MONASH University

ACCIDENT
RESEARCH
CENTRE

VSRG RESEARCH PROGRAM: Identifying Future Vehicle Safety Priority Areas in Australia for the Light Vehicle Fleet

LAURIE BUDD
STUART NEWSTEAD

OCTOBER, 2020
(RELEASED DECEMBER, 2021)

REPORT NO. 359

MONASH University

ACCIDENT RESEARCH CENTRE

Project Sponsored By

Australian Government

NSW GOVERNMENT

Queensland Government

Government of South Australia
Department for Infrastructure and Transport

GOVERNMENT OF WESTERN AUSTRALIA

ROAD SAFETY COMMISSION

NZ TRANSPORT AGENCY
WAKA KOTAHI

ACC
Te Kaporeihana Āwhina Hunga Whara
prevention. care. recovery.

NRMA

RAA

RAC
For the better

RACQ

RACV

TAC Transport Accident Commission

vicroads

MONASH University

ACCIDENT RESEARCH CENTRE

MONASH UNIVERSITY ACCIDENT RESEARCH CENTRE REPORT DOCUMENTATION PAGE

Report No.	Report Date	Release Date	ISBN	ISSN	Pages
359	October 2020	December 2021	978-1-925413-29-8	1835-4815 (On-Line)	59 + Appendices

Title and sub-title:

VSRG RESEARCH PROGRAM: IDENTIFYING FUTURE VEHICLE SAFETY PRIORITY AREAS IN AUSTRALIA FOR THE LIGHT VEHICLE FLEET

Author(s)	Type of Report
Budd, L., & Newstead, S.	Final Report

Sponsoring Organisations - This project was funded as contract research by the following organisations:

Transport for New South Wales, New South Wales State Insurance Regulatory Authority, Royal Automobile Club of Victoria, NRMA Motoring and Services, Victorian Department of Transport (VicRoads), Royal Automobile Club of Western Australia, Transport Accident Commission, New Zealand Transport Agency, Queensland Department of Transport and Main Roads, Royal Automobile Club of Queensland, Royal Automobile Association of South Australia, South Australian Department of Infrastructure and Transport , Accident Compensation Corporation New Zealand, the Australian Government Department of Infrastructure, Transport, Regional Development and Communications, and the Road Safety Commission of Western Australia.

Abstract:

This analysis aimed to identify future priority action areas for light vehicle safety by identifying crash types that will not be fully addressed in the future by projected improvements in active and passive safety in the light vehicle fleet. Modelling the likely future crash profile of the light vehicle fleet in Australia identifies target areas for future vehicle design and technology improvements that will assist in achieving the goals of Towards Zero. Analysis was based on the analysis of real-world crash data from 5 Australian jurisdictions overlaying current evidence on vehicle safety feature fitment and effectiveness.

Three future vehicle safety priority areas were identified from the analysis: (i) fatal pedestrian crashes, (ii) single vehicle frontal crashes with fixed objects, (iii) front-to-front vehicle crashes both at intersections and midblocks and front-to-side impacts at intersections including straight crossing path and right turn across path crash types. These crash types were projected to be the largest contributors to fatalities by 2030. Although not the most prevalent crash type, crashes involving bicycles and mopeds were forecast to grow proportionately over the study period. Remaining crash types in 2030 will be poorly addressed by current vehicle safety technologies. For example when considering single vehicle fixed object crashes, ESC will provide no further benefits in reducing single vehicle crashes after 2030 since the fleet will have achieved full fitment in the 2030 vehicle fleet whilst current evidence suggests AEB has limited impact in addressing high speed crashes with fixed objects.

This analysis highlighted the limitations in fatality and serious injury reductions related to the natural penetration of vehicle safety technology fitment. Significant number of fatalities resulting from intersection crashes, single vehicle run off road and head on crashes will remain whist pedestrian crashes will grow in their proportionate importance. Additional or enhanced vehicle safety technologies will need to be developed that better address these crash types such as AEB effective for high speed fixed object crashes and V to V technologies to mitigate intersection crashes. In addition, means to address the key remaining crash types elsewhere in the system need to be considered through measures such as road infrastructure treatments and appropriate speed limit setting for high risk environments where vehicle safety technology proves inadequate.

Key words:

Vehicle Fitment, Active safety, Passive safety, AEB LDW BSD airbags, active headlights, ESC V2P V2B ITS, LKA collision mitigation.

Monash University Accident Research Centre Building 70, Monash University Victoria 3800, Australia. Telephone: +61 3 9905 4371, Fax: +61 3 9905 4363

PREFACE

Project Manager / Team Leader:

- Associate Professor Stuart Newstead

Research Team:

- Laurie Budd

Contributor Statement

- Associate Professor Stuart Newstead: Project concept and Report review
- Laurie Budd: Crash analysis, project framework and report

Ethics Statement

Ethics approval was not required for this project.

ACKNOWLEDGMENTS

Linda Watson and Casey Rampollard are acknowledged for preparing the matched UCSR model codes and Redbook safety technology fitment data.

CONTENTS

ACKNOWLEDGMENTS iv

CONTENTS v

FIGURES vii

TABLES ix

EXECUTIVE SUMMARY x

Introduction x

Analysis Approach xi

Results xii

Vehicle Safety Priority Areas xix

Vehicle Safety Priority Area One: Fatal pedestrian crashes xix

Vehicle Safety Priority Area Two: Single vehicle frontal crashes with fixed objects xx

Vehicle Safety Priority Area Three: Front-to-front vehicle crashes both at intersections and midblocks and front-to-side impacts at intersections including straight crossing path and right turn across path crash types xxi

Summary xxii

IDENTIFYING FUTURE VEHICLE SAFETY PRIORITY AREAS IN AUSTRALIA 2

1 Background 3

2 Project Aims and Scope addressed in this document 3

3 Data and projected data 5

3.1 Crash data 5

3.2 Safety technology fitment status 5

3.3 Crashworthiness ratings 6

3.4 Crash Costs 7

4 Methods 8

4.1 Analysis approach 8

4.2 Crash types 8

4.3 Recent trends of injury crashes and injuries by crash type, location and vehicle type 9

4.4 Active safety technolgies used in modelling 10

4.5 Crash types sensitive to this set of vehicle technologies 11

4.6 Crashes avoided by active technologies 11

4.7 Crash types not sensitive to this set of active light vehicle safety technologies 13

4.8 Injuries avoided by passive safety and vehicle design 13

4.9 Injuries not avoided by vehicle safety technologies and vehicle design 14

4.10 Crash Costs 14
5 Baseline trends 15
5.1 Crash trends over 2006 to 2016 15
5.2 Trends in sensitivity to active technologies over 2006 to 2016 18
5.3 Technologies best targeting fatalities 20
5.4 Penetration of technology by year of manufacture 21
5.5 Penetration of technology by crash year 22
5.6 Summary of Baseline trends 24
6 Crashes prevented by active safety technology 25
6.1 Active vehicle technologies which best address the baseline crash trends 30
6.2 Crash types addressed by active safety technologies 33
7 Injuries prevented (and not prevented) by active and passive safety technology 39
7.1 Additional injury avoidance from passive safety technology 39
7.2 Regional differences 42
7.3 Market group differences 43
8 Summary of vehicle safety technology analysis 45
8.1 Crash type being poorly addressed by vehicle safety technologies 45
8.2 Crash types with poor expectations for improvements in crash avoidance (through vehicle safety technologies) beyond 2030 47
8.3 Other crash types and their limitations 49
9 Vehicle safety priority areas 52
9.1 Priority One: Fatal pedestrian crashes 52
9.2 Priority Two: Single vehicle frontal crashes with fixed objects 53
9.3 Priority Three: Front-to-front vehicle crashes both at intersections and midblocks and front-to-side impacts at intersections including straight crossing path and right turn across path crash types 54
10 References 56
Appendix A 60
A.1 Charts which illustrate crash trends over 2006 to 2016 60
A.2 Charts demonstrating the distribution of sensitivity to active technologies, by crash type over 2006 to 2016 65
A.3 Charts demonstrating the proportion of injuries in crashes sensitive to a technology in 2016 by region, market group 74
A.4 2016 crash counts by severity and crash type 79
A.5 Active technology published effectiveness 80
GLOSSARY 82

FIGURES

Figure 1 2016 & projected 2030 distribution of injury crash types for fatal and serious injury crashes for all crashes and by metropolitan and rural regions xiii

Figure 2 2016 Crash injuries by location and severity disaggregated by vehicle safety technology projections in 2030 xiv

Figure 3 2016 Crash injuries by broad market group and severity disaggregated by vehicle safety technology projections in 2030 xv

Figure 4 2016 Crash injuries by type, road user type and severity disaggregated by vehicle safety technology projections in 2030 xvii

Figure 5 2016 Injury crashes by location and severity disaggregated by active vehicle safety technology projections in 2030 xviii

Figure 6 Proportion of injuries contributed by each crash type in 2016 17

Figure 7 Rates of sensitivity by severity for active safety technologies in 2016 20

Figure 8 Penetration of active safety technologies into light vehicles of fatal crashes 22

Figure 9 Penetration of active safety technologies into light vehicles of serious injury crashes 23

Figure 10 Penetration of active safety technologies into light vehicles of minor injury crashes 23

Figure 11 2016 & projected 2030 distribution of injury crash types for fatal and serious injury crashes for all crashes and by metropolitan and rural regions 29

Figure 12 2016 Crash injuries by location and severity disaggregated by vehicle safety technology projections in 2030 30

Figure 13 Crashes sensitive to active safety technologies predicted to be avoided, by crash severity 32

Figure 14 2016 Injury crashes by location and severity disaggregated by active vehicle safety technology projections in 2030 35

Figure 15 Percentage of fatal single vehicle forward-moving crashes avoided through additional active safety technology penetration 36

Figure 16 Percentage of serious injury single vehicle forward-moving crashes avoided through additional active safety technology penetration 36

