided	9	33	1	43
Additional Minor injuries avoided	11	107	2	120
Financial benefits, 2016-2045 ($AU, 2012)	$6,882,916	$15,262,629	$533,823	$22,679,367
GTR requirement cost ($AU, 2012)	$2,429,834	$2,429,834	$2,429,834	$2,429,834
BCR (30 year period)	**2.83**	**6.28**	**0.22**	**9.33**

Table 8.15a Incremental benefits of a GTR for M1 vehicle front seat occupants, over and above BAU of SAB installation for Australia, 2016-2045, *assuming 40% increment benefit*

Incremental benefits	**Pole impacts**	**Vehicle-to-Vehicle**	**Other fixed object**	**Total**
Additional Fatalities avoided	390	373	16	779
Additional TBI-severe avoided	170	351	18	539
Additional TBI-moderate avoided	48	271	5	325
Additional Paraplegia avoided	8	20	1	29
Additional Serious injuries avoided	1333	4759	142	6234
Additional Minor injuries avoided	1559	15642	315	17515
Financial benefits, 2016-2045 ($AU, 2012)	$1,005,785,991	$2,230,295,876	$78,006,361	$3,314,088,228
GTR requirement cost ($AU, 2012)	$276,117,445	$276,117,445	$276,117,445	$276,117,445
BCR (30 year period)	**3.64**	**8.08**	**0.28**	**12.00**
BCR in Yr 30	6.54	14.60	0.51	21.65

Table 8.15b Incremental benefits of a GTR for M1 vehicle front seat occupants, over and above BAU of SAB installation for Australia, average per annum, *assuming 40% increment benefit*

Incremental benefits	**Pole impacts**	**Vehicle-to-Vehicle**	**Other fixed object**	**Total**
Additional Fatalities avoided	13	12	0.5	26
Additional TBI-severe avoided	6	12	1	18
Additional TBI-moderate avoided	2	9	0.17	11
Additional Paraplegia avoided	0.3	1	0.03	1
Additional Serious injuries avoided	44	159	5	208
Additional Minor injuries avoided	52	521	11	584
Financial benefits, 2016-2045 ($AU, 2012)	$33,526,200	$74,343,196	$2,600,212	$110,469,608
GTR requirement cost ($AU, 2012)	$9,203,915	$9,203,915	$9,203,915	$9,203,915
BCR (30 year period)	**3.64**	**8.08**	**0.28**	**12.00**

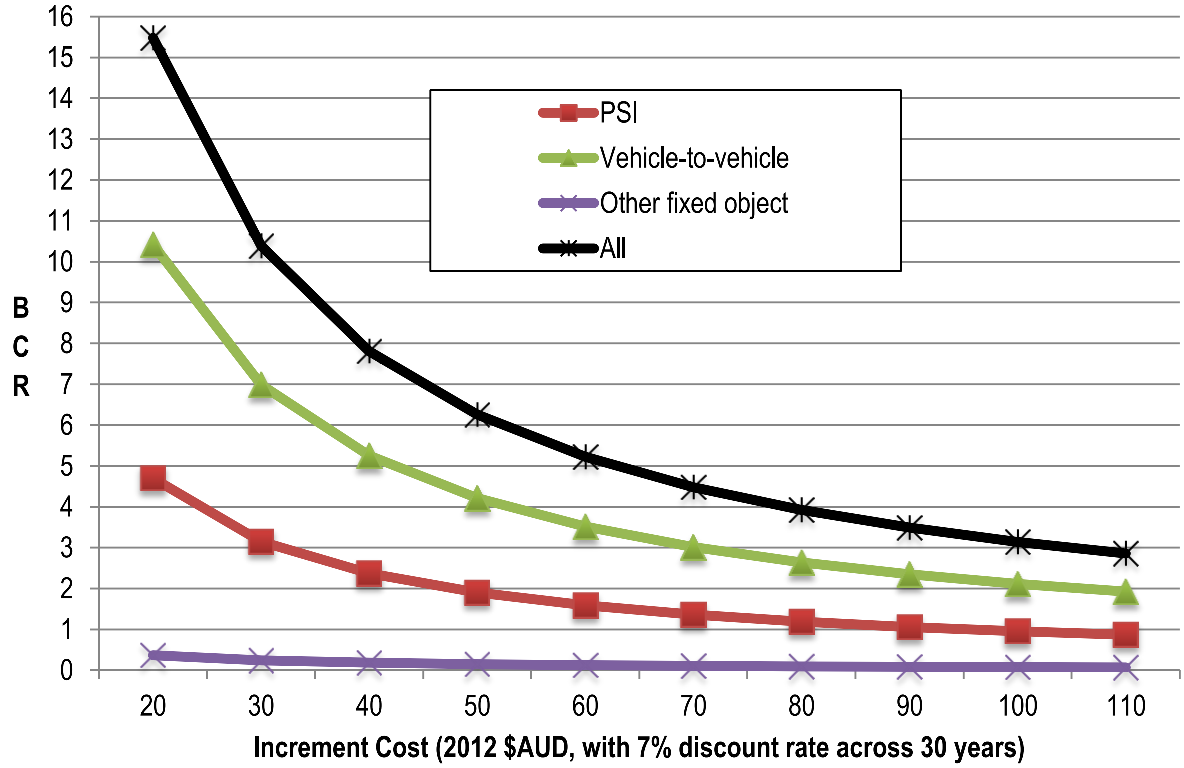


Figure 8.9. BCR values for Australia across the range of increment costs for the PSI GTR, Class M1 vehicle front seat occupants at 40% effectiveness

8.5.4.3 Summary of additional benefits for M1 vehicle front seat occupants given variable GTR safety effectiveness and costs of meeting the GTR

Figure 8.10 presents a summary of the BCRs across a range of increment costs and the 20%, 30% and 40% GTR increment effectiveness values for Australia beyond what is currently reported with side impact airbags (and associated side impact protection systems) in the literature. The proposed PSI GTR would be highly cost effective, with positive BCRs beyond $AU 110 incremental cost for the lowest effectiveness value of 20%.

It must be noted that the 30% increment was used as the basis for improvements in side impact safety due to the proposed GTR. In practical terms, this means that the GTR was assumed to provide a further 9.6% reduction and 10.2% reduction in the risk of fatalities and injuries, above the currently reported 32% and 34% reductions observed in fatality and injuries with side impact (head + thorax) airbags. It would be expected that the proposed GTR would demand significantly improved safety, over and above the current regulations, particularly with respect to the head and the thorax of the crash-involved occupant. This premise is reflected in the BCRs presented below across a broad range of costs.

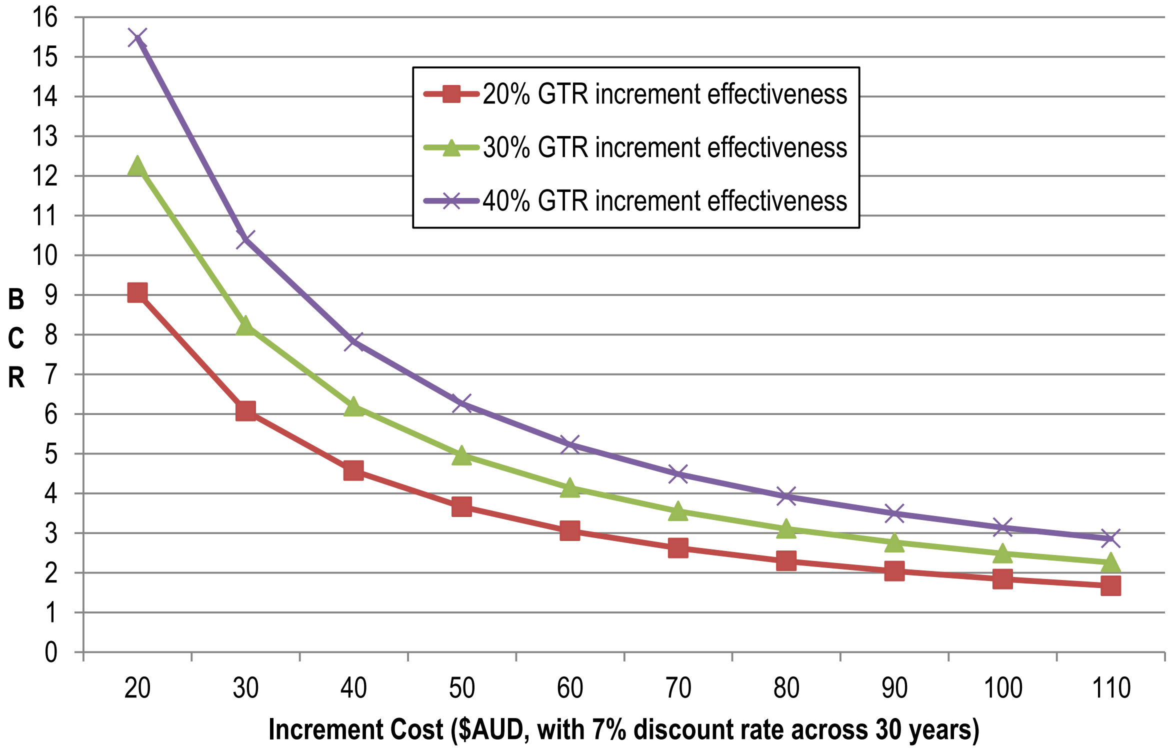


Figure 8.10. BCR values for Australia across the range of increment costs for the PSI GTR, Class M1 vehicle front seat occupants at 20%, 30% and 40% effectiveness

8.6 Benefits and Costs associated with the GTR for N1 vehicle front seat occupants

Following the analysis of the likely benefits and costs of the GTR for M1 category vehicles, the same process is followed in deriving the benefits and costs for N1 vehicles. This section details benefits and costs of the GTR for front row occupants.

8.6.1 Processes and key assumptions

The benefit and cost structures used in the analysis were described in detail in previous sections. The analysis reported here relates to the likely effectiveness of the PSI GTR in mitigating fatalities and serious injuries for front seat occupants of N1 vehicles.

The costs of meeting the PSI GTR are as follows:

1. For vehicles without SAB fitted, the cost was $AU 303.58 ($ 2012 dollars)
2. For vehicles with a side curtain airbag fitted as standard, the GTR increment cost of $AU 29.82 ($ 2012 dollars) was used.

The procedure for estimating the fleet fitment costs was described earlier (see Section 8.4). The reader is referred to Appendix 8.11 for further detail on ESC and SAB penetration, and associated costs.

8.6.2 Estimated benefits and costs of the GTR for N1 vehicle front occupants

Table 8.16 (a) (b) presents the number of front row fatalities and injuries avoided by type, their associated dollar value and the financial cost of implementation for Victoria.