Figure 17 Percentage of minor injury single vehicle forward-moving crashes avoided through additional active safety technology penetration 36

Figure 18 Percentage of fatal forward-moving multi-motor vehicle crashes avoided through additional active safety technology penetration 37

Figure 19 Percentage of serious injury forward-moving multi-motor vehicle crashes avoided through additional active safety technology penetration 37

Figure 20 Percentage of minor injury forward-moving multi-motor vehicle crashes avoided through additional active safety technology penetration 37

Figure 21 Percentage fatal reversing vehicle crashes avoided through additional active safety technology penetration 38

Figure 22 Percentage of serious injury reversing vehicle crashes avoided through additional active safety technology penetration 38

Figure 23 Percentage of minor injury reversing vehicle crashes avoided through additional active safety technology penetration 38

Figure 24 Light Vehicle occupant projected injuries by crash year 40

Figure 25 2016 Crash injuries by broad market group and severity disaggregated by vehicle safety technology projections in 2030 41

Figure 26 2016 Crash injuries by type, road user type and severity disaggregated by vehicle safety technology projections in 2030 41

Figure 27 Regional Percentage of front occupant injuries by crash type & severity in 2016 (initial) and 2030 (remaining) 42

Figure 28 Percentage of front occupant injuries within a speed zone by crash type & severity in 2016 (initial) and 2030 (remaining) 43

Figure 29 Percentage LCV involved crash injuries by crash type, occupant type & severity in 2016 (initial) and 2030 (remaining) 44

Figure 30 Percentage SUV involved crash injuries by crash type, occupant type & severity in 2016 (initial) and 2030 (remaining) 44

Figure 31 Percentage of light vehicle occupant injuries by position and severity from straight crossing path crashes 51

Figure 32 Serious injury crash count over 2006 to 2016 for bicycle and moped crashes 60

Figure 33 Pedestrian fatal crash count over 2006 to 2016 60

Figure 34 Rural single vehicle into object, serious injury count over 2006 to 2016 60

Figure 35 Recent increasing fatal crash count over 2006 to 2016 for multi-vehicle crashes 61

Figure 36 Increasing serious injury crash count over 2006 to 2016 for rural multi-vehicle crashes 61

Figure 37 Increasing serious injury crash count over 2006 to 2016 for metropolitan multi-vehicle crashes 61

Figure 38 Proportion of injuries contributed by each crash type in 2016 by region 62

Figure 39 Proportion of injuries contributed by each crash type in 2016 by market group crash (I) 63

Figure 40 Proportion of injuries contributed by each crash type in 2016 by market group crash (II) 64

Figure 41 The distribution of technology sensitive crashes by severity and crash year for type 1 crashes with overturn 65

Figure 42 The distribution of technology sensitive crashes by severity and crash year for type 1 crashes with no overturn 65

Figure 43 The distribution of technology sensitive crashes by severity and crash year for type 2 crashes 66

Figure 44 The distribution of technology sensitive crashes by severity and crash year for type 3 crashes 66

Figure 45 The distribution of technology sensitive crashes by severity and crash year for type 4 crashes 67

Figure 46 The distribution of technology sensitive crashes by severity and crash year for type 5 crashes 67

Figure 47 The distribution of technology sensitive crashes by severity and crash year for type 6 crashes with side impact 68

Figure 48 The distribution of technology sensitive crashes by severity and crash year for type 6 crashes with motor vehicle reversing 68

Figure 49 The distribution of technology sensitive crashes by severity and crash year for type 6 crashes with bicycle/moped running into rear of vehicle 69

Figure 50 The distribution of technology sensitive crashes by severity and crash year for type 7 crashes 69

Figure 51 The distribution of technology sensitive crashes by severity and crash year for type 8 crashes........... 70

Figure 52 The distribution of technology sensitive crashes by severity and crash year for type 9 crashes: forward moving 70

Figure 53 The distribution of technology sensitive crashes by severity and crash year for type 9 crashes: reversing 71

Figure 54 The distribution of technology sensitive crashes by severity and crash year for type 10 crashes: forward moving 71

Figure 55 The distribution of technology sensitive crashes by severity and crash year for 10 crashes: reversing 72

Figure 56 The distribution of technology sensitive crashes by severity and crash year for type 11 crashes......... 72

Figure 57 The distribution of technology sensitive crashes by severity and crash year for type 12 crashes......... 73

Figure 58 Rates of sensitivity by severity for active safety technologies in 2016 by Region 74

Figure 59 Rates of sensitivity by severity for active safety technologies in 2016 by Market Group (I) 75

Figure 60 Rates of sensitivity by severity for active safety technologies in 2016 by Market Group (II) 76

Figure 61 Rates of sensitivity by severity for active safety technologies in 2016 by Crash Type (I).................... 77

Figure 62 Rates of sensitivity by severity for active safety technologies in 2016 by Crash Type (II)................... 78

TABLES

Table 1 Projected 2030 injury crashes avoided through active safety technologies: overall and by region 26

Table 2 Projected 2030 injury crashes avoided through active safety technologies: by involved market type..... 27

Table 3 Projected 2030 injury crash percentage reduction from active safety technology: by involved crash type 34

Table 4 Summary of 2016 and 2030 crashes 46

Table 5 2016 crashes by crash type and crash severity 79

Table 6 Effectiveness used in estimating potential crashes avoided... 80

Table 7 Effectiveness used in estimating potential injuries avoided.. 81

EXECUTIVE SUMMARY

Introduction

There is a significant body of research that can inform government and motoring club policy development and advocacy on vehicle crash risk and occupant injury outcomes and their relationship with new vehicle safety technologies. Formulating priorities for future road safety strategies requires supporting analysis to predict what the future crash population will look like and to assess how the countermeasures either already in place or planned will address the crash problems forecast. This allows unaddressed crash problems to be identified and, in response, allows strategies to be modified or expanded to cover these problems including the development of new countermeasures. The need to develop new countermeasures for unaddressed problems also assists in defining the requirements for fundamental research to inform countermeasure development. This approach can be used for all aspects of the safe system, including safe vehicles, and has been used here to identify the likely residual crash problems unaddressed by active and passive vehicle safety technologies that are currently permeating the light vehicle fleet.

The aim of this project was to identify future vehicle safety priorities in Australia through an integrated analytical approach based on mass data records from police reported crashes. Firstly, future crash population profiles were predicted based on past trends. Projections considered categorisation of crash trends by factors relevant to vehicle safety countermeasures including crash type, vehicle type and location. The next phase of the project considered vehicle safety countermeasures already in place including emerging new vehicle safety technologies and their expected impact on projected future road trauma levels. From this analysis the likely residual unaddressed road safety problems were identified. The final stage of the project was a review of potential future vehicle safety countermeasures that may address the residual road safety problems identified. From this review, areas of road trauma unlikely to be addressed by any current countermeasures were identified and recommendations for countermeasures, which included those newly developed, were made. The project focussed primarily on the light vehicle fleet in Australia.

The project aimed to identify priorities for future vehicle safety improvement in the light vehicle fleet through:

- analysing the 2006 to 2016 crash population trends by crash type, vehicle type and location;
- analysing the 2006 to 2016 injury burden from crashes by severity, crash type, vehicle type and location;
- projecting the likely future crash population from 2017 to 2030 based on past trends by crash type, vehicle type and location;
- projecting the potential of active safety technologies to reduce the crash injury burden by crash types, vehicle types and crash location;
- projecting the expected benefits of improved crashworthiness (as a proxy for vehicle design and potential passive safety technologies) to further reduce the crash injury burden by crash types, vehicle types and crash location;
- profiling injuries that could not be prevented by the rollout of active and passive safety technologies and projected safety improvements to vehicle; and

- analysing the types and circumstances of crashes not projected to be prevented by safer vehicles and associated technology to identify vehicle safety priority areas.

Analysis Approach

The analysis estimated potential crashes avoided by active safety technologies in an Australian light vehicle crash fleet projected from 2017 to 2030. Light vehicle injury crashes were defined as any crashes involving at least one light vehicle and at least one injured person. Unless otherwise stated, the term ‘injuries’ referred to any person injured in a crash: pedestrian, bicyclist, rider or vehicle occupant. Projected crashes potentially mitigated by vehicle active safety technologies and rates of fitment of crash involved vehicles with these technologies were combined to estimate potential crash savings. The effectiveness of crash avoidance technologies was taken from the published studies based on real-world data. Where effectiveness estimates from real-world crash analyses were unavailable, reductions were based on meta-analysis, or on studies using simulations, combined with in-depth crash data analyses. Future technology fitment to vehicles was projected from current trends. Models of projected future vehicle crashworthiness (measuring the risk of death or seirous injury to vehicle drivers per crash invovlement) were used to estimate the additional benefits of advancements in vehicle deign and passive safety systems. The remaining crashes and injuries, which were not avoided by active or passive safety technologies, informed the assessment of future vehicle safety priority areas.

The crashes and injuries estimated to be saved in the projected crash years were analysed based on 12[1] crash types relevant to the techhnologies. These are:

- Single light vehicle crashes (no collision with bicycle/moped/pedestrian, may involve collisions with parked vehicles):
    1. first event rollover or no collision,
    2. first event collision to front,
    3. first event collision with side (L, R) or rear (vehicle going forward and has spun around), and
    4. first event collision to rear when reversing.
- Light vehicle to bicycle/moped crashes:
    5. vehicle hits bicycle/moped – front, and
    6. collision of bicycle/moped to rear/side of vehicle- (e.g. bicyclists hit rear of forward-moving vehicle or vehicle reverses).
- Light vehicle to pedestrian crashes:
    7. frontal impact (vehicle not-reversing), and
    8. rear impact (vehicle reversing).
- Multi-vehicle, light vehicle to other motor vehicle collisions (collision between the two motor vehicles in the first event or only two vehicle crashes if that could not be determined) crashes:
    9. front-rear impact,

[1] Rear-to-rear collisions were evaluated also, however their contribution was so small to be insignificant.