The effect of the GTR is estimated to be 14 lives saved, 17 severe TBI cases avoided, 7 moderate TBI cases avoided, 4 instances of paraplegia avoided, 113 serious and 497 minor injuries avoided. In financial terms, the injury cost savings equate to approximately $AU 83.7 million, with $AU 21 million attributable to PSI savings. With the cost of implementation being $AU 41.5 million, the overall BCR was 2.02:1.

Table 8.16a Incremental benefits of a GTR for N1 vehicle front seat occupants (30%), over and above BAU of SAB installation for Victoria, 2016-2045

Incremental benefits	Pole impacts	Vehicle-to-Vehicle	Other fixed object	Total
Additional Fatalities avoided	5	9	0	14
Additional TBI-severe avoided	3	13	1	17
Additional TBI-moderate avoided	3	3	1	7
Additional Paraplegia avoided	1	3	0	4
Additional Serious injuries avoided	27	75	10	113
Additional Minor injuries avoided	60	432	5	497
Financial benefits, 2016-2045	$21,079,593	$57,298,757	$5,327,125	$83,705,475
Financial benefits, 2016-2045 ($AU, 2012)	$41,524,082	$41,524,082	$41,524,082	$41,524,082
GTR requirement cost ($AU, 2012)	**0.51**	**1.38**	**0.13**	**2.02**
BCR in Yr 30	0.95	2.67	0.24	3.87

Table 8.16b Incremental benefits of a GTR for N1 vehicle front seat occupants (30%), over and above BAU of SAB installation for Victoria, per annum

Incremental benefits	**Pole impacts**	**Vehicle-to-Vehicle**	**Other fixed object**	**Total**
Additional Fatalities avoided	0.2	0.3	0.0	0.5
Additional TBI-severe avoided	0.1	0.4	0.04	0.6
Additional TBI-moderate avoided	0.1	0.1	0.03	0.2
Additional Paraplegia avoided	0.03	0.1	0.01	0.1
Additional Serious injuries avoided	0.9	2.5	0.3	3.8
Additional Minor injuries avoided	2.0	14.4	0.2	16.6
Financial benefits, 2016-2045 ($AU, 2012)	$702,653	$1,909,959	$177,571	$2,790,183
GTR requirement cost ($AU, 2012)	$1,384,136	$1,384,136	$1,384,136	$1,384,136
BCR (30 year period)	**0.51**	**1.38**	**0.13**	**2.02**

The estimated costs and benefits of the GTR for occupants of N1 vehicles derived for Victoria form the basis of Australian estimates[27] (see Table 8.17a, Table 8.17b). For Australia, over the 30 year period, it is estimated that the GTR will result in 67 fewer front row fatalities, 88 severe TBI injuries avoided and 34 moderate TBI injuries avoided. A small number of instances of paraplegia are also estimated to be avoided (n = 22) while the number of occupants saved from serious and minor injuries is large. Translated into monetary values, the fatality and injury savings equate to $AU 407 million over the period, for an implementation cost of $AU 157 million; hence the overall BCR was 2.59:1. The high incidence of severe head injury and the high cost associated with these injuries, coupled with the cost of meeting the GTR results in a high BCR. The savings and cost estimates are also expressed on an annual basis in Table 8.17b.

Table 8.17a Incremental benefits of a GTR for N1 vehicle front seat occupants (30%), over and above BAU of SAB installation for Australia, 2016-2045

Incremental benefits	**Pole impacts**	**Vehicle-to-Vehicle**	**Other fixed object**	**Total**
Additional Fatalities avoided	24	43	0	67
Additional TBI-severe avoided	18	64	7	88
Additional TBI-moderate avoided	13	16	5	34
Additional Paraplegia avoided	4	16	2	22
Additional Serious injuries avoided	138	382	53	574
Additional Minor injuries avoided	306	2199	27	2532
Financial benefits, 2016-2045 ($AU, 2012)	$102,677,223	$279,098,236	$25,948,052	$407,723,511
GTR requirement cost ($AU, 2012)	$157,288,189	$157,288,189	$157,288,189	$157,288,189
BCR (30 year period)	**0.65**	**1.77**	**0.16**	**2.59**
BCR in Yr 30	1.23	3.44	0.31	4.97

27 Based on 2000 – 2009 Australian population statistics: Victoria comprises 24.76% of the Australian national population, and we use a 4.037 inflation factor to scale up crash statistics to Australia; a secondary inflation factor is also included to account for the differential road safety performance between Victoria and the other jurisdiction (*1.262). The total inflation factor used was 4.87093 on the benefits side, and 3.87 on the cost side to account for the proportion of new vehicles sold in Victoria within Australia.

Table 8.17b Incremental benefits of a GTR for N1 vehicle front seat occupants (30%), over and above BAU of SAB installation for Australia, average per annum

Incremental benefits	Pole impacts	Vehicle-to-Vehicle	Other fixed object	Total
Additional Fatalities avoided	1	1	0	2
Additional TBI-severe avoided	1	2	0.2	3
Additional TBI-moderate avoided	0.4	1	0.17	1
Additional Paraplegia avoided	0.1	1	0.06	1
Additional Serious injuries avoided	5	13	2	19
Additional Minor injuries avoided	10	73	1	84
Financial benefits, 2016-2045 ($AU, 2012)	$3,422,574	$9,303,275	$864,935	$13,590,784
GTR requirement cost ($AU, 2012)	$5,242,940	$5,242,940	$5,242,940	$5,242,940
BCR (30 year period)	**0.65**	**1.77**	**0.16**	**2.59**

8.6.3 Sensitivity analysis for N1 vehicle front seat occupants, using increment cost as the variable factor

Figure 8.11 presents the BCRs across a range of incremental cost values, ranging from $AU 20 through to $AU 70 per vehicle.

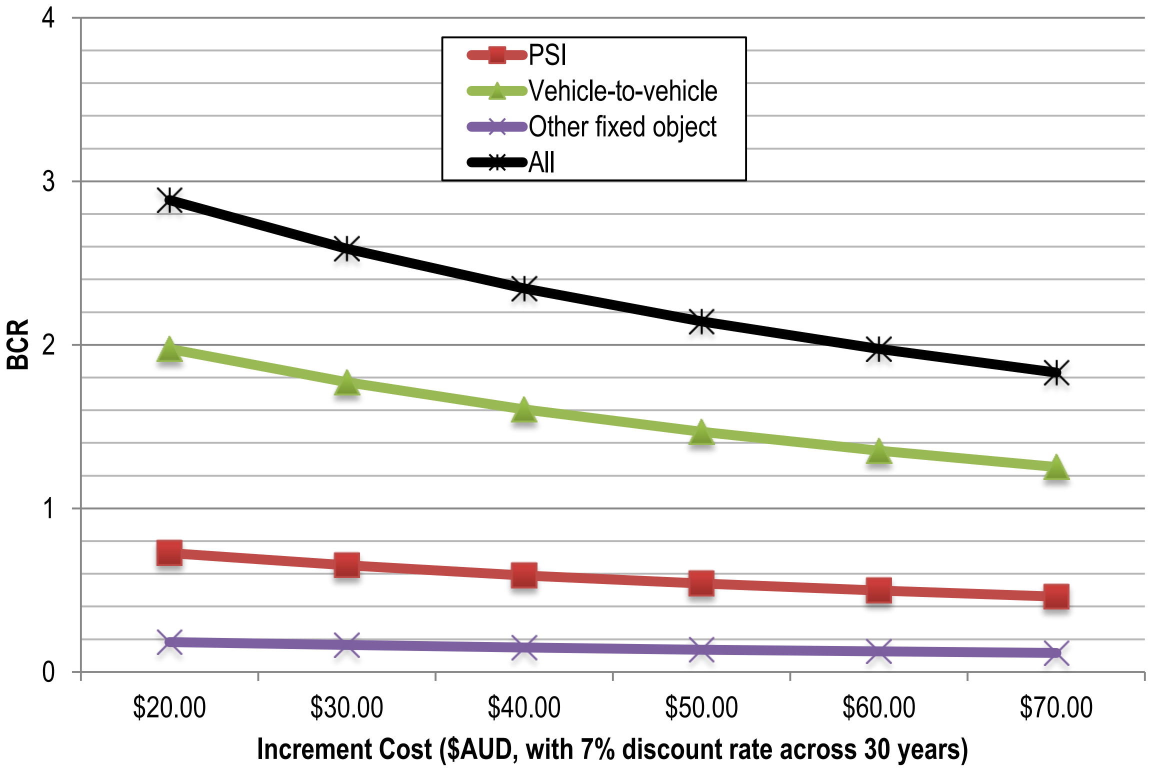


Figure 8.11. BCR values for Australia across the range of increment costs for the PSI GTR, Class N1 vehicles, front seat occupants for a 30% benefit increment

8.6.4 Sensitivity analysis for N1 vehicles, using increment percent benefit and cost as the variable factor

The expected increment benefit associated with the GTR was set at 30% over and above reported curtain and thorax side impact airbags. The following sub-sections present the calculated benefits and associated BCRs using an increment value of 20% and 40%.

8.6.4.1 20% additional benefit due to GTR for N1 front seat occupants

Using a value of 20% as the added benefit due to the GTR, rather than the nominated 30% value, implementation of the GTR remains highly cost effective (see Table 8.18a / b). Thirty year and per annum savings for Australia are presented in Tables 19a and 19b.

A graphical representation of the BCRs over the 30 year period and across variable incremental costs is presented in Figure 8.12.