10 front-to-side,
11 front-to-front, and
12 side-to-side impacts.

Results

Projected injuries saved from the additional penetration of current *active* and *passive* safety technologies to those likely to be available in the 2030 light vehicle fleet amounted to 351 fatalities, 7,086 serious injuries and 12,345 minor injuries per annum, saving a total of $3,174 million in human losses. About one third of all fatal and serious injuries were projected to be avoided through the additional penetration of active and passive safety technologies.

In 2030, 207 fatal crashes, 3,369 serious injury crashes and 8,492 minor injury crashes were projected to be avoided because of the additional penetration of *active* safety technologies which amounts to $2,091 million dollars of social road crash costs.

Figure 1 compares the 2016 and projected 2030 distributions of types of crashes <u>not</u> avoided by active safety technology by crash severity and region. Active safety technologies were projected to noticeably decrease the proportion of single forward-moving vehicle collisions across all severities, as well as serious and minor front-to-rear collisions. Conversely the proportions of bicycle/moped, fatal pedestrian, serious and minor front-to-front, minor front-to-side, fatal and serious rural front-to-side crashes were predicted to noticeably increase. Practically no differences in crash distributions of any severity are expected in remote regions.

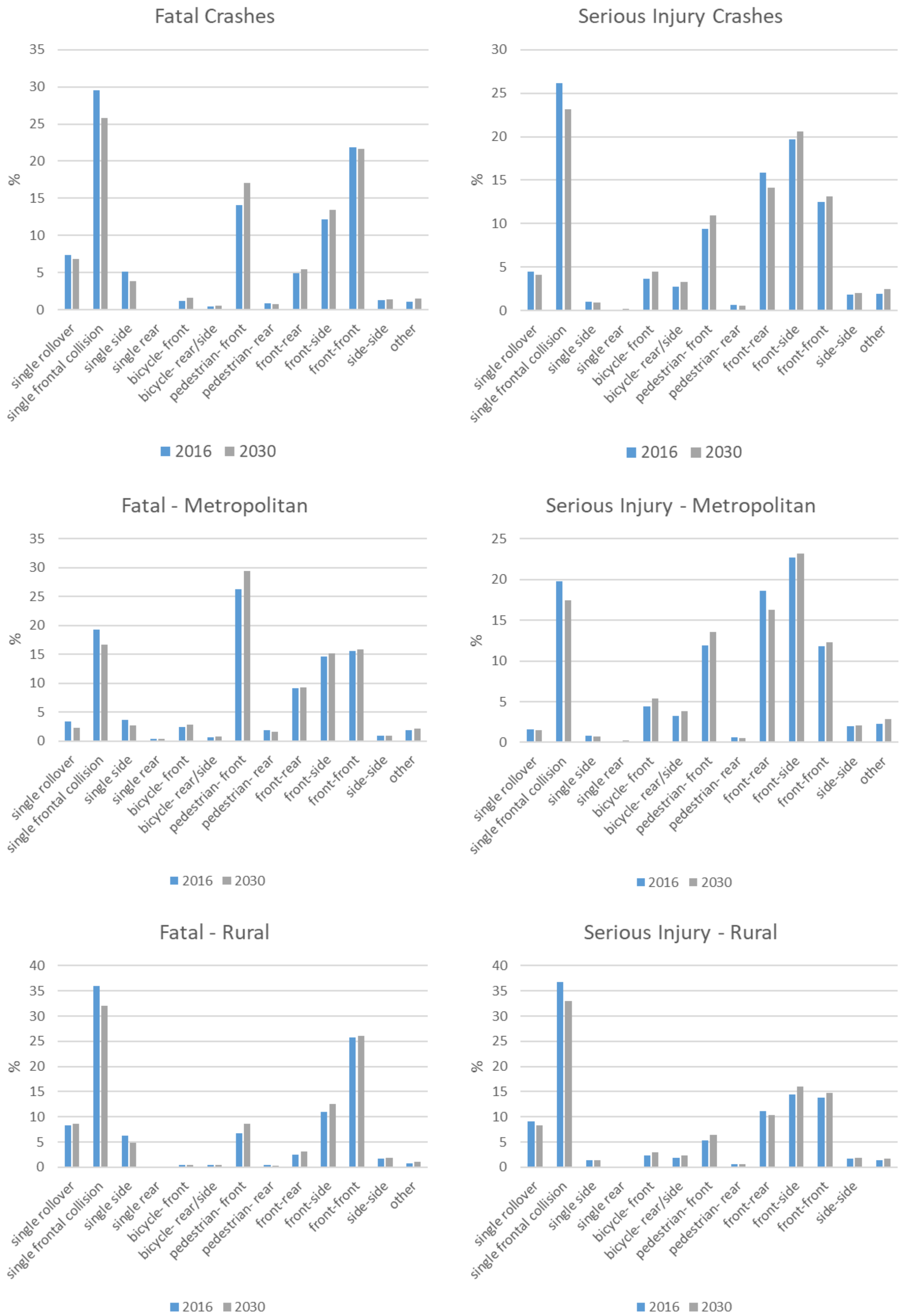


Figure 1 2016 & projected 2030 distribution of injury crash types for fatal and serious injury crashes for all crashes and by metropolitan and rural regions

Figure 2 shows the total number of injuries from crashes in 2016 and indicates those estimated to be avoided from projected 2030 active and passive safety technologies, by severity and region. It shows that, currently, rural regions contribute most fatalities and metropolitan regions are the location of most non-fatal crash injuries. These differential trends were replicated in the injuries avoided through active safety technologies alone. More serious injuries were avoided through the additional future effects of passive safety technologies in metropolitan areas than in rural regions. In terms of proportions of injuries avoided, more than a third of fatalities and serious injuries were expected to be avoided in 2030 through vehicle active and poassive safety improvements, with the greatest proportionate savings in rural regions. More than a quarter of all minor injuries were predicted to be avoided, with similar proportions in rural and metropolitan regions.

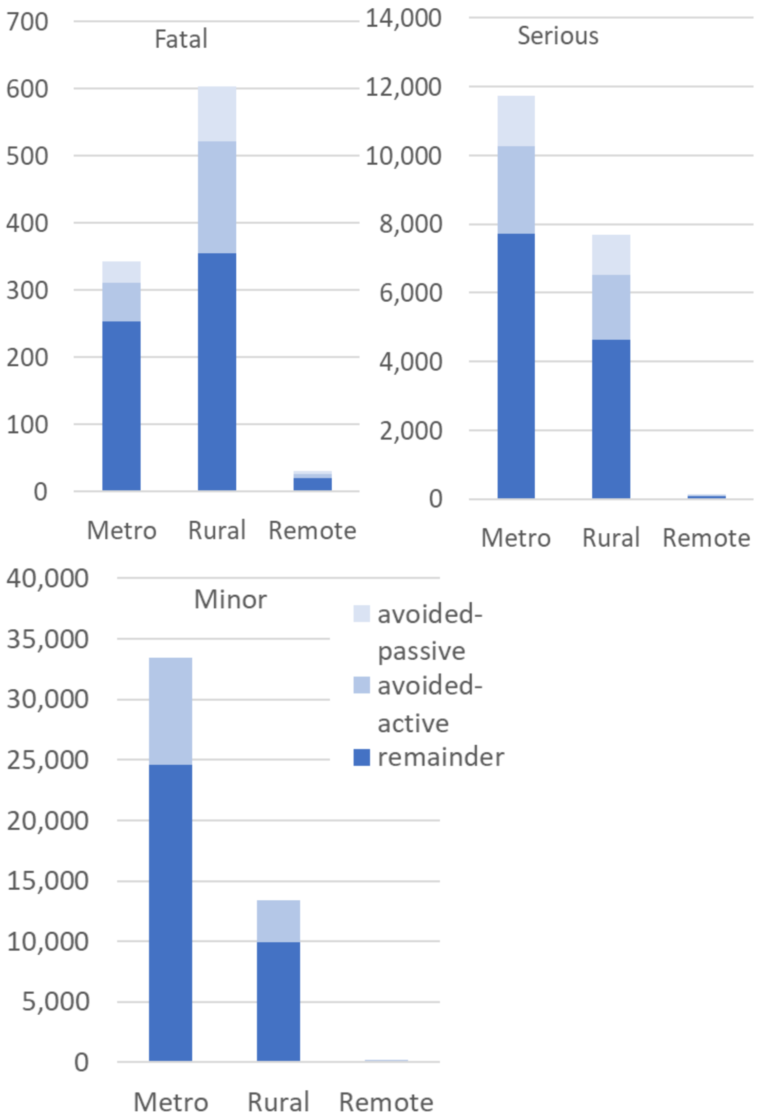


Figure 2 Total injuries from crashes in 2016 by location and severity and predicted savings by 2030 due to improved vehicle active and passive safety

Figure 3 gives injuries resulting from crashes in 2016 by severity and broad vehicle market group along with projected savings by 2030 due to active and poassive vehicle safety improvements. Large, medium and people mover market groups were aggregated for analysis with crashes involving these vehicles contributing greatest number of fatalities. Although not representing the greatest crash numbers, SUVs and LCVs were over-represented in fatal crashes. Small and light vehicles were grouped together for analysis with crashes involving these vehicles contributing the greatest number of serious and minor injuries. Small, medium and large SUVs contributed the least number of fatalities and commercial van and utility (LCV) crashes contributed the least number of serious and minor injuries. Trends in proportion savings due to improved passive and active safety by 2030 were similar across market groups with the exception of fatalities where SUV fatalities were predicted to be reduced least, and LCV fatalities redulced least through active safety technologies. This may be explained by the poorer predicted penetration of active technologies expected in the light commercial vehicle market.