Table 8.18a Incremental benefits of a GTR for N1 vehicle front seat occupants, over and above BAU of SAB installation for Victoria, 2016-2045, _assuming 20% increment benefit_

Incremental benefits	Pole impacts	Vehicle-to-Vehicle	Other fixed object	Total
Additional Fatalities avoided	4	7	0	11
Additional TBI-severe avoided	3	10	1	13
Additional TBI-moderate avoided	2	2	1	5
Additional Paraplegia avoided	1	2	0	3
Additional Serious injuries avoided	21	58	8	86
Additional Minor injuries avoided	46	331	4	382
Financial benefits, 2016-2045 ($AU, 2012)	$16,375,361	$44,457,326	$4,138,296	$64,970,983
GTR requirement cost ($AU, 2012)	$41,524,082	$41,524,082	$41,524,082	$41,524,082
BCR (30 year period)	**0.39**	**1.07**	**0.10**	**1.56**
BCR in Yr 30	0.72	2.01	0.18	2.90

Table 8.18b Incremental benefits of a GTR for N1 vehicle front seat occupants, over and above BAU of SAB installation for Victoria, average per annum, _assuming 20% increment benefit_

Incremental benefits	Pole impacts	Vehicle-to-Vehicle	Other fixed object	Total
Additional Fatalities avoided	0.1	0.2	0.0	0.4
Additional TBI-severe avoided	0.1	0.3	0.03	0.4
Additional TBI-moderate avoided	0.1	0.1	0.03	0.2
Additional Paraplegia avoided	0.02	0.1	0.01	0.1
Additional Serious injuries avoided	0.7	1.9	0.3	2.9
Additional Minor injuries avoided	1.5	11.0	0.1	12.7
Financial benefits, 2016-2045 ($AU, 2012)	$545,845	$1,481,911	$137,943	$2,165,699
GTR requirement cost ($AU, 2012)	$1,384,136	$1,384,136	$1,384,136	$1,384,136
BCR (30 year period)	**0.39**	**1.07**	**0.10**	**1.56**

Table 8.19a Incremental benefits of a GTR for N1 vehicle front seat occupants, over and above BAU of SAB installation for Australia, 2016-2045, *assuming 20% increment benefit*

Incremental benefits	**Pole impacts**	**Vehicle-to-Vehicle**	**Other fixed object**	**Total**
Additional Fatalities avoided	18	33	0	51
Additional TBI-severe avoided	14	49	5	68
Additional TBI-moderate avoided	10	12	4	26
Additional Paraplegia avoided	3	12	1	17
Additional Serious injuries avoided	106	294	41	441
Additional Minor injuries avoided	235	1689	21	1945
Financial benefits, 2016-2045 ($AU, 2012)	$79,763,236	$216,548,525	$20,157,349	$316,469,110
GTR requirement cost ($AU, 2012)	$157,288,189	$157,288,189	$157,288,189	$157,288,189
BCR (30 year period)	**0.51**	**1.38**	**0.13**	**2.01**
BCR in Yr 30	0.92	2.58	0.23	3.74

Table 8.19b Incremental benefits of a GTR for N1 vehicle front seat occupants, over and above BAU of SAB installation for Australia, average per annum, *assuming 20% increment benefit*

Incremental benefits	**Pole impacts**	**Vehicle-to-Vehicle**	**Other fixed object**	**Total**
Additional Fatalities avoided	1	1	0	2
Additional TBI-severe avoided	0	2	0.2	2
Additional TBI-moderate avoided	0.3	0	0.13	1
Additional Paraplegia avoided	0.1	0	0.04	1
Additional Serious injuries avoided	4	10	1	15
Additional Minor injuries avoided	8	56	1	65
Financial benefits, 2016-2045 ($AU, 2012)	$2,658,775	$7,218,284	$671,912	$10,548,970
GTR requirement cost ($AU, 2012)	$5,242,940	$5,242,940	$5,242,940	$5,242,940
BCR (30 year period)	**0.51**	**1.38**	**0.13**	**2.01**

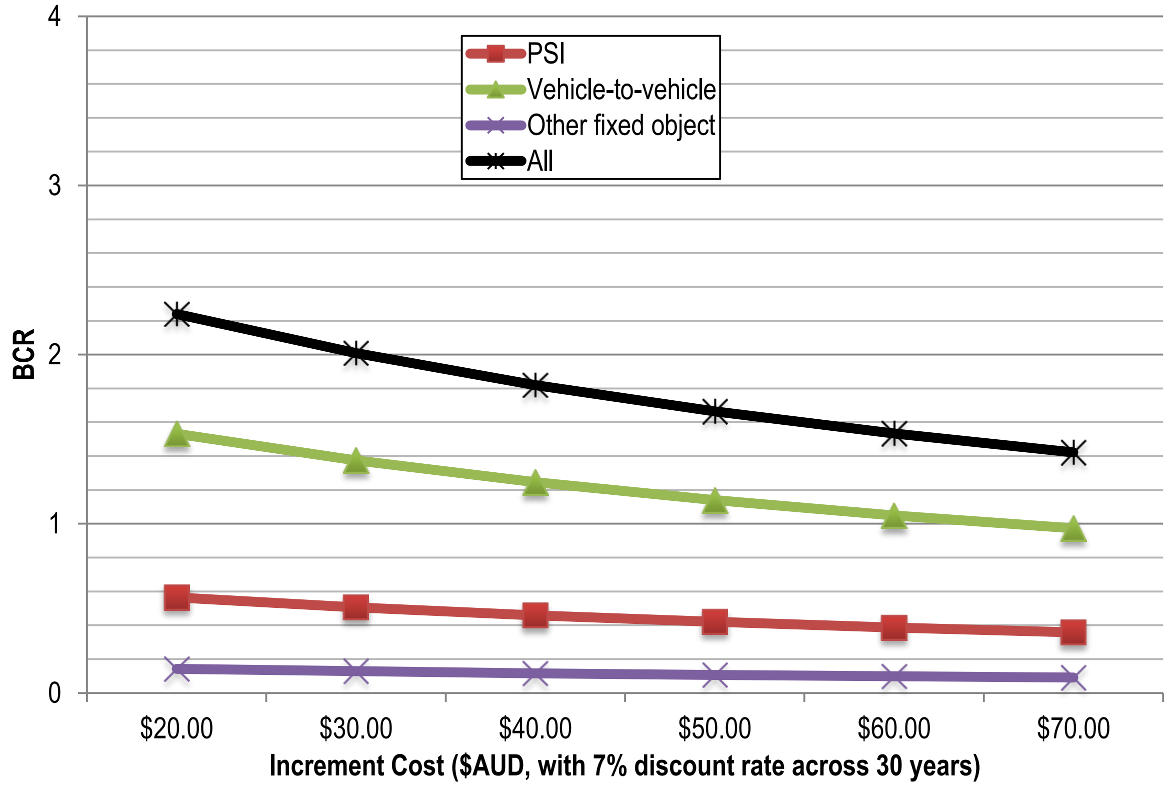


Figure 8.12. BCR values for Australia across the range of increment costs at 20% increment benefit for N1 vehicle front seat occupants

8.6.4.2 40% additional benefit due to GTR for N1 front seat occupants

Using a 40% increment, the number of fatalities avoided and injuries mitigated is substantial. Given the comparatively low business-as-usual fitment of side airbags in N1 vehicles, the small number of units sold and the high risk of serious injury, the savings delivered by the GTR are significant (Table 8.20, Victoria; Table 8.21, Australia). Figure 8.13 presents the BCR values across a range of increment costs.

Table 8.20a Incremental benefits of a GTR for N1 vehicle front seat occupants, over and above BAU of SAB installation for Victoria, 2016-2045, _assuming 40% increment benefit_

Incremental benefits	**Pole impacts**	**Vehicle-to-Vehicle**	**Other fixed object**	**Total**
Additional Fatalities avoided	6	11	0	17
Additional TBI-severe avoided	4	15	2	21
Additional TBI-moderate avoided	3	4	1	8
Additional Paraplegia avoided	1	4	0	5
Additional Serious injuries avoided	33	92	13	139
Additional Minor injuries avoided	74	532	6	612
Financial benefits, 2016-2045 ($AU, 2012)	$25,783,826	$70,140,188	$6,515,954	$102,439,968
GTR requirement cost ($AU, 2012)	$41,524,082	$41,524,082	$41,524,082	$41,524,082
BCR (30 year period)	**0.62**	**1.69**	**0.16**	**2.47**
BCR in Yr 30	1.19	3.34	0.30	4.83

Table 8.20b Incremental benefits of a GTR for N1 vehicle front seat occupants, over and above BAU of SAB installation for Victoria, average per annum, _assuming 40% increment benefit_

Incremental benefits	**Pole impacts**	**Vehicle-to-Vehicle**	**Other fixed object**	**Total**
Additional Fatalities avoided	0.2	0.4	0.0	0.6
Additional TBI-severe avoided	0.1	0.5	0.06	0.7
Additional TBI-moderate avoided	0.1	0.1	0.04	0.3
Additional Paraplegia avoided	0.04	0.1	0.01	0.2
Additional Serious injuries avoided	1.1	3.1	0.4	4.6
Additional Minor injuries avoided	2.5	17.7	0.2	20.4
Financial benefits, 2016-2045 ($AU, 2012)	$859,461	$2,338,006	$217,198	$3,414,666
GTR requirement cost ($AU, 2012)	$1,384,136	$1,384,136	$1,384,136	$1,384,136
BCR (30 year period)	**0.62**	**1.69**	**0.16**	**2.47**

Table 8.21a Incremental benefits of a GTR for N1 vehicle front seat occupants, over and above BAU of SAB installation for Australia, 2016-2045, *assuming 40% increment benefit*

Incremental benefits	**Pole impacts**	**Vehicle-to-Vehicle**	**Other fixed object**	**Total**
Additional Fatalities avoided	30	53	0	83
Additional TBI-severe avoided	22	79	8	109
Additional TBI-moderate avoided	16	20	6	42
Additional Paraplegia avoided	5	20	2	27
Additional Serious injuries avoided	170	471	65	706
Additional Minor injuries avoided	377	2709	33	3119
Financial benefits, 2016-2045 ($AU, 2012)	$125,591,209	$341,647,947	$31,738,755	$498,977,911
GTR requirement cost ($AU, 2012)	$157,288,189	$157,288,189	$157,288,189	$157,288,189
BCR (30 year period)	**0.80**	**2.17**	**0.20**	**3.17**
BCR in Yr 30	1.53	4.29	0.39	6.21

Table 8.21b Incremental benefits of a GTR for N1 vehicle front seat occupants, over and above BAU of SAB installation for Australia, average per annum, *assuming 40% increment benefit*

Incremental benefits	**Pole impacts**	**Vehicle-to-Vehicle**	**Other fixed object**	**Total**
Additional Fatalities avoided	1	2	0	3
Additional TBI-severe avoided	1	3	0.3	4
Additional TBI-moderate avoided	0.5	1	0.21	1
Additional Paraplegia avoided	0.2	1	0.07	1
Additional Serious injuries avoided	6	16	2	24
Additional Minor injuries avoided	13	90	1	104
Financial benefits, 2016-2045 ($AU, 2012)	$4,186,374	$11,388,265	$1,057,959	$16,632,597
GTR requirement cost ($AU, 2012)	$5,242,940	$5,242,940	$5,242,940	$5,242,940
BCR (30 year period)	**0.80**	**2.17**	**0.20**	**3.17**