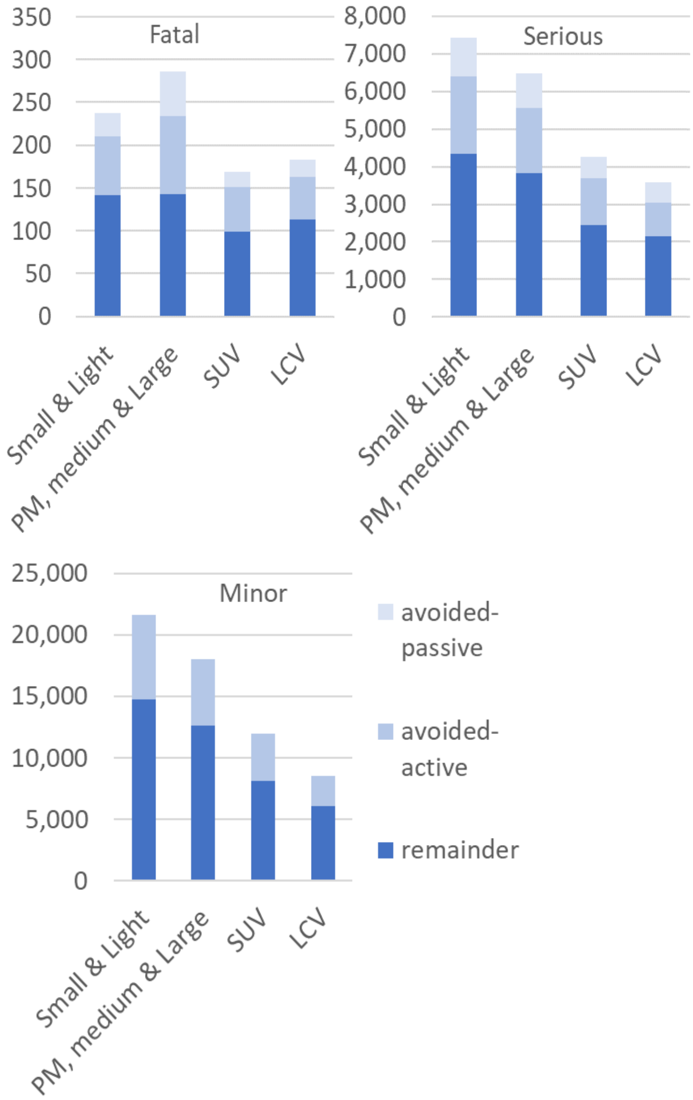
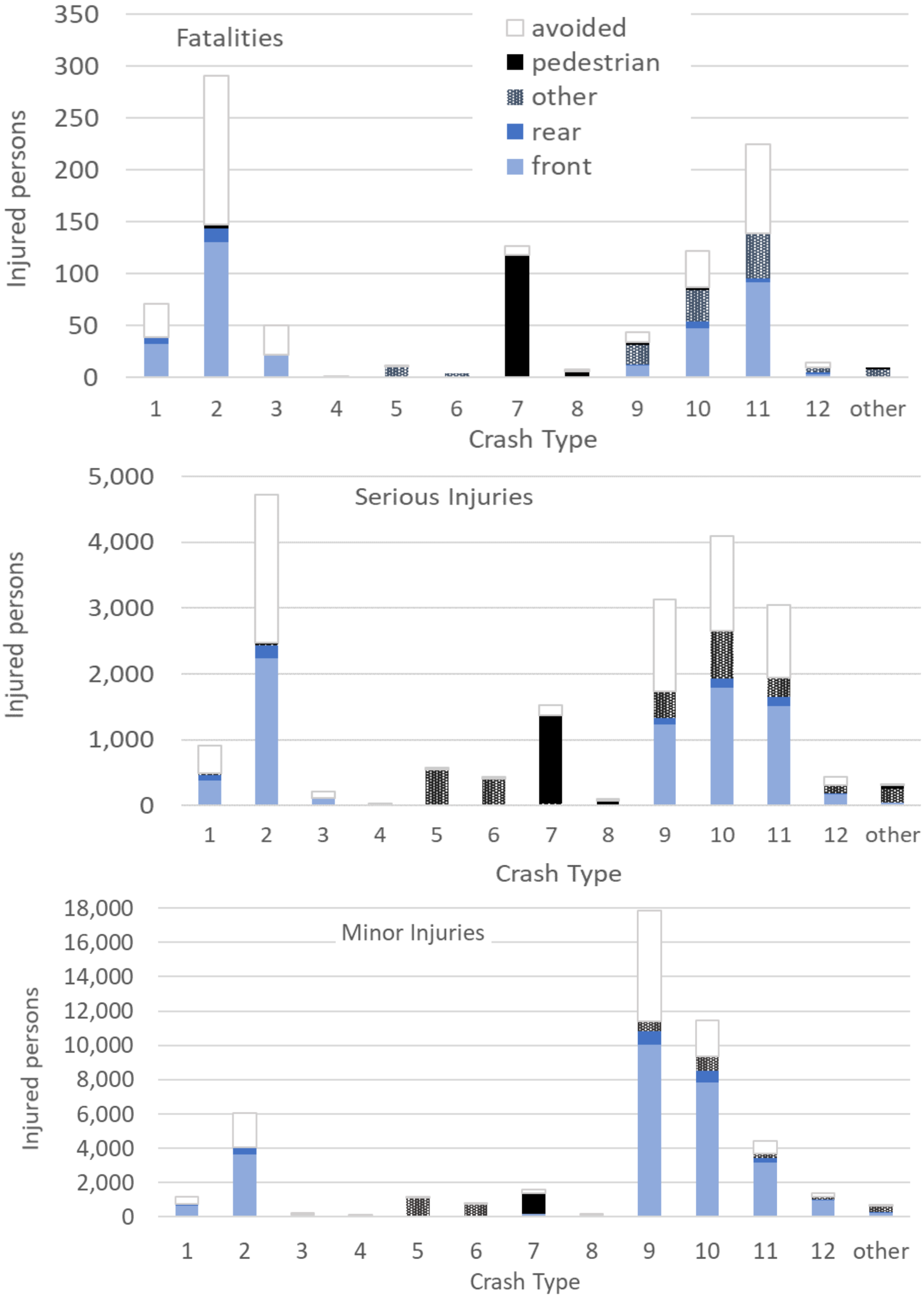


Figure 3 Total injuries from 2016 crashes by broad market group and severity and predicted savings by 2030 due to improved vehicle active and passive safety

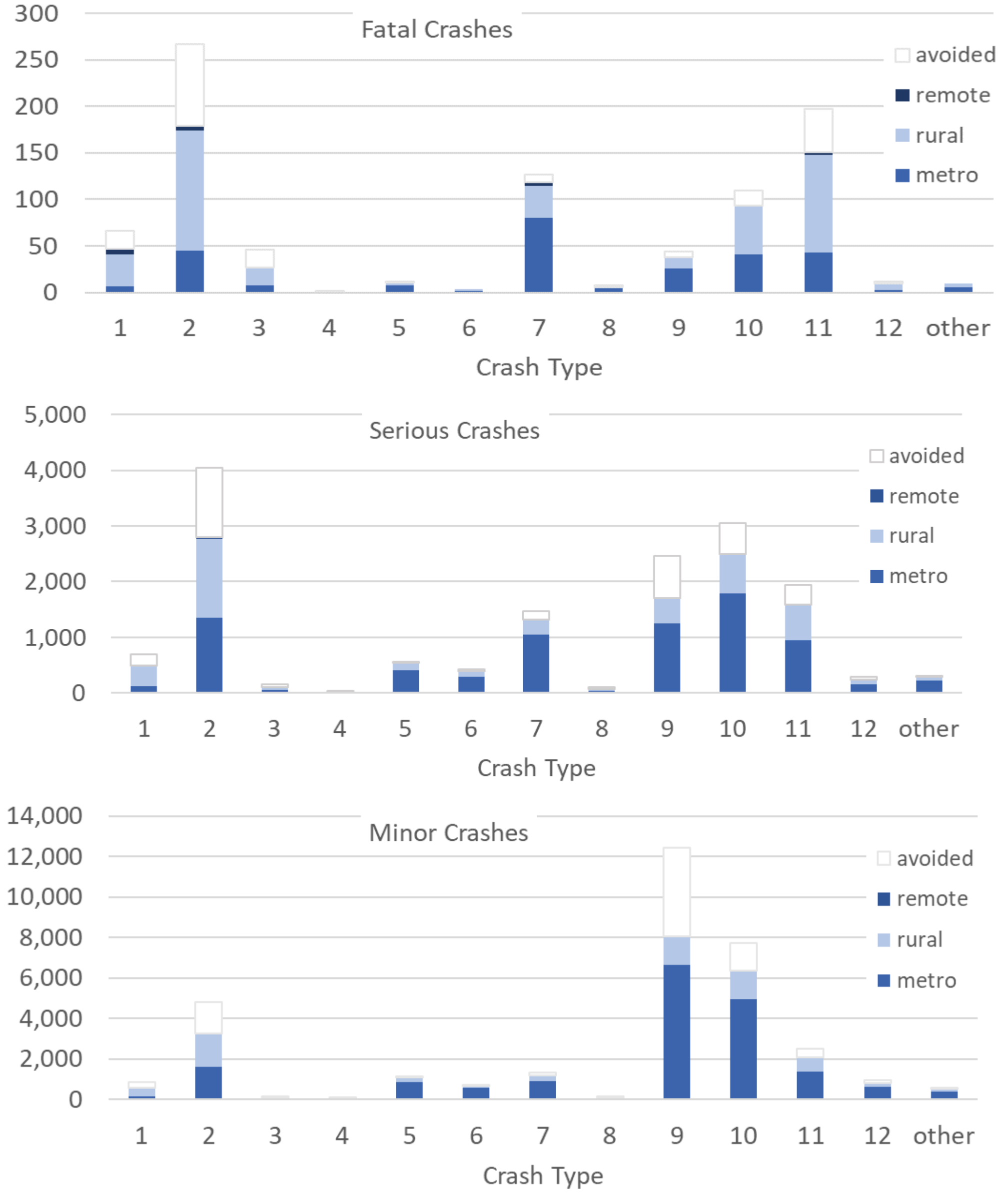
Figure 4 presents total injuries by crash type and those avoided by active and passive vehicle safety improvements. Furthermore, the injuries not avoided have been disaggregated by road user type: light vehicle front and rear occupants, pedestrian and other vehicle occupants/road users. Vulnerable road users make up a large proportion of the fatalities in the remaining crashes. Generally, the ‘other’ road user types from bicycle and moped crashes (crash types 5 and 6) are bicyclists or moped riders and those from crash types 9-12 are motorcyclists. Because bicyclist, moped rider and pedestrian fatalities were predicted to be largely not avoided, vulnerable road users represent an increased proportion of the 2030 remaining crash fatalities. Results for crashes rather than injuries are presented in Figure 5 and show the same trends. Most crash types were considered to have some potential to be avoided by active safety technologies, so it is still likely that avoidance will further increase beyond 2030 due to increased market penetration and technological developments which increase effectiveness.