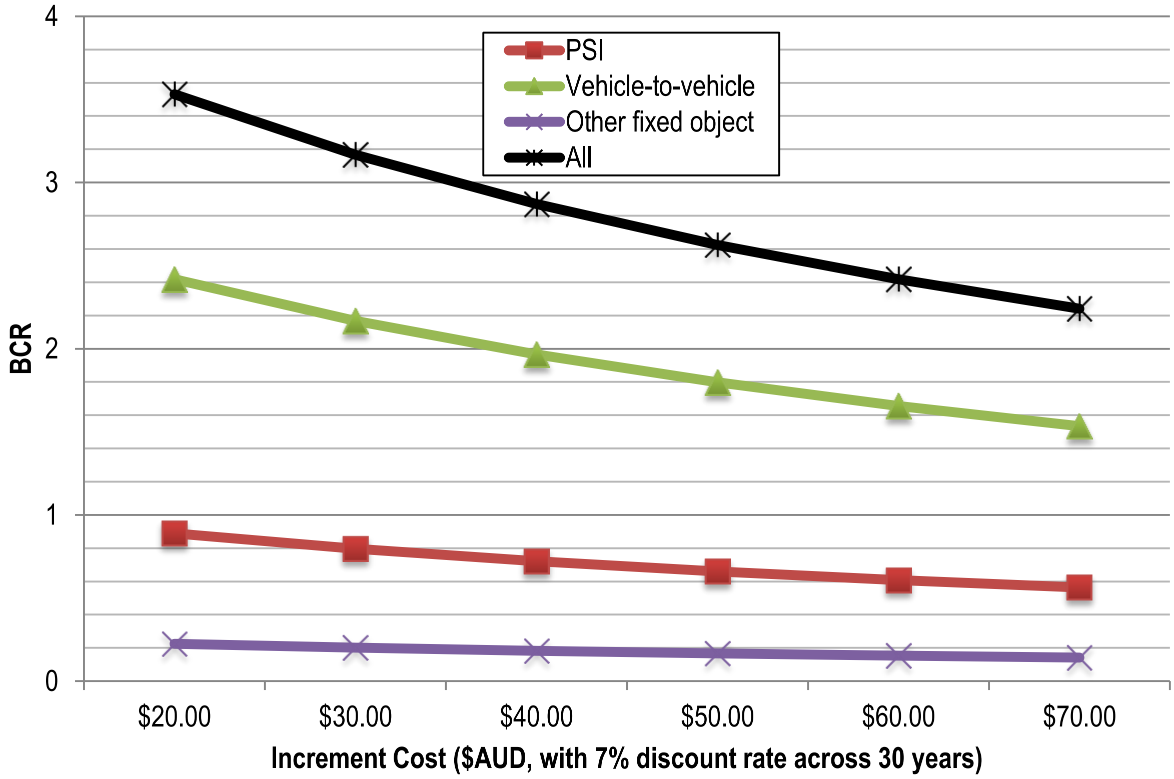


Figure 8.13. BCR values for Australia across the range of increment costs at 40% increment benefit for N1 vehicle front seat occupants

8.6.4.3 Summary of additional benefits for N1 vehicle front seat occupants given variable GTR safety effectiveness and costs of meeting the GTR

Figure 8.14 presents a summary of the BCRs across a range of increment costs and effectiveness values of 20%, 30% and 40% of currently reported side impact protection benefits as seen in the literature. Across the full range of incremental costs and expected percent improvement in side impact safety the BCR value is above 1.5.

The overall BCR value remains at or above 1.0 at the lower cost points for the three specified effectiveness values across the increment cost range.

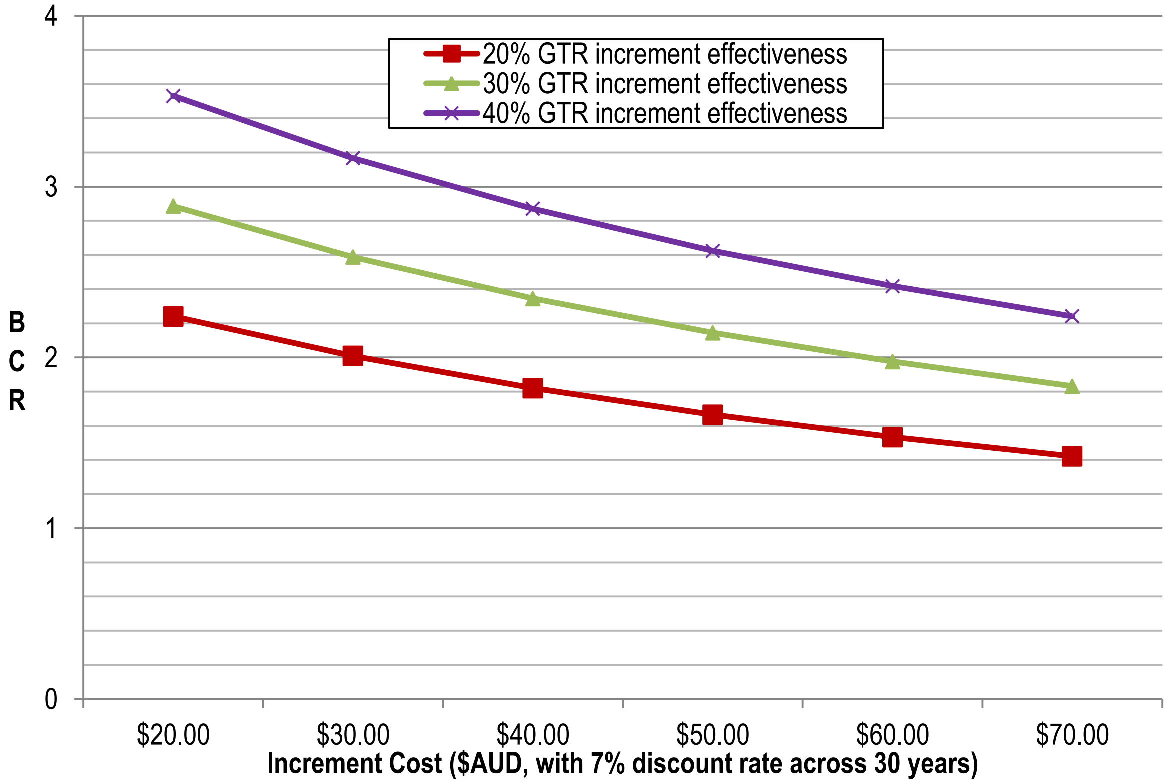


Figure 8.14. BCR values for Australia across the range of increment costs for the PSI GTR, Class N1 vehicle front seat occupants at 20%, 30% and 40% effectiveness

8.7 Summary of incremental benefits associated with a PSI GTR for M1 and N1 vehicles for front row and all vehicle occupants

8.7.1 BCR values for M1 and N1 occupants across a range of GTR increment effectiveness values

The analysis reported here demonstrates the proposed GTR is highly cost effective for front row occupants of both M1 and N1 vehicles. Given the requirements of the PSI GTR, the safety benefits to the occupants in the front row and the rear are likely to be similar, if not the same. Indeed, while side airbag effectiveness studies have focussed on the driver, this is more than likely due to the availabililty of data rather than any lack of side impact airbag effectiveness for other occupants (i.e. passengers). Indeed, our analysis of the in-depth databases highlights current difficulties in obtaining real-world data where side airbags have deployed.

In addition to the front row occupant analysis described in the previous sections, the benefits analysis was extended to two additional scenarios, these being:

- front row occupants but where four sensor increment costs were used for M1 and weighted two / four sensor increment costs were used for N1 vehicles (to allow for twin vab N1 vehicles), and
- all occupants (front, rear) using four sensor increment costs for M1 vehicles and and weighted two / four sensor increment costs were used for N1 vehicles (to allow for twin vab N1 vehicles).

These additional analysis were performed as a sensitivty analysis in the case of front occupants where manufacturers may elect to cover all seating positions, and to be in line with the likely inclusion of the rear seating positions as part of phase-in requirements of the PSI GTR.

In summary, across all configurations, the derived BCR values at each increment percent value demonstrate that the proposed PSI GTR is highly cost-effective (Table 8.22).

Table 8.22 GTR BCR values for M1 and N1 front row and front / rear seat occupants involved in side impact crashes, by increment effectiveness (Australia)

GTR increment†	Front occupants		Front occupants		All occupants‡	
	BCR (30 yr. period)	BCR (equilibrium, at 30th year)	BCR (30 yr. period)	BCR (equilibrium, at 30th year)	BCR (30 yr. period)	BCR (equilibrium, at 30th year)
M1	*Weighted 2 / 4 sensor cost*		*4 sensor cost*		*4 sensor cost*	
20%	7.02	11.65	3.47	5.73	3.99	6.58
30%	***9.51***	***16.65***	***4.70***	***8.18***	***5.41***	***9.41***
40%	12.00	21.65	5.94	10.64	6.83	12.24
N1	*2 sensor cost*		*Weighted 2 / 4 sensor cost (single / dual cab)*		*Weighted 2 / 4 sensor cost (single / dual cab)*	
20%	2.01	3.74	1.88	3.40	2.07	3.75
30%	***2.59***	***4.97***	***2.42***	***4.53***	***2.67***	***5.00***
40%	3.17	6.21	2.96	5.66	3.27	6.24

† percent increment over and above current SAB effectiveness: fatality, 32%; injury, 34%
‡ all occupants means front and rear outboard seated occupants

While the notion that the GTR will have similar effects for non-struck side and rear occupants is contestable, the results presented above demonstrate the significant potential of improved side impact protection demanded by the GTR. It is especially important to note the comments made in the EEVC report that benefits of a pole test would be expected to accrue to the non-struck side occupant.

8.7.2 Integrated savings and associated BCR values for M1 (2/4 sensor) and N1 (2 sensor) front seat occupants for Australia and the associated economic benefits and costs

The PSI GTR is aimed at both the M1 vehicle class and the N1 vehicle class. The overall benefits of the GTR are therefore of interest. Of principal interest are the benefits of the PSI GTR to occupants in the front seats, and certainly our analysis indicates that front seat occupants represent *at least 85%* of injured occupants of vehicles invovled in crashes. Notably, in N1 vehicles, all fatalities occurred in the front row.

Table 8.23a presents the savings for front seat occupants involved in M1 and N1-involved side impact crashes combined for Australia.

The modelling undertaken here states that 675 front row occupant fatalities would be avoided over the first 30-year span of the PSI GTR (range: 489 to 861; see Table 8.23b, 8.23c) and there are significant injury reductions in each severity category.

The economic benefits associated with these fatality and injury savings are significant. Overall, approximately $AU 3 billion in savings will be made, for an outlay of $AU 0.43 billion, with the BCR being 7.00:1 (*BCR range: 5.20-8.80)*. BCR values remained positive across the range of increment effectiveness spectrum and installation cost points. All benefits and costs are expressed in 2012 dollar values.

Table 8.23a Total front seat fatalities and injuries avoided in Australia, assuming an effectiveness increment of 30%

M1 / N1	Pole impacts	Vehicle-to-Vehicle	Other fixed object	Total
Additional Fatalities avoided	329	334	12	675
Additional TBI-severe avoided	150	338	21	509
Additional TBI-moderate avoided	51	228	9	288
Additional Paraplegia avoided	11	32	2	45
Additional Serious injuries avoided	1179	4099	164	5442
Additional Minor injuries avoided	1524	14414	273	16210
Financial benefits, 2016-2045 ($AU, 2012)	$899,788,259	$2,045,946,515	$87,770,082	$3,033,504,857
GTR requirement cost ($AU, 2012)	$433,405,635	$433,405,635	$433,405,635	$433,405,635
BCR (30 year period)	**2.08**	**4.72**	**0.20**	**7.00**

Table 8.23b and Table 8.23c presents the national savings associated with the GTR at increment values of 20% and 40% respectively, serving as a sensitivity analysis. These provide the lower and upper bounds on the point estimate savings presented in Table 8.23a.

Table 8.23b Total front seat fatalities and injuries avoided in Australia due to the PSI GTR, assuming a 20% incremental benefit

M1 / N1	Pole impacts	Vehicle-to-Vehicle	Other fixed object	Total
Additional Fatalities avoided	238	243	9	489
Additional TBI-severe avoided	109	246	15	371
Additional TBI-moderate avoided	38	165	7	209
Additional Paraplegia avoided	8	24	2	33
Additional Serious injuries avoided	855	2968	120	3944
Additional Minor injuries avoided	1112	10478	198	11787
Financial benefits, 2016-2045 ($AU, 2012)	$668,199,318	$1,519,949,208	$65,795,047	$2,253,943,574
GTR requirement cost ($AU, 2012)	$433,405,635	$433,405,635	$433,405,635	$433,405,635
BCR (30 year period)	**1.54**	**3.51**	**0.15**	**5.20**

Table 8.23c Total front seat fatalities and injuries avoided in Australia due to the PSI GTR, assuming a 40% incremental benefit

M1 / N1	Pole impacts	Vehicle-to-Vehicle	Other fixed object	Total
Additional Fatalities avoided	420	426	16	861
Additional TBI-severe avoided	192	430	26	648
Additional TBI-moderate avoided	65	291	11	367
Additional Paraplegia avoided	14	40	3	56
Additional Serious injuries avoided	1503	5230	207	6940
Additional Minor injuries avoided	1936	18350	348	20634
Financial benefits, 2016-2045 ($AU, 2012)	$1,131,377,200	$2,571,943,822	$109,745,117	$3,813,066,139
GTR requirement cost ($AU, 2012)	$433,405,635	$433,405,635	$433,405,635	$433,405,635
BCR (30 year period)	**2.61**	**5.93**	**0.25**	**8.80**

8.7.3 Integrated savings and the associated BCR values for M1 (4 sensor) and N1 (2 / 4 sensor) front seat occupants for Australia and the associated economic benefits and costs

Of interest is the implications on the overall BCR when four sensor costs are used for all M1 vehicles and for a proportion of N1 vehicles, given the number of dual cab 4 x 4 vehicles in the N1 category.

Table 8.24a, 8.24b and Table 8.24c presents the fatality and injury reduction benefits associated with the PSI GTR, both in numeric and economic terms for the principal increment value of 30% and the lower and upper benefit values (i.e., 20%, 40%). It is estimated that the PSI GTR will result in 675 fewer fatalities (range: 489-861) and significantly fewer occupants with severe and moderate TBI. These are the same as the previous section (8.7.2).

With financial benefits being $AU 3 billion (2012 dollars) but using a different cost structure ($AU 0.72 billion, 2012 dollars), the overall BCR for M1 and N1 front seat occupants was 4.17:1 at 30% GTR increment effectiveness (*BCR range: 3.10-5.25)*.

Table 8.24a Total front occupant fatalities and injuries avoided in Australia (30% GTR effectiveness increment)

M1 / N1	Pole impacts	Vehicle-to-Vehicle	Other fixed object	Total
Additional Fatalities avoided	329	334	12	675
Additional TBI-severe avoided	150	338	21	509
Additional TBI-moderate avoided	51	228	9	288
Additional Paraplegia avoided	11	32	2	45
Additional Serious injuries avoided	1179	4099	164	5442
Additional Minor injuries avoided	1524	14414	272	16210
Financial benefits, 2016-2045 ($AU, 2012)	$899,788,259	$2,045,946,515	$87,918,247	$3,033,653,021
GTR requirement cost ($AU, 2012)	$726,927,417	$726,927,417	$726,927,417	$726,927,417
BCR (30 year period)	**1.24**	**2.81**	**0.12**	**4.17**

Table 8.24b Total front occupant fatalities and injuries avoided in Australia (20% GTR effectiveness increment)

M1 / N1	Pole impacts	Vehicle-to-Vehicle	Other fixed object	Total
Additional Fatalities avoided	238	243	9	489
Additional TBI-severe avoided	109	246	15	371
Additional TBI-moderate avoided	38	165	7	209
Additional Paraplegia avoided	8	24	2	33
Additional Serious injuries avoided	855	2968	120	3944
Additional Minor injuries avoided	1112	10478	198	11787
Financial benefits, 2016-2045 ($AU, 2012)	$668,199,318	$1,519,949,208	$65,795,047	$2,253,943,574
GTR requirement cost ($AU, 2012)	$726,927,417	$726,927,417	$726,927,417	$726,927,417
BCR (30 year period)	**0.92**	**2.09**	**0.09**	**3.10**

Table 8.24c Total front occupant fatalities and injuries avoided in Australia (40% GTR effectiveness increment)

M1 / N1	Pole impacts	Vehicle-to-Vehicle	Other fixed object	Total
Additional Fatalities avoided	420	426	16	861
Additional TBI-severe avoided	192	430	27	648
Additional TBI-moderate avoided	65	291	12	367
Additional Paraplegia avoided	14	40	3	56
Additional Serious injuries avoided	1503	5230	207	6940
Additional Minor injuries avoided	1936	18350	347	20633
Financial benefits, 2016-2045 ($AU, 2012)	$1,131,377,200	$2,571,943,822	$109,926,347	$3,813,247,369
GTR requirement cost ($AU, 2012)	$726,927,417	$726,927,417	$726,927,417	$726,927,417
BCR (30 year period)	**1.56**	**3.54**	**0.15**	**5.25**

8.7.4 Integrated savings and the associated BCR values for M1 (4 sensor) and N1 (2 / 4 sensor) front and rear seat (all) occupants for Australia and the associated economic benefits and costs

The analysis of the benefits of the proposed PSI GTR across all seating postiions is important to consider. To ensure coverage of all seat positions four sensor incremental costs for all M1 vehicles and a weighted two-four sensor cost for N1 vehicles were applied.

Table 8.25a, 8.25b and Table 8.25c presents the fatality and injury reduction benefits associated with the PSI GTR, both in numeric and economic terms for the principal increment value of 30% and the lower and upper benefit values (i.e., 20%, 40%). At 30% increment effectiveness, it is estimated that the PSI GTR will result in 761 fewer fatalities (range: 551-971) and significantly fewer occupants with severe and moderate TBI.

The financial savings associated with the fatality and injury reductions equates to $AU 3.5 billion (*range: $AU 2.6 billion to $4.3 billion, 2012 dollars)* for a economic cost of $AU 0.72 billion (2012 dollars). Hence, the overall BCR for M1 and N1 veihcle occupants was 4.77:1 at 30% GTR increment effectiveness (*BCR Range:* 3.55-6.00).

Table 8.25a Total front and rear seat occupant fatalities and injuries avoided in Australia (30% GTR effectiveness increment)

M1 / N1	**Pole impacts**	**Vehicle-to-Vehicle**	**Other fixed object**	**Total**
Additional Fatalities avoided	353	396	12	761
Additional TBI-severe avoided	173	392	21	586
Additional TBI-moderate avoided	60	266	9	335
Additional Paraplegia avoided	13	36	2	51
Additional Serious injuries avoided	1354	4784	164	6302
Additional Minor injuries avoided	1745	15907	325	17978
Financial benefits, 2016-2045 ($AU, 2012)	$1,005,078,212	$2,376,484,294	$88,546,262	$3,470,108,769
GTR requirement cost ($AU, 2012)	$726,927,417	$726,927,417	$726,927,417	$726,927,417
BCR (30 year period)	**1.38**	**3.27**	**0.12**	**4.77**

Table 8.25b Total front and rear seat occupant fatalities and injuries avoided in Australia (20% GTR effectiveness increment)

M1 / N1	**Pole impacts**	**Vehicle-to-Vehicle**	**Other fixed object**	**Total**
Additional Fatalities avoided	255	287	9	551
Additional TBI-severe avoided	125	286	15	426
Additional TBI-moderate avoided	44	192	7	243
Additional Paraplegia avoided	10	27	2	38
Additional Serious injuries avoided	983	3462	120	4565
Additional Minor injuries avoided	1272	11561	236	13069
Financial benefits, 2016-2045 ($AU, 2012)	$746,724,647	$1,764,053,626	$66,375,844	$2,577,154,117
GTR requirement cost ($AU, 2012)	$726,927,417	$726,927,417	$726,927,417	$726,927,417
BCR (30 year period)	**1.03**	**2.43**	**0.09**	**3.55**

Table 8.25c Total front and rear seat occupant fatalities and injuries avoided in Australia (40% GTR effectiveness increment)

M1 / N1	**Pole impacts**	**Vehicle-to-Vehicle**	**Other fixed object**	**Total**
Additional Fatalities avoided	451	504	16	971
Additional TBI-severe avoided	220	499	26	745
Additional TBI-moderate avoided	76	340	11	427
Additional Paraplegia avoided	16	45	3	64
Additional Serious injuries avoided	1725	6104	207	8036
Additional Minor injuries avoided	2218	20258	414	22890
Financial benefits, 2016-2045 ($AU, 2012)	$1,263,431,778	$2,987,454,678	$110,716,680	$4,361,603,136
GTR requirement cost ($AU, 2012)	$726,927,417	$726,927,417	$726,927,417	$726,927,417
BCR (30 year period)	**1.74**	**4.11**	**0.15**	**6.00**

8.7.5 Summary comment

The determination of the benefits and costs of the PSI GTR highlights the large savings in terms of fewer occupants kiiled in side impact crashes. In addition, the injury reduction benefit of the PSI GTR is significant. The PSI GTR will demand improvements in the side impact safety performance of all vehicles. It is clear that the financial benefits associated with fatality and injury reductions significantly outweigh the costs of implementation. The BCR estimates presented here, along with lower and upper values, highlight the robustness of the injury reduction benefits.

8.8 Appendix 8a – Fleet Vehicle Age for Class M1 vehicles

Table A8a. Percent distribution of vehicle age for M1 vehicles involved in crashes.