1	single rollover	5	Bicycle/moped-front	9	front-rear
2	single frontal collision	6	Bicycle/moped-rear/side	10	front-side
3	single side	7	pedestrian-front	11	front-front
4	single rear	8	pedestrian-rear	12	side-side

Figure 4 Total injuries from 2016 crashes by crash and road user type and severity and predicted savings by 2030 due to improved vehicle active and passive safety

Figure 5 presents the projected 2030 crash reduction percentages from active safety technology by region, crash severity and crash type. This figure highlights the poorer avoidance of: reversing (4), bicycle/moped type (5 & 6), pedestrian (7), front-to-side (10) and side-to-side (12) collisions. It also clearly demonstrates that except for pedestrian and bicycle/moped crashes, most remaining fatal crashes by crash type were in rural regions and mostly from single vehicle, front-to-front and front-to-side collisions.



1	single rollover	5	Bicycle/moped-front	9	front-rear
2	single frontal collision	6	Bicycle/moped-rear/side	10	front-side
3	single side	7	pedestrian-front	11	front-front
4	single rear	8	pedestrian-rear	12	side-side

Figure 5 Total 2016 crashes by crash and road user type and severity and predicted savings by 2030 due to improved vehicle active and passive safety

Vehicle Safety Priority Areas

The final stage of the project was a review of current or emerging vehicle safety countermeasures that may address the residual road safety problems identified. From this review, areas of road trauma unlikely to be addressed by any current countermeasures were identified and recommendations on future potential vehicle safety priority areas for the light vehicle fleet in Australia have been made, for which new countermeasures will need to be developed.

Vehicle Safety Priority Area One: Fatal pedestrian crashes

Fatal pedestrian crashes and non-fatal pedestrian crashes involving SUVs were predicted to increase over 2006 to 2016. In metropolitan regions, pedestrian crashes were one of the largest contributors to severe trauma and this crash type is also more likely to be fatal than most other crash types. In 2030, fatal pedestrian crashes were predicted to make up a larger proportion of injury crashes than in 2016. This means that active safety technologies are not predicted to adequately address a crash growth area, which is a high contributor to trauma with severe injury outcomes. It is also a crash type of specific concern in metropolitan regions. Furthermore, by definition, passive safety modelled with crashworthiness has no effect on pedestrian injury, so after applying both active and passive safety measures, this crash type was predicted to be the third largest crash type contributor to both fatal and serious injuries in 2030.

Pedestrian crashes are chiefly addressed by AEB systems with pedestrian detection capability. Natural penetration rates of AEB with this capability were projected to be lagging and this technology is curently rarely present in light commercial vehicles.

As a significant contributor to metropolitan road fatalities, pedestrian crashes are a crash type with serious outcomes. They have not been adequately addressed by vehicle safety technology with 2030 projections of only 11% crash avoidance and relative growth in the crash type. By targetting pedestrian fatalities, reductions in non-fatal pedestrian crashes will also follow. Both relative and absolute estimated reductions in 2030 rural fatal crashes achieved from active and passive vehicle safety technologies were greater for rural regions. Targetting pedestrian fatal crashes will assist in improving avoidance of fatal crashes in metropolitan regions.

Some suggested countermeasures are:

- Increase penetration of vehicle pedestrian safety features such as AEB with vulnerable road user detection and pedestrian frienfly vehicle frontal structures to find out these are not naturally penetrating the light vehicle fleet at rates similar to other technologies.
- Encourage the increased uptake of pedestrian-AEB systems, particularly in LCVs which currently have limited fitment. This may also improve bicycle and moped crash outcomes.
- Investigate the possibilities offered by vehicle-to-pedestrian and vehicle-to-infrastructure communication technology and deploy what is found to be effective. There is a great body of research on intelligent transport systems (ITS). Silla, Rämä et al. (2017) esimated that almost half of vehicle-to-pedestrian crash injuries could be avoided with vehicle-to-pedestrian technology. ITS systems interacting mobile phone technology with vehicle telematics so that both drivers and pedestrians are alerted to impending collisions may be particularly effective.

- Encourage vehicle design improvements for pedestrian safety or the uptake of pedestrian protection technology such as night vision and active hood / windshield A-frame airbags. Fredriksson, Shin et al. (2011) estimated the latter to decrease AIS 3+ pedestrian injury risk from 85-100% to 20%. This is pertinent for SU vehicles which demonstrated an increase baseline trend of pedestrian crashes.

Vehicle Safety Priority Area Two: Single vehicle frontal crashes with fixed objects

Single vehicle frontal crashes with fixed objects were estimated to be best addressed by active safety technology, however this crash type was projected to make up 21% of all injury crashes in 2030 and two thirds of current crashes were projected to *not* be avoided by vehicle safety technologies in 2030.

These were amongst the most serious crash types, particularly for small and light vehicles and involving rollover in remote regions. They were also amongst the largest contributors to serious road trauma. Single vehicle-to-object crashes were observed to increase over 2006 to 2016, for serious and rural crashes, or when certain market groups were involved.

ESC, LDW/LKA and active headlamps were the main technologies addressing single vehicle fatal frontal crashes modelled in this analysis. In 2030, ESC was estimated to have almost saturated the crashed vehicle fleet, so will have no more to offer in crash avoidance beyond 2030. Both LDW/LKA and active headlamps were shown to have potential beyond 2030 due to poorer crashed fleet penetration in 2016; especially for light commercial vehicles which lagged severely. Just over half the crashed light vehicle fleet were predicted to be fitted with LDW or active headlights by 2030.

Some suggested countermeasures are:

- Increase penetration of technologies in the fleet to address fatigue, speeding and inattention are not naturally penetrating the light vehicle fleet at rates similar to other vehicle safety technologies. Single vehicle forward-moving crashes are often the result of speeding, driver inattention and driver fatigue and the fitment analysis found poor projected uptake of speed, fatigue and inattention systems such as speed zone reminder, speed alert, speed limiter, driver fatigue warning, driver attention detector.
- Increase penetration of technologies in the fleet including LDW/LKA and active headlights, especially within the LCV market group.
- Increase penetration of relevant passive safety technologies, especially within the light commercial market group which are severely lagging: e.g. front passenger head airbag, all rear airbags and rollover protection (which is also lagging in SUVs).
- Investigate programs targetted at enhancing driver acceptance of lane departure warning systems, especially for professional drivers. Reagan and McCartt (2016) found LDW systems to only be switched on 33% of the time. Preferrable, encourage the increased uptake of Active Lane Keep Assist systems which default to be active at each journey.
- Increase the proportion of roads with edgelines. Most LDW/LKA systems currently rely on edgelines and do not function where there are no lanemarkings. Increasing

the proportion of lanemarkings on roads where fatigue, speeding and inattention are likely will increase the real world effectiveness of LDW/LKA.

- Investigate ways to improve injury outcomes in small and light vehicle single vehicle crashes. This may involve vehicle design or encouraging uptake of passive safety systems such as rollover protection, active headrests, and the various airbags currently available. Small and light vehicles were found to have poorer outcomes in these crash types.
- Investigate ways to improve injury outcomes in remote locations because remote single vehicle crashes were found to have poorer outcomes. This could include encouraging uptake of automatic crash notification systems or to educate remote region drivers about them. Automatic crash notification systems are an emerging safety technology designed to notify emergency responders that a crash has occurred and provide its location. This not only speeds up the response, but may be the only way that some crashes are detected before fatalities occur.

Vehicle Safety Priority Area Three: Front-to-front vehicle crashes both at intersections and midblocks and front-to-side impacts at intersections including straight crossing path and right turn across path crash types

Thirty-seven percent of crashes in 2030 were projected to be front-to-front or front-to-side crashes. In 2016, 57% of front-to-front collisions were at intersections and 35% came from adjacent approaches. In 2016, 80% of front-to-side were at intersections and 43% came from adjacent directions. Furthermore, fatal and serious front-to-side crashes were projected to increase in proportion in rural areas between 2016 and 2030. Both front-to-front and front-to-side crashes are significant contributors to road fatalities and injuries generally and more than 80% of these two crash types were *not* projected to be avoided in 2030 through vehicle safety imprvements.

These crashes generally are generally not prevented by AEB systems and then only in low speed environments. Intersection-AEB systems which target straight crossing path crashes have only recently been commercialised.

Targetting front-to-front and front-to-side crashes improves rural and metropolitan crash outcomes, because although most intersection crashes occur in metropolitan regions, most of the remaining <u>fatal</u> front-to-front and front-to-side crashes in 2030 were projected to be rural.

Some suggested countermeasures are:

- Improve penetration of ITS, high speed AEB systems and intersection-AEB technologies in the light vehicle fleet at rates similar to other technologies. Intersection AEB systems which target straight crossing path collisions are likely to be able to prevent around 40% of straight crossing path crashes and if AEB systems could improve speed range sensitivity both generally and specifically for *right turn/other direction* crashes more fatalities could be avoided. Furthermore, an increased speed range in general AEB systems could aid avoidance of high-speed front-to-rear crashes.
- Identify ways to enhance the natural penetration of relevant passive safety technologies, especially within the light commercial market group which are severely lagging: e.g. front passenger head airbag and all rear airbags.

- Investigate the possibilities offered by vehicle-to-vehicle and vehicle-to-infrastructure communication technology and deploy what is found to be effective. There is great body of research on intelligent transport systems (ITS). It is possible for intelligent intersection infrastructure to warn drivers of approaching vehicles from cross directions.
- Continue to expand red light speed camera programs for signalised intersections. These have proven effectiveness (Budd, Scully et al. 2011) on these crash types (44% casualty crash reduction).

Summary

Three future vehicle safety priority areas were identified from the analysis: (i) fatal pedestrian crashes, (ii) single vehicle frontal crashes with fixed objects, (iii) front-to-front vehicle crashes both at intersections and midblocks and front-to-side impacts at intersections including straight crossing path and right turn across path crash types. These crash types were projected to be the largest contributors to fatalities by 2030. Although not the most prevalent crash type, crashes involving bicycles and mopeds were forecast to grow proportionately over the study period. Remaining crash types in 2030 will be poorly addressed by current vehicle safety technologies. For example when considering single vehicle fixed object crashes, ESC will provide no further benefits in reducing single vehicle crashes after 2030 since the fleet will have achieved full fitment in 2030 vehicle fleet whilst current evidence suggests AEB has limited impact in addressing high speed crashes with fixed objects.

This analysis highlighted the limitations in fatality and serious injury reductions related to the natural penetration of vehicle safety technology fitment. Significant numbers of fatalities resulting from intersection crashes, single vehicle run off road and head on crashes will remain whist pedestrian crashes will grow in their proportionate importance. Additional or enhanced vehicle safety technologies will need to be developed that better address these crash types such as AEB effective for fixed object crashes and V to V technologies to mitigate intersection crashes. In addition, means to address the key remaining crash types elsewhere in the system need to be considered through measures such as road infrastructure treatments and appropriate speed limit setting for high risk environments where vehicle safety technology proves inadequate.

MONASH University

ACCIDENT
RESEARCH
CENTRE

IDENTIFYING FUTURE VEHICLE SAFETY PRIORITY AREAS IN AUSTRALIA

1 BACKGROUND

There is a significant body of research that can inform government and motoring club policy development and advocacy on vehicle crash risk and occupant injury outcomes and their relationship with new vehicle safety technologies. Formulating priorities for future road safety strategies requires supporting analysis to predict what the future crash population will look like and to assess how the countermeasures either already in place or planned will address the crash problems forecast. This allows unaddressed crash problems to be identified and in response, allows strategies to be modified or expanded to cover these problems including the development of new countermeasures. The need to develop new countermeasures for unaddressed problems also assists in defining the requirements for fundamental research to inform countermeasure development. This approach can be used for all aspects of the safe system including safe vehicles and has been used here to identify the likely residual crash problems unaddressed by active and passive vehicle safety technologies that are currently permeating the light vehicle fleet.

2 PROJECT AIMS AND SCOPE ADDRESSED IN THIS DOCUMENT

The aim of this project was to identify future vehicle safety priorities in Australia through an integrated analytical approach based on mass data records from police reported crashes. Firstly, future crash population profiles were predicted based on past trends. Projections considered categorisation of crash trends by factors relevant to vehicle safety countermeasures including crash type, vehicle type and location. The next phase of the project considered vehicle safety countermeasures already in place including emerging new vehicle safety technologies and their expected impact on projected future road trauma levels. From this analysis the likely residual unaddressed road safety problems were identified. The final stage of the project was a review of potential future vehicle safety countermeasures that may address the residual road safety problems identified. From this review, areas of road trauma unlikely to be addressed by any current countermeasures were identified and recommendations for countermeasures, which included those newly developed, were made. The project focussed primarily on the light vehicle fleet in Australia.

The project aimed to identify priorities for future vehicle safety improvement in the light vehicle fleet through:

- analysing the 2006 to 2016 crash population trends by crash type, vehicle type and location;
- analysing the 2006 to 2016 injury burden by severity, crash type, vehicle type and location;
- projecting the likely future crash population from 2017 to 2030 based on past trends by crash type, vehicle type and location;
- projecting the potential of active safety technologies to reduce the crash injury burden by crash types, vehicle types and crash location;
- projecting the expeced benefits of improved crashworthiness (as a proxy for vehicle design and potential passive safety technologies) to further reduce the crash injury burden by crash types, vehicle types and crash location;
- profiling injuries that could not be prevented by the rollout of active and passive safety technologies and projected safety improvements to vehicle; and
- analysing the types and circumstances of crashes not projected to be prevented by safer vehicles and associated technology to identify vehicle safety priority areas.

The project included analysis of *light vehicle crashes* by type, location, market group and sensitivity to emerging active and passive safety technologies. The vehicles used arose from Australian crash data from New South Wales, Victoria, Queensland, Western Australia and South Australia. It was assumed that these jurisdictions represented Australia in entirety and that the light vehicles of the crash data were a sample representative of all Australian light vehicles. In reality, the injuries from the crash data analysed approximated 95% of national road injuries.

This document focuses on *light vehicle injury-crash* and *injury* reductions affected by emerging active and passive safety technologies fitted to light vehicles. Safety technologies within crashed light vehicles were assumed to be representative of safety technologies present within the entire Australian light vehicle fleet so that technology penetration could be modelled using only *crashed* light vehicles. Fitment of emerging safety technologies to heavy vehicles or motorcycles was not considered.

Light vehicle injury-crash and *injury* reductions were metered against the current crash and crash injury trends disaggregated by crash type, vehicle type and location. Light vehicle injury crashes were defined as any crashes involving at least one light vehicle *and* at least one injured person. Unless otherwise stated the term 'injuries' referred to any persons injured in a crash: pedestrian, bicyclist, rider or vehicle occupant. Bicycles, motorcycles, pedestrians and heavy vehicles may be involved in light vehicle crashes, so injuries to motorcyclists, bicyclists, riders, pedestrians and heavy vehicle occupants contributed to the light vehicle crash injury count.

Where available, *light vehicle injury-crash* reductions were informed by the effectiveness of emerging *active* safety technologies on real world targeted injury crashes. Where real world crash analyses were unavailable, reductions were based on meta-analysis, or on studies using simulations, combined with in-depth crash data analyses. Confidence intervals for estimates of crashes or injuries saved in this analysis are based on the confidence intervals of the literature estimates of active technology effectiveness. These are generally 95% confidence intervals.

The scope of this document does not include explanations on how these technologies work or the add-on costs of these technologies. A recent European Commission publication (European Commission 2016) succinctly explains current and emerging advanced driver assistance systems. Other references listed at the end of this and the supporting documentation may be explored for further vehicle safety systems information.

Models of projected crashworthiness ratings were used to estimate the benefits of advancements in vehicle design and market penetration of *passive* safety systems. Innovations in vehicle design are not considered in this document beyond the contribution that design makes within vehicle safety ratings.

Furthermore, the role of road infrastructure in crash prevention is not within the scope of this document; as such, crashes avoided through intelligent safety systems requiring communication with infrastructure will not be considered.

Also, this document does not table or measure safety benefits by crash causation.

This document refers to a literature review of current or emerging vehicle safety countermeasures presented in supporting documentation. From this literature review, fitment trends, and the identified residual crash and injury trends, recommendations on future potential priority countermeasures were made to target residual areas of road trauma.

3 DATA AND PROJECTED DATA

3.1 Crash data

Light vehicles were extracted from Australian Police reported crash data of 2006 to 2016. The data were provided by jurisdictional bodies of Western Australia, South Australia, Victoria, Queensland and New South Wales for the 2018 Used Car Safety Ratings (Newstead, Watson et al. 2018). During the process of calculation of the Used Car Safety Ratings (UCSR), model codes and market groups were added to the Australian crash data where possible. The model codes were used to match crashworthiness ratings and safety technology fitment status within each year of manufacture.

The 2016 crash year was used as the baseline for projected crash data years from 2017 to 2030. With each projected crash year beyond 2016, each light vehicle year of manufacture was advanced by one, so that the vehicle age distribution remained constant. All other aspects of the crash data remained unchanged from 2016 for all projected crash years, so that the projected crash data had the same annual crash type, market group, vehicle age, injury severity and injured road user distribution.

3.2 Safety technology fitment status

Emerging safety technology fitment status were determined using the RedBook Lookup Guide (Automotive Data Services Pty Ltd 2014) and with data purchased from Redbook. (Redbook provides specification data for vehicles sold in Australia and New Zealand.) Redbook fitment data were matched with UCSR model codes and reclassified as “ALL” where all model variants were fitted with the standard feature, and “SOME” where only some of the model variants were fitted with the standard feature. The fitment codes (with values of *all*, *some* or *unknown*) were matched with Australian crash data models by model code and years of manufacture. The following active safety features were available for matching:

ABS (Antilock Brakes)
Active Headlamps
Blind Spot Sensor
Blind Spot with Active Assist
Brake Assist
Brake Emergency Display - Hazard/Stoplights
Camera - Front Vision
Camera - Front Vision x2
Camera - Rear Vision
Camera - Side Vision
Camera - Wireless Mobile
Centre Differential
Collision Mitigation - Forward (High speed)
Collision Mitigation - Forward (Low speed)
Collision Mitigation - Reversing
Collision Warning - Forward
Collision Warning - Rearward
Control - Corner Braking
Control - Electronic Damper
Control - Electronic Stability
Control - Park Distance Front
Control - Park Distance Rear
Control - Park Distance Side
Control - Pedestrian Avoidance with Braking
Control - Rollover Stability
Control - Traction
Control - Trailer Sway
Cruise Control - Distance Control
Cruise Control - with Brake Function (limiter)
Daytime Running Lights
Driver Attention Detection
EBD (Electronic Brake Force Distribution)
Fog Lamps - Active (Cornering/steering)
Head Up Display
Hill Holder
Lane Departure - with Passive Steer Assist
Lane Departure Warning
Lane Keeping - Active Assist
Night Vision - Display Screen
Speed Limiter
Speed Zone Reminder
Telematics
Verbal Warning System
Warning - Driver Fatigue
Warning - Rear Cross Traffic (when reversing)
Warning - Road Sign Display
Warning - Speed Alert.