Age of vehicle	Frequency	Percent	Valid Percent	Cumulative Percent
0	3908	2.1	2.1	2.1
1	9153	4.9	4.9	7.0
2	9008	4.9	4.9	11.9
3	9078	4.9	4.9	16.8
4	9270	5.0	5.0	21.8
5	9482	5.1	5.1	26.9
6	9401	5.1	5.1	31.9
7	9335	5.0	5.0	37.0
8	9326	5.0	5.0	42.0
9	9279	5.0	5.0	47.0
10	9402	5.1	5.1	52.0
11	9410	5.1	5.1	57.1
12	9095	4.9	4.9	62.0
13	9209	5.0	5.0	67.0
14	8845	4.8	4.8	71.7
15	8596	4.6	4.6	76.4
16	7610	4.1	4.1	80.5
17	7043	3.8	3.8	84.3
18	6106	3.3	3.3	87.5
19	5173	2.8	2.8	90.3
20	4092	2.2	2.2	92.5
21	3261	1.8	1.8	94.3
22	2575	1.4	1.4	95.7
23	1957	1.1	1.1	96.7
24	1466	.8	.8	97.5
25	1106	.6	.6	98.1
26	792	.4	.4	98.5
27	600	.3	.3	98.9
28	477	.3	.3	99.1
29	409	.2	.2	99.3
30	287	.2	.2	99.5
31	237	.1	.1	99.6
32	190	.1	.1	99.7
33	154	.1	.1	99.8
34	101	.1	.1	99.9
35	73	.0	.0	99.9
36	55	.0	.0	99.9
37	37	.0	.0	100.0
38	30	.0	.0	100.0
39	20	.0	.0	100.0
40	9	.0	.0	100.0
41	11	.0	.0	100.0
42	4	.0	.0	100.0
43	6	.0	.0	100.0
Total	185,678	100.0	100.0	

Source: Linda Watson, MUARC – Used Car Safety Rating program data

8.9 Appendix 8b – M1 ESC and Side Curtain fitment and penetration rates

Table A8b. ESC and side curtain airbag fitment into passenger vehicles, and fleet penetration.

	Business-as-usual case						GTR / mandate effect		
Year	ESC fitment into new vehicles	Cum. % vehicles entering fleet by vehicle age	Percent fitment of ESC in fleet [multiplier]	% of new vehicles with curtain SAB	Cum % vehicles entering fleet by vehicle age	Percent fitment of curtain SAB in fleet [multiplier]	% exposed to SAB due to GTR factor (1-BAU fitment)	Fitted sold with curtain SAB (GTR safety benefit)	Percent fitment of SCA in the fleet [GTR multiplier]
2006	22.2%	26.9%	6.0%	24.1%	7.0%	1.7%			
2007	36.6%	31.9%	11.7%	33.9%	11.9%	4.0%			
2008	47.8%	37.0%	17.7%	41.5%	16.8%	7.0%			
2009	63.3%	42.0%	26.6%	52.2%	21.8%	11.4%			
2010	71.3%	47.0%	33.5%	59.5%	26.9%	16.0%			
2011	80.9%	52.0%	42.1%	72.4%	31.9%	23.1%			
2012	86.8%	57.1%	49.6%	78.3%	37.0%	29.0%			
2013	92.7%	62.0%	57.5%	84.2%	42.0%	35.4%			
2014	98.6%	67.0%	66.1%	90.1%	47.0%	42.3%			
2015	100.0%	71.7%	71.7%	96.0%	52.0%	49.9%			
2016	100.0%	76.4%	76.4%	96.7%	57.1%	55.2%	44.8%	100.0%	2.1%
2017	100.0%	80.5%	80.5%	96.7%	62.0%	60.0%	40.0%	100.0%	7.0%
2018	100.0%	84.3%	84.3%	96.7%	67.0%	64.8%	35.2%	100.0%	11.9%
2019	100.0%	87.5%	87.5%	96.7%	71.7%	69.3%	30.7%	100.0%	16.8%
2020	100.0%	90.3%	90.3%	96.7%	76.4%	73.9%	26.1%	100.0%	21.8%
2021	100.0%	92.5%	92.5%	96.7%	80.5%	77.8%	22.2%	100.0%	26.9%
2022	100.0%	94.3%	94.3%	96.7%	84.3%	81.5%	18.5%	100.0%	31.9%
2023	100.0%	95.7%	95.7%	96.7%	87.5%	84.6%	15.4%	100.0%	37.0%
2024	100.0%	96.7%	96.7%	96.7%	90.3%	87.3%	12.7%	100.0%	42.0%
2025	100.0%	97.5%	97.5%	96.7%	92.5%	89.4%	10.6%	100.0%	47.0%
2026	100.0%	98.1%	98.1%	96.7%	94.3%	91.2%	8.8%	100.0%	52.0%
2027	100.0%	98.5%	98.5%	96.7%	95.7%	92.5%	7.5%	100.0%	57.1%
2028	100.0%	98.9%	98.9%	96.7%	96.7%	93.5%	6.5%	100.0%	62.0%
2029	100.0%	99.1%	99.1%	96.7%	97.5%	94.3%	5.7%	100.0%	67.0%
2030	100.0%	99.3%	99.3%	96.7%	98.1%	94.9%	5.1%	100.0%	71.7%
2031	100.0%	99.5%	99.5%	96.7%	98.5%	95.2%	4.8%	100.0%	76.4%
2032	100.0%	99.6%	99.6%	96.7%	98.9%	95.6%	4.4%	100.0%	80.5%
2033	100.0%	99.7%	99.7%	96.7%	99.1%	95.8%	4.2%	100.0%	84.3%
2034	100.0%	99.8%	99.8%	96.7%	99.3%	96.0%	4.0%	100.0%	87.5%
2035	100.0%	99.9%	99.9%	96.7%	99.5%	96.2%	3.8%	100.0%	90.3%
2036	100.0%	99.9%	99.9%	96.7%	99.6%	96.3%	3.7%	100.0%	92.5%
2037	100.0%	99.9%	99.9%	96.7%	99.7%	96.4%	3.6%	100.0%	94.3%
2038	100.0%	100.0%	100.0%	96.7%	99.8%	96.5%	3.5%	100.0%	95.7%
2039	100.0%	100.0%	100.0%	96.7%	99.9%	96.6%	3.4%	100.0%	96.7%
2040	100.0%	100.0%	100.0%	96.7%	99.9%	96.6%	3.4%	100.0%	97.5%
2041	100.0%	100.0%	100.0%	96.7%	99.9%	96.6%	3.4%	100.0%	98.1%
2042	100.0%	100.0%	100.0%	96.7%	100.0%	96.7%	3.3%	100.0%	98.5%
2043	100.0%	100.0%	100.0%	96.7%	100.0%	96.7%	3.3%	100.0%	98.9%
2044	100.0%	100.0%	100.0%	96.7%	100.0%	96.7%	3.3%	100.0%	99.1%
2045	100.0%	100.0%	100.0%	96.7%	100.0%	96.7%	3.3%	100.0%	99.3%

Appendix 8c – Fleet Vehicle Age for Class N1 vehicles

Table A8c. Percent distribution of vehicle age for N1 vehicles (derived from crash involvement).[57]

Age of vehicle	Frequency	Percent	Valid Percent	Cumulative Percent
.00	4,827	3.8	3.8	3.8
1	12,860	10.1	10.1	13.9
2	12,301	9.7	9.7	23.6
3	11,375	8.9	9.0	32.6
4	10,457	8.2	8.2	40.8
5	9,159	7.2	7.2	48.0
6	8,150	6.4	6.4	54.4
7	7,523	5.9	5.9	60.3
8	6,827	5.4	5.4	65.7
9	6,054	4.8	4.8	70.5
10	5,449	4.3	4.3	74.8
11	4,954	3.9	3.9	78.7
12	4,609	3.6	3.6	82.3
13	4,063	3.2	3.2	85.5
14	3,489	2.7	2.7	88.2
15	3,001	2.4	2.4	90.6
16	2,776	2.2	2.2	92.8
17	2,489	2.0	2.0	94.7
18	1,994	1.6	1.6	96.3
19	1,496	1.2	1.2	97.5
20	**1,070**	**.8**	**.8**	**98.3**
21	755	.6	.6	98.9
22	645	.5	.5	99.4
23	381	.3	.3	99.7
24	216	.2	.2	99.9
25	90	.1	.1	100
26	42	.0	.0	100
Total	127,052	99.8	100	
Unknown	277	.2		
Total	127,329	100.0		

8.10 Appendix 8d – N1 Side Curtain fitment and penetration rates

Table A8d. Penetration path of ESC and side curtain airbags in N1 vehicles, as well as GTR increment costs

	Business-as-usual scenario							**PSI GTR scenario**					
Year	New veh. sold	% ESC fitment	*Cum % vehicles entering fleet (starting year 0)*	Percent fitment of ESC in the fleet (crash-involved) [multiplier]	Fitted sold with front curtain SAB (all N1 veh. types)	Cum % vehicles entering fleet (starting year 0)	Percent fitment of SCA in the fleet (crash-involved) [multiplier]	Fitted sold with front SCA (GTR) [1-BAU]	*Cum % vehicles entering fleet (starting year 0)*	Additional percent of new vehicles in fleet fitted with SAB due to GTR	Percent fitment of SCA in the fleet (crash-involved) [GTR multiplier]	2 sensor SAB cost (2012 $) ($m.)	Weighted 2 / 4 sensor SAB Cost (2012 $) ($m.)
2006	33352	1.90	3.8	0.07	0.00		0.0						
2007	35527	1.73	13.9	0.24	0.00		0.0						
2008	38080	1.47	23.6	0.35	0.00		0.0						
2009	40485	16.69	32.6	5.44	6.82	3.8	0.3						
2010	40195	21.25	40.8	8.67	12.72	13.9	1.8						
2011	37869	26.80	48.0	12.86	17.31	23.6	4.1						
2012	41114	56.13	54.4	30.53	45.78	32.6	14.9						
2013	41393	63.06	60.3	38.02	47.98	40.8	19.6						
2014	42842	70.56	65.7	46.36	53.17	48.0	25.5						
2015	44342	78.06	70.5	55.03	58.36	54.4	31.7						
2016	44815	85.56	74.8	64.00	63.55	60.3	38.3	36.45	3.8	1.4	39.7	4.43	4.63
2017	45459	93.06	78.7	73.24	68.74	65.7	45.2	31.26	13.9	4.3	49.5	3.74	3.92
2018	46105	95.24	82.3	78.39	73.94	70.5	52.1	26.06	23.6	6.2	58.3	3.11	3.28
2019	46760	96.45	85.5	82.46	76.52	74.8	57.2	23.48	32.6	7.7	64.9	2.74	2.91
2020	47419	97.66	88.2	86.13	79.11	78.7	62.3	20.89	40.8	8.5	70.8	2.40	2.56
2021	48099	98.86	90.6	89.57	81.70	82.3	67.2	18.30	48.0	8.8	76.0	2.09	2.24
2022	48792	100	92.8	92.80	84.29	85.5	72.1	15.71	54.4	8.5	80.6	1.81	1.95
2023	49508	100	94.7	94.70	84.53	88.2	74.6	15.47	60.3	9.3	83.9	1.70	1.83
2024	50232	100	96.3	96.30	84.77	90.6	76.8	15.23	65.	10.0	86.8	1.59	1.72
2025	50962	100	97.5	97.50	85.01	92.8	78.9	14.99	70.5	10.6	89.5	1.50	1.62
2026	51698	100	98.3	98.30	85.25	94.7	80.7	14.75	74.8	11.0	91.8	1.41	1.52
2027	52443	100	98.9	98.90	85.50	96.3	82.3	14.50	78.7	11.4	93.7	1.32	1.43
2028	53196	100	99.4	99.40	85.74	97.5	83.6	14.26	82.3	11.7	95.3	1.24	1.34
2029	53956	100	99.7	99.70	85.98	98.3	84.5	14.02	85.5	12.0	96.5	1.17	1.26
2030	54725	100	99.9	99.90	86.22	98.9	85.3	13.78	88.2	12.2	97.4	1.09	1.19
2031	55500	100	100	100	86.46	99.4	85.9	13.54	90.6	12.3	98.2	1.03	1.11
2032	56282	100	100	100	86.70	99.7	86.4	13.30	92.8	12.3	98.8	0.96	1.05
2033	57070	100	100	100	86.94	99.9	86.9	13.06	94.7	12.4	99.2	0.90	0.98
2034	57863	100	100	100	87.18	100	87.2	12.82	96.3	12.3	99.5	0.85	0.92
2035	58661	100	100	100	87.43	100	87.4	12.57	97.5	12.3	99.7	0.79	0.87
2036	59462	100	100	100	87.67	100	87.7	12.33	98.3	12.1	99.8	0.75	0.81
2037	60265	100	100	100	87.91	100	87.9	12.09	98.9	12.0	99.9	0.70	0.76
2038	61068	100	100	100	88.15	100	88.1	11.85	99.4	11.8	99.9	0.65	0.71
2039	61870	100	100	100	88.39	100	88.4	11.61	99.7	11.6	100	0.61	0.67
2040	62670	100	100	100	88.63	100	88.6	11.37	99.9	11.4	100	0.57	0.63
2041	63469	100	100	100	88.87	100	88.9	11.13	100	11.1	100	0.54	0.59
2042	64266	100	100	100	89.11	100	89.1	10.89	100	10.9	100	0.50	0.55
2043	65060	100	100	100	89.36	100	89.4	10.64	100	10.6	100	0.47	0.52
2044	65853	100	100	100	89.60	100	89.6	10.40	100	10.4	100	0.44	0.48
2045	66729	100	100	100	89.84	100	89.8	10.16	100	10.2	100	0.41	0.45