The following passive safety features were available for model matching:

- Airbag - Driver
- Airbag - Knee Driver
- Airbag - Knee Passenger
- Airbag - Passenger
- Airbag - Pedestrian (bonnet)
- Airbag - Side Driver
- Airbag - Side Front Passenger
- Airbags - Head for 1st Row Seats (Front)
- Airbags - Head for 2nd Row Seats
- Airbags - Head for 3rd Row Seats
- Airbags - Pelvic Region 1st Row Seats
- Airbags - Seatbelt 1st Row Occupants
- Airbags - Seatbelt 2nd Row Occupants
- Airbags - Side for 1st Row Occupants (Front)
- Airbags - Side for 2nd Row Occupants (rear)
- Bonnet - Active Safety
- Headrests - Active
- Roll Bar
- Rollover protection
- Seatbelt - Race Harness
- Seats - Anti-submarining

Logistic regression modelling of fitment to light vehicles crashed over the years 2006 to 2016 was used to project the probability of fitment by technology type, market group[2] and vehicle year of manufacture. Standard fitment in any model variant was considered a fitment event for the model. Possible over-estimation of fitment because of this assumption was countered by underestimation from the conservative practices of not considering fitment where it was optional, unknown or on vehicles manufactured prior to 1982. Details of methods used and the analysis of fitment trends may be found in the *Fitment Analysis* supporting documentation for this report.

The probabilities of fitment estimated for each *active* safety technology, market group and year of manufacture from 1982 to 2030 were matched onto the projected crash data.

3.3 Crashworthiness ratings

Crashworthiness ratings (CWR) are defined as the risks of driver fatalities and serious injuries in injury crashes (Newstead, Watson et al. 2018). CWR are estimated annually from Australian and New Zealand crash data. CWR were available for specific models, by market group and year of manufacture from 1982 and by year of manufacture from 1961. The CWRs by year of manufacture were projected to 2030 using logistic regression modelling.

These ratings were attached to both 2000 to 2016 crash data and to crash data projections. For 2000-2016 data, where a rating was available for a current model, regardless of year of manufacture, the model-based CWR was used. Where this was not available and the year of manufacture was less than 2017, CWRs calculated for specific year of manufacture and market group combinations were matched. For cases without a market group assignment, and with a year of manufacture between 1961 and 2016, CWRs calculated for specific year of manufacture were matched. CWR were similarly matched onto projected crash data. However, for years of manufacture projected from 2017 to 2030, projected CWR were attached, except when the model-based CWR was lower.

[2] Where regression modelling by market group was not possible, markets were condensed to three groups: SUV, light commercials and others. Where there was no representation for a market, zero fitment was assumed over the entire period.

3.4 Crash Costs

Australian injury costs were derived from the (2009) BITRE report number 118, "Cost of road crashes in 2006". The 2006 human loss value of a fatality was costed at $2.4 million and the human loss of a hospitalisation at $214 thousand. A fatal crash was valued at $2.67 million, a serious injury crash at $266 thousand and a minor injury crash at $14.7 thousand Australian 2006 dollars. BITRE uses a hybrid of the human capital and the willingness-to-pay approaches (Risbey, Cregan et al. 2010). The 2006 social costs of fatal, serious (hospitalised injuries) and minor injury crashes were inflated to 2019 costs using the September consumer price index (Australian Bureau of Statistics 2019) to $ 3.55 million, $354 thousand and $20 thousand respectively. The 2019 value of human losses for a fatality were $AUS 3.19 million and for a serious injury were $AUS 285 thousand.

4 METHODS

4.1 Analysis approach

This analysis estimated the potential crashes avoided by active safety technologies in an Australian light vehicle crash fleet projected from 2017 to 2030. Light vehicle injury crashes were defined as any crashes involving at least one light vehicle and at least one injured person and unless otherwise stated the term 'injuries' referred to any person injured in a crash: pedestrian, bicyclist, rider or vehicle occupant. Projected crashes potentially mitigated by vehicle active safety technologies and involved vehicle rates of fitment with these technologies were combined to permit the estimation. The effectiveness of crash avoidance technologies was taken from the published studies based on real-world data. Where real-world crash analyses were unavailable, reductions were based on meta-analysis, or on studies using simulations, combined with in-depth crash data analyses. Technology fitment to vehicles was projected from current trends. Models of projected crashworthiness ratings were used to estimate the additional benefits of advancements in vehicle deign and passive safety systems. The remaining crashes and injuries, which were not avoided by active or passive safety technologies, informed the assessment of future vehicle safety priority areas.

4.2 Crash types

The crashes and injuries estimated to be saved in the projected crash years were analysed by 12[3] crash types. These are listed below.

- Single light vehicle crashes (no collision with bicycle/moped/pedestrian; may involve collisions with parked vehicles):
  1 first event rollover or no collision,
  2 first event collision to front,
  3 first event collision with side (L, R) or rear (vehicle going forward and has spun around), and
  4 first event collision to rear when reversing.

- Light vehicle to bicycle/moped crashes:
  5 Vehicle hits bicycle/moped – front, and
  6 Collision of bicyce/moped to rear/side of vehicle- (e.g. bicyclists hit rear of forward-moving vehicle or vehicle reverses).
- Light vehicle to pedestrian crashes:
  7 frontal impact (vehicle not-reversing), and
  8 rear impact (vehicle reversing).

[3] Rear-to-rear collisions were evaluated also, however their contribution was so small to be insignificant.

- Multi-vehicle, light vehicle to other motor vehicle collisions (collision between the two motor vehicles in the first event or only two vehicle crashes if that cannot be determined) crashes:
  9 front-rear impact,
  10 front-to-side ,
  11 front-to-front, and
  12 side-to-side impacts.

It was not possible to model crash reductions from active safety technologies in crashes of more than two motor vehicles, where the two vehicles in the first event could not be determined or inferred.

4.3 Recent trends of injury crashes and injuries by crash type, location and vehicle type

This polychotomy of crash types acknowledges the differences in the ability of active technologies to detect different road users, and the differences in the ability of vehicle design or passive technologies to address occupant injuries by impact point. Inclusion within each of the twelve crash categories was determined using both crash types (as described in most jurisdictional data as DCA or RUM codes), and the jurisdictional sub-codes used to identify the vehicles of the DCA/RUM codes. Where sub-coding was not present, vehicle directional approach, impact locations and other crash data variables were used to estimate the (sub-)code for vehicles in two-vehicle crashes. Jurisdictional differences in the way crash data were collected has meant that some assumptions have been made; particularly for defining impact points, and in identifying first crash event vehicles.

Trends by crash type, in light vehicle injury crashes and in light vehicle crash injuries over 2006 to 2016, were analysed using charts and tables. Furthermore, analysis included disaggregation by road user type, location, market group and by crash or injury severity.

Road user type could be pedestrian, light motor vehicle occupant or other (e.g. occupant of heavy vehicle, motorcycle or bicycle). Light motor vehicle occupants were identified as driver, front passengers and rear passengers.

Locations were defined as metropolitan, rural or remote. *Remote* included regions in SA and WA only.

Injury severity was defined fatal, serious but not fatal and minor. A serious injury involved a hospital admission; a minor injury did not.

A crash with at least one person fatally injured was defined as a fatal crash; if there were no fatalities, but at least one person was seriously injured, the crash was serious. A minor injury crash involved no hospital admissions and no fatalities.

Vehicle types were defined by the Used Car Safety Rating market groups: Commercial Utilities (CU), Commercial Vans (CV), People Movers (PM), Large, Medium and Small Sports Utility Vehicles (SUVL,SUVM and SUVS) and Large, Medium, Small and Light (L, M, S and SL) cars. Note that crash aggregates by these groups were not mutually exclusive. This means that the sum of crashes by market group does not equal the crash total across all market groups. This is because a crash may have included more than one light-vehicle type, so it will be counted once in each of the involved market group crash aggregates.For example, a crash involving a light and a medium car will be counted once in the light car crash aggregates and once in the medium car crash aggregates. However, crashes within crash aggregates, overall or by market group, were never dublicated; for example, in the instance where two medium vehicles collided, the crash was counted only once within the medium market group aggregates.

4.4 Active safety technolgies used in modelling

Current literature was used to characterise current or emerging vehicle safety countermeasures which addressed the road safety problems identified by the analysis of crash data. From the literature search, a set of active safety technologies were chosen to estimate the potential safety benefits achievable with market driven technology uptake. To be selected, an active safety feature had to have incompletely penetrated the current fleet and had to have a published effectiveness significantly greater than zero (measured preferably in a real-world analysis) which could additionally be translated to the restrictions imposed by police reported crash data variables. In addition to these two features, selection also considered their potential to reduce road trauma through increased uptake, recent and projected technological advancement, efficacy and the crash types they specifically targeted. The choice of active technologies was additionally limited to those with available fitment data. The active technologies modelling in this analysis were:

- Electronic Stability Control (ESC)
- Automated Emergency Braking (AEB)
- Pedestrian AEB (Ped-AEB systems are designed specifically for pedestrian detection)
- Lane Departure Warning or Lane Keep Assist (LDW/LKA)
- Blind Spot Detection or Side View Assist (BSD/SVA)
- Adaptive or Active Headlamps (ADHL)
- Reversing or Rear Camera (RC)
- Rear Cross Traffic Alert (RXA)
- Telematic intelligent transport systems: vehicle-to-vehicle (V2V), vehicle-to-bicycle (V2B) and vehicle-to-pedestrian (V2P)

The literature review output included summary tables for published articles which included effectiveness and target populations for each of the selected active safety technologies. These are found in the supporting documentation: *Literature review and crash sensitivitity.* The literature review enabled the identification of the crash types sensitive to specific active technologies where real-world effectiveness has been reported. Where more than one study was available for a technology, the one chosen to estimate effectiveness in the analysis was the most recent and relevant study with respect to being a real-world analysis, definable within the limits of crash data variables and transferable to Australian conditions. It was preferred that the study estimated crashes avoided, however, for technologies addressing pedestrian and bicycle collisions (V2P, V2B, broadly sensitive crashes with general AEB and pedestrian-AEB), only injured person reductions were available.