9 DISCUSSION

This report set out to determine the 'safety need' for the establishment of a PSI GTR under the 1998 Global Agreement. The proposed regulation, sponsored by the Australian Government, seeks to develop and implement a side impact crash test specific to narrow object impacts, such as trees and poles.

Based on the series of analyses conducted here, it can be stated that there is a clear need for the enhanced protection of occupants in narrow object impact crashes. Narrow object impacts represent a substantial part of the crash problem, both in the UK and in Australia, and are associated with significant costs to the community.

The analysis of the in-depth data from Australia, the UK and Germany[28] reveals a higher risk of injury to the head, thorax, abdomen-pelvis and lower extremities in narrow object impacts than in vehicle-to-vehicle side impact crashes. These findings were reinforced by the analysis of the Transport Accident Commission Claims Data, which represents a census of all persons injured and making a claim due to their involvement in a traffic crash. This data showed a significantly elevated risk of injury in pole side impact crashes relative to vehicle-to-vehicle side impact crashes, with the head and thorax being up to three times more likely to sustain a 'serious' injury.

Finally, an assessment was made of the likely savings associated with the implementation of a PSI GTR, given certain assumptions. The two key assumptions related to the likely injury reduction benefit associated with the PSI GTR itself given the current implementation of curtain airbags and the expected benefits of ESC. The cost-effectiveness analysis for M1 (passenger vehicles) and N1 vehicles (light commercial) vehicles accounted for the fact that ESC will prevent a number of crashes in the future, whilst also recognising the current fitment rates of head protecting side curtain airbags and thorax protecting side impact airbags.

For front seat occupants of passenger vehicles (M1 vehicles), the introduction of a PSI GTR would be highly cost-effective with BCR of 9.51:1 over the 30 year period (2016 - 2045) with a 7% discount rate applied to both costs and benefits. In person terms, the lives of an estimated 608 occupant fatalities were avoided across the 30 years, 421 cases of severe and 254 cases of moderate traumatic brain injury avoided, 23 cases of paraplegia avoided, 4868 serious injuries and 13,679 minor injuries avoided. In financial terms, the GTR would save the Australian community $AU 2.6 billion for an outlay of $AU 0.27 billion.

For front seat occupants of light commercial vehicles (N1 vehicles), the PSI GTR would be cost-effective, and like the M1 vehicle category, much of the benefit is driven by vehicle-to-vehicle side impact crash injury mitigation. The overall BCR was 2.59:1, with benefits being $AU 0.41 billion for a cost of 0.15 billion. Over the 30 year period, 67 lives throughout Australia would be saved, 88 severe traumatic brain injury cases avoided and a large number of serious and minor injuries avoided.

The combined benefit of the GTR for M1 and N1 vehicles was seen to be highly cost-effective (BCR 7.00:1). Commencing in the year 2016, and over the 30-year period, the PSI GTR would achieve injury cost savings of $AU 3 billion for an outlay of $AU 0.43 billion. In person terms, 675 occupants of vehicles involved in side impact crashes would survive. In addition, the GTR would deliver sizeable reductions in the number of occupants sustaining severe TBI (n = 509), moderate TBI (n = 288), paraplegia (n = 45), and 'serious' injuries (n = 5442).

The above findings relate to front seat occupants of M1 and N1vehicles assuming a weighted two / four sensor system for M1 vehicles and a two sensor system for all N1 vehicles. When considering only front seat occupants but using four sensor SAB systems for all M1 vehicles and a weighted mix of two and four sensor SAB systems for N1 vehicles, the BCRs are somewhat lower, but nonetheless remain above 3.10 (20% effectiveness).

Further savings are gained with the inclusion of rear seat occupants with 761 lives saved and 586 severe TBI injuries avoided, as well as a large number of other injury types avoided. Overall for Australia, and considering all

28 Refer: PSI-05-04 - (BAST) Pole Side Impact Accidents in Germany, http://www.unece.org/trans/main/wp29/wp29wgs/wp29grsp/psimpact_5.html

occupants of M1 and N1 vehicles, the safety benefits associated with the enhanced side impact protection demanded by the PSI GTR is highly cost effective, with a BCR of 4.77:1 with total savings being $AU 3.47 billion (2012 dollar values) for an outlay of $AU 0.726 billion (2012 dollar values) spread over the 30-year period 2016 to 2045.

The findings of this report support and reinforce the position of the EEVC Working Group 13 on Pole Side Impact Protection that stated...

> ...the introduction of a regulatory pole test (to the current Euro NCAP specification with full dummy assessment) into the existing UN-ECE Regulation 95 would deliver significant benefits to society in terms of fatal and serious injuries saved." (p.4, p.26)[64]

In the interpretation of findings, the EEVC state that "introduction of the pole test alone was predicted to deliver the same benefits as the combination of the pole and AE-MDB tests" (p.12), with an additional 75 lives saved and 222 serious injuries avoided over and above current improvements (in the UK), but with only 28 fatalities and 85 serious injuries avoided via the modified barrier test – this clearly points to the benefit being driven by meeting the pole test. The EEVC state:

> In summary, the greatest societal benefit from the five options considered would be delivered through the introduction of the pole test (Option C) or the introduction of the AE-MDB and pole test (Option E) (p.13).

Also as noted by the EEVC W.G. 13, the benefits though the implementation of advanced side impact protection resulting from the addition of a pole side impact test would also be relevant to non-struck side occupant. Our analysis including non-struck side occupants demonstrated that implementation of the GTR would be cost beneficial for both M1 and N1 vehicle occupants. Adoption of lower US per unit costs as per the FMVSS 214 regulatory impact report results in the reported BCRs being higher and positive for all 30% GTR increment configurations.

In sum, the findings of this report highlight the injurious nature of side impact crashes. It is clear that side impact crashes carry a high risk of serious injuries with the head and thorax being most at risk. This is despite the data analysis being undertaken on vehicles manufactured from the year 2000 onwards, the implication being that these vehicles are subject to an existing side impact barrier performance-based test.

These findings clearly demonstrate the need for enhanced side impact protection. The position for the development and introduction of a pole side impact test that would demand an on average 30% improvement in side impact protection over and above current practice by focussing on the head and thorax is supported by the cost-effectiveness analysis reported here. The sensitivity analysis gives further confidence in the findings. In short, the evidence in support of a proposed pole side impact regulatory test is overwhelming.

10 REFERENCES

1. United Nations General Assembly. Resolution proclaiming a Decade of Action for Road Safety 2011-2020 (A/64/L.44/Rev.1) New York: United Nations; 2010.

2. World Health Organization. Global status report on road safety: time for action. Geneva: World Health Organization, 2009.

3. World Health Organisation. Plan for the Decade of Action for Road Safety 2011-2020. Geneva: WHO; 2010.

4. UN ECE. Decade of action for Road Safety – WP.29 actions, Informal document WP.29-154-18 (154th WP.29 session, 21-24 June 2011, agenda item 8.9.). Geneva: UN ECE; 2011.

5. UN ECE Working Party on Road Traffic Safety. Decade of Action for Road Safety - UNECE Plan 2011–2020 (Document: WP29-155-14e). Geneva: UN ECE; 2011.

6. Bureau of Infrastructure Transport and Regional Economics (BITRE). Road Deaths Australia 2010 Statistical Summary. Canberra ACT: BITRE; 2011.

7. Bureau of Infrastructure Transport and Regional Economics (BITRE). Road deaths Australia: 2008 Statistical Summary. Canberra: Department of Infrastructure, Transport, Regional Development and Local Government; 2009.

8. DITRDLG. Road deaths Australia: 2007 Statistical Summary. Department of Infrastructure, Transport, Regional Development and Local Government (DITRDLG); 2008.

9. AAAM. The Abbreviated Injury Scale (AIS) - 1990, 1998 Update. Des Plaines, IL: Association for the Advancement of Automotive Medicine (AAAM); 1998.

10. Transport Accident Commission. Annual Report 2010. Melbourne: Transport Accident Commission; 2010.

11. SAE. ‘Collision Deformation Classification - SAE J224 MAR80. Warrendale, Pennsylvania, USA: Society of Automotive Engineers, Inc; 1980.

12. Australian Bureau of Statistics. 3101.0 Australian Demographic Statistics, TABLE 4. Estimated Resident Population, States and Territories (Number). Canberra: Australian Bureau of Statistics; 2010.

13. Australian Bureau of Statistics (ABS). Motor vehicle census, Cat. No. 9309.0. Canberra: ABS; 2010.

14. Access Economics. The economic cost of spinal cord injury and traumatic brain injury in Australia. Melbourne: Access Economics Pty Limited for The Victorian Neurotrauma Initiative; 2009.

15. NHTSA. FMVSS NO. 214 Amending side impact dynamic test adding oblique pole test - Final regulatory impact analysis. Washington, DC: U.S. Department Of Transportation; 2007.

16. Commonwealth of Australia. Vehicle Standard (Australian Design Rule 72/00 – Dynamic Side Impact Occupant Protection) 2005. Canberra: Commonwealth Government of Australia; 2005.

17. United Nations - Economic Commission for Europe (UN ECE). Uniform Provisions concerning the approval of vehicles with regard to the protection of the occupants in the event of a lateral collision, Regulation 95. Geneva; 1998.

18. Braver ER, Kyrychenko SY. Efficacy of side air bags in reducing drivers deaths in driver-side collisions. *American Journal of Epidemiology* 2004; 159(6): 556-64

19. McCartt AT, Kyrychenko SY. Efficacy of side airbags in reducing driver deaths in driver-side car and SUV collisions. *Traffic inj prev* 2007; 8(2): 162-70.

20. Kahane CJ. An Evaluation of Side Impact Protection FMVSS 214 TTI(d) Improvements and Side Air Bags, NHTSA Technical Report, DOT HS 810 748. Washington, DC: National Highway and Traffic Safety Administration; 2007.

21. Lange R, Soderborg N, Pearc H, Balavich K, Huang S. Side impact air bag efficacy, injury mitigation performance in vehicle models with and without side impact air bags and inflatable head protection. Paper Number 11-0115. *Proceedings of the 22nd International Technical Conference on the Enhanced Safety of Vehicles (ESV), June 13-16, Washington DC* 2011.

22. McGwin G, Metzger J, Rue LW. The influence of side airbags on the risk of head and thoracic injury after motor vehicle collisions. *Journal of Trauma* 2004; 56(3): 512-7.

23. Scarboro M, Rudd R, Sochor M. Nearside occupants in low delta-v side impact crashes: Analysis of injury and vehicle damage patterns. Paper Number 07-0225. *Proceedings of the 20th International Technical Conference on the Enhanced Safety of Vehicles (ESV), June 18-21, Lyon, France* 2007.

24. McGwin G, Modjarrad K, Duma S, Rue L. Association between upper extremity injuries and side airbag availability. *Journal of Trauma* 2008; 64(5): 1297-301.

25. Stadter G, Grabowski JG, Burke C, Aldaghlas TA, Robinson L, Fakhry SM. Injury and side impact air bag deployment in near and far sided motor vehicle crashes, United States, 2000-2005. *Journal of Trauma* 2008; 65(6): 1333-8.

26. UAB CIREN Center. Side Airbag Effectiveness: A Matched Cohort Study Using CIREN and NASS/CDS. Alabama: University of Alabama; 2011.

27. McGwin G, Metzger J, Porterfield JR, Moran SG, Rue LW. Association between side air bags and risk of injury in motor vehicle collisions with near-side impact. *Journal of Trauma* 2003; 55(3): 430-4.

28. Smith TG, Wessells HB, Mack CD, Kaufman R, Bulger EM, Voelzke BB. Examination of the impact of airbags on renal injury using a national database. *Journal of the American College of Surgeons* 2010; 211(3): 355-60.

29. Stigson H, Kullgren A. Effect of side impact protection in reducing injuries. Paper Number 11-0319. *Proceedings of the 22nd International Technical Conference on the Enhanced Safety of Vehicles (ESV), June 13-16, Washington DC* 2011.

30. Page Y, Thomas P, Herve V, Kirk A. The effectiveness of side airbags in preventing thoracic injuries in Europe. *Proceedings of the Expert Symposium on Accident Research, Hannover, 1-2 September, 2006* 2006.

31. Australia Bureau of Statistics. 3101.0 - Australian Demographic Statistics, Sep 2011. Canberra: Australia Bureau of Statistics; 2011.

32. Bureau of Infrastructure Transport and Regional Economics (BITRE). Road Deaths Australia 2009 Statistical Summary. Canberra ACT: BITRE; 2010.

33. Department for Transport (DfT). A valuation of road accidents and casualties in Great Britain in 2010. London: Department for Transport, UK; 2010.

34. Vittinghoff E, Glidden DV, Shiboski SC, McCulloch CE. Regression methods in biostatistics: Linear, logistic, survival and repeated measures models. New York, NY: Springer; 2005.

35. Commonwealth of Australia. Vehicle Standard Australian Design Rule 72/00 - Dynamic Side Impact Occupant Protection, http://wwwcomlawgovau/Series/F2005L03992. 2005.

36. Baker S, O'Neill B, Haddon W, Long W. The Injury Severity Score: A method for describing patients with multiple injuries and evaluating emergency care. *Journal of Trauma* 1974; 14: 187-96.

37. Hosmer DW, Lemeshow S. Applied logistic regression. 2nd ed. New York: John Wiley & Sons; 2000.

38. Edwards MJ, Hynd D, Cuerden R, Thompson A, Carroll J, Broughton J. Side impact safety. Wokingham, United Kingdom: TRL Ltd; 2008.

39. Victorian Institute of Forensic Medicine. Fatal Road Crash Database (FRCD) Book 4 - Data Users Manual (Version 5.8). Melbourne: Victorian Institute of Forensic Medicine; 2008.

40. Department of Finance and Deregulation. Best Practice Regulation Guidance Note: Value of statistical life. Canberra: Office of Best Practice Regulation, Australian Government; 2008.

41. Australia Bureau of Statistics. Consumer Price Index, Australia, Mar 2012, Cat. No. 6401.0. Canberra: Australia Bureau of Statistics; 2012.

42. Australian Government. Best practice regulation handbook. Canberra: Office of Best Practice Regulation, Department of Finance and Deregulation; 2010.

43. National Coronial Information Service. National Coronial Information System Coding Manual and User Guide, Version 4.0. Melbourne: Victorian Institute of Forensic Medicine; 2010.

44. Australian Bureau of Statistics. Causes of Death, Australia, 2008 - Technical Note 1 2008 COD Collection - Process Improvements; Cat. No. 3303.0. Canberra: Australian Bureau of Statistics; 2010.

45. NCCH. The International statistical classification of diseases and related health problems, 10th revision, Australian modification (ICD-10-AM). 2nd ed. Sydney: National Centre for Classification in Health [NCCH]; 2000.

46. UAS Department of Health and Human Services. International Classification of Diseases, Ninth Revision, Clinical Modification (ICD-9-CM). Hobart, Tasmania: Department of Community and Health Services; 1992.

47. StataCorp. Stata MP Version 12 for Windows. College Station, TX: USA: StataCorp; 2011.

48. Human Services Victoria. Review of Trauma and Emergency Services Victoria 1999. Melbourne: Human Services Victoria; 1999.

49. StataCorp. Stata: Release 12. Statistical Software. College Station, TX: StataCorp LP; 2011.

50. Mitchell MN. Integrating and visualizing regression models using Stata. College Station, TX: StataCorp LP; 2012.

51. Fildes B, Logan D, Fitzharris M, Scully J, Burton D. ANCIS – The First Three Years (Report No. 207). Clayton, Australia: Monash University Accident Research Centre; 2003.

52. Australian Bureau of Statistics. Motor Vehicle Census by make, model, postcode, vehicle body and State, At 31 March 2010 (Cat. 9309.0). Canberra: Commonwealth of Australia; 2011.

53. Transport Accident Commission. Road Safety Statistical Summary, December 2009. Geelong: Transport Accident Commission, 2010.

54. Meyerson S. Calculating Benefits for Oblique Pole Side Impact Rulemaking, PSI-01-16. Presentation to 1st Meeting of the Informal Group on Pole Side Impact GTR (PSI), Bonn, Germany. National Highway Traffic Safety Administration, US Department of Transport; 2010, Available at: http://www.unece.org/fileadmin/DAM/trans/doc/2010/wp29grsp/PSI-01-16e.pdf.

55. Kim YW, Ham BR, Choi IH, Bae HI. Study on improving occupant injury performance for FMVSS214 side pole impact, Paper No. 09-0100. 21st International Technical Conference on the Enhanced Safety of Vehicles. Stuttgart, Germany: National Highway and Traffic Safety Administration; 2009.

56. Scully J, Newstead S. Evaluation of electronic stability control effectiveness in Australia. *Accid Anal Prev* 2008; 40: 2050-7.

57. Fitzharris M, Scully J, Newstead S. Analysis of the likely benefits of electronic stability control (ESC) for light commercial vehicles. Clayton: Monash University Accident Research Centre (Consultant Report); 2010.

58. Scully J, Newstead S. Follow-up evaluation of electronic stability control effectiveness in Australia, Report 306. Clayton: Monash University Accident Research Centre; 2010.

59. Fitzharris M, Scully J, Newstead S. Analysis of the likely benefits to Australia of the fitment of electronic stability control (ESC) in light commercial vehicles. Clayton: Monash University Accident Research Centre 2010.

60. Høye A. The effects of Electronic Stability Control (ESC) on crashes--An update. *Accident Analysis & Prevention* 2011; 43(3): 1148-59.

61. Australian Bureau of Statistics. 6401.0 Consumer Price Index, Australia: TABLES 1 and 2. CPI: All Groups, Index Numbers and Percentage Changes. Canberra: Australian Bureau of Statistics; 2010.

62. Bureau of Transport Economics. Road crash costs in Australia. Canberra: Bureau of Transport Economics [BTE], 2000.

63. Teasdale G, Jennett B. Assessment of coma and impaired consciousness: A practical scale. *Lancet* 1974; 2: 81-4.

64. European Enhanced Vehicle Safety Committee (EEVC). Working Group 13 (Side impact protection), Report to Steering Committee. www.eevc.org; 2010.

65. VicRoads. ESC mandatory from 1 Janury 2011. 2011. http://www.vicroads.vic.gov.au/Home/SafetyAndRules/SaferVehicles/BuyingASafeCar/ESCmandatoryfrom1January2011.htm (accessed 17 June 2012).

66. Fitzharris M, Cockfield S, Truong J, et al. Effectiveness and estimation of the likely benefits of side impact airbags in passenger vehicles in Victoria, Paper 11-0245. 22nd International Technical Conference on the Enhanced Safety of Vehicles. Washington, DC, USA; 2011.

67. Fildes B, Fitzharris M, Koppel S, Vulcan P, Brooks C. Benefits of seat belt reminder systems. *Annual proceedings / Association for the Advancement of Automotive Medicine Association for the Advancement of Automotive Medicine* 2003; 47: 253-66.

68. Insurance Institute for Highway Safety. Estimated time of arrival. *IIHS Status Report* 2012; 47(1).