The studies chosen from the literature review which were used in the analysis are presented in appendix A.5 in Table 6 and Table 7. These tables list the technology, the chosen study and the ranges and point estimates of the percentages of crashes or injuries avoided, by severity. Where the literature sourced effectiveness estimates were for injuries or injury crashes as a whole, the fatal, serious and minor reductions were identical. Furthermore, where the source disaggregated only as fatal and non-fatal, the serious and minor reductions will be identical. Occasionally, one study was used for one crash type, and another for a different crash type; for example LDW, reverse camera, V2V, ADH and AEB sensitive crashes. The table identifies where studies were chosen by crash type.

4.5 Crash types sensitive to this set of vehicle technologies

Sensitive crashes for each active safety technology were identified from literature. The summary of this process is contained in the supporting documentation, “Literature review and crash sensitiviity”. The process of identifying sensitive crashes was similar to that used in other future impact evaluations of crash data such as that of Strandroth (2015), Ostling, Lubbe et al. (2019), Budd, Keall et al. (2015) and Anderson, Hutchinson et al. (2010).

The criteria for sensitivity included conditions available in the crash data such as crash type, weather, speed zone, and number of motor-vehicles involved in the first crash event. Where such crash information was unavailable for a specific jurisdiction, approximations based on trends in other jurisdictions were applied. Each crash was categorised as sensitive or not sensitive to each of the selected active vehicle safety technologies.

A sensitive crash was further restricted in this analysis to only those where a light vehicle in the crash was considered sensitive to the technology. It is often the case in a multi-motor vehicle collision, that fitment in only one of the vehicles would mean that a crash is avoided. For example, a rear-end crash is a crash sensitive to AEB technology. There are two vehicles in a rear-end collision: a colliding vehicle and a target vehicle. AEB can only prevent the crash when the colliding vehicle is fitted with the AEB technology. In this instance, the target vehicle fitment is irrelevant. For the crash to be considered sensitive, the colliding vehicle would have to be a light vehicle, and for a crash to be avoided, the technology would have to be in the colliding vehicle. For the purposes of this analysis, the term *sensitive vehicle* is used to describe the vehicle in a *sensitive crash* in which fitment must occur for the crash to be avoided.

Sensitive crashes were identified using only the vehicles involved in the first collision event. For single vehicle crash types identification was not complicated. For multi-vehicle crash types, the two first event vehicles were those used to classify the accident type described in the jurisdictional data by such variables as the DCA code. For most jurisdictions these two vehicles were identified in the data. Where this did not occur, they could be inferred by the fact that only two vehicles were listed for the crash, or by eliminating parked vehicles, examining impact locations and using the order of the unit identifier.

4.6 Crashes avoided by active technologies

Sensitive crashes may not actually be avoided; a variety of reasons contribute to effectiveness. Factors that contribute to a sensitive crash not being avoided by a technology may include intentional behaviours such as excessive speed or avoidance manouvres, absence of edge-lines (for lane departure warnings), light or weather conditions not conducive to sensor function, alcohol, drug or fatigue affected driving or manual over-riding. With the exception of some descriptions of weather and light, none of these contributing factors are described adequately in the crash data, so cannot be used to add specificity to the sensitive crash set. However, unlike measures of efficacy in small scale simulations, observational studies and laboratory crash-dummy tests, measures of real-world effectiveness factor in the real-world situations where the technology does not cause a crash to be avoided. Therefore, the accuracy of the estimates of crashes avoided in this analysis are dependent upon how closely the sensitive crash set matches the crash set used to create the effectiveness rating.

The real-world effectiveness for the sensitive set of crashes gives an indication of the proportion of sensitive crashes within the crash dataset which could be avoided with vehicle fitment. It is a conservative estimate in that active technologies which fail to prevent a crash, may mitigate injuries through impact speed reduction. This study does not capture injury mitigation from active safety systems with the exception of injuries avoided by pedestrian-AEB systems, general AEB systems acting on only broadly sensitive crashes, and vehicle-to-pedestrian and vehicle-to-bicycle communication systems. For these exceptions, literature effectiveness was available only as injury reductions (and not crash reductions).

Crashes avoided from active technology fitment were calculated for the projected years 2017 to 2030. With each new projected crash year beyond 2016, the year of manufacture was advanced by one, and the probability of the technology fitment was matched to the new year of manufacture. **Avoided sensitive crashes were estimated for each crash by the product of the fitment probability in the sensitive vehicle and the technology effectiveness.** The theoretical proportion avoided for each crash was then aggregated by crash year, crash severity, location, market group and crash type to produce aggregate estimates of crashes avoided. This methodology has purposefully been kept simple as it is primarily being used to identify future safety priorities, rather than to comprehensively quantify the potential savings to society of vehicle safety technologies.

Estimation of crashes and injuries avoided by safety technology is secondary. Whilst the estimates may be used to clearly show the differential impact of each of the technologies and the differences by region and crash type, the estimate itself is not as easily interpreted. Each estimate is achieved under controlled crash conditions and circumstances, by merely manipulating the penetration of active safety technology into the fleet of crashed light passenger vehicles. The change in crashes is a measurement under the condition that all other factors do not change, which of course is not a real-world situation. In reality there are changes to climate, infrastructure, speed zones and traffic flow, as well as changing trends in drug and alcohol use, fatigue, immigration, and distances travelled, and changing distributions of vehicle age, driver age, urbanisation and vehicle types. All of these may additionally contribute to the net changes in crash rates and severity over time. Thus, the estimates of crashes avoided by active safety technology in light vehicles are not the net average overall expected crash reductions, but reductions specific to the technologies studied, under a specific set of crash conditions.

Crashes avoided have been calculated in an additive hierarchical manner, by effectiveness. This technique has been widely accepted and used in literature (Corben, Logan et al. 2009, Elvik 2009). When a crash was associated withsensitivity to more than one active technology, the most effective technology reduction was applied first. This was followed by the next most effective, where the effectiveness was applied to the proportion (not-avoided) remaining, and so on. In this analysis, effects have been considered independent, because only active technologies were being applied, and each active technology works in a different manner and usually on a different set of crashes.

The methods used on the crashes with multiple technology sensitivities were conservative and were likely to under-estimate the crashes avoided. This is because with each application of a crash effectiveness, the remaining un-avoided crashes were in reality likely to be better matched to the next technology. Thus, the remainder is likely to have a greater concentration of crashes sensitive to the next technology than the original sensitive crash set. If the remnant becomes more concentrated with sensitive crashes, then the applied effectiveness will under-estimate the crashes avoided.

Sometimes multiple sensitivities needed to be isolated by further disaggregation of the crash type. This was true when the sensitive crash set for literature effectiveness was structured with prior crash events or driver intent. Attempts were made to isolate the effects of ESC, lane change and lane departure warning systems, which shared some sensitive crashes in theory but in reality only one of the set of technologies would dominate the crash avoidance. For example, run-off road crashes may be caused by an initial loss of control. This is a situation where ESC would be effective. However, if the run-off road crash was due to a lane departure without a prior loss of control, a lane departure warning system would more effective than ESC. The effectiveness reductions applied to sensitive crashes in this study were generally sourced from evaluations independent of causation, so the proportions of run-off road crashes with or without prior loss-of control events, were inherent to the effectiveness rating. This was not the case for the same-direction crashes sensitive to both lane-change and lane-departure warnings where some of the literature sourced studies of real-world effectiveness were based on sensitive crash sets defined by the driver intent prior to the crash. To illustrate, consider a lane departure event which causes a same direction side-swipe crash. The cause could be an unintentional lane drift or an intentional lane change without due care and the LDW or BSD technology effectiveness is dependent on the driver intent. Jurisdictions with driver intent variables were used to approximate the proportion of intentional lane changes, and these proportions were used to adjust the sensitive crash pool prior to applying either the BSD or the LDW crash avoidance effectiveness. Details of this process are included int the supporting documentation: *Literature review and crash sensitivity.*

Crash data of the 2016 crash year presents only the crashes not avoided, even with the fitment of current technology in sensitive vehicles manufactured prior to 2017. However, if the fitment modelling used on the forecast crash data was applied to the 2016 crash data, crashes were predicted to be avoided. The crashes predicted to be avoided in the 2017 to 2030 projections were adjusted, to account for the "mis-forecasted" 2016 baseline. Adjustments to were not made to the forecasted crashes involving vehicles "*manufactured*" after 2016. By 2030, the adjustment amounted to less than 0.1% of the 2030 crashed vehicles.

The supporting documentation: *Literature review and crash sensitivity* contains more information on literature effectiveness and sensitive crash sets.

4.7 Crash types not sensitive to this set of active light vehicle safety technologies

Crashes not sensitive to any of the analysed set of active vehicle safety technologies were estimated and aggregated by crash type, crash severity, location and vehicle type. Additionally, the supporting documentation: *Literature review and crash sensitivity* contains a profile of the set of crash types not identified as sensitive to any of the active safety technologies reviewed.

4.8 Injuries avoided by passive safety and vehicle design

For each crash, the crash injuries of each severity and road user were considered reduced by the active technology in the same proportions as the crash. For each 2016 crash and injury severity, the proportion of injuries by road user type were determined. These 2016 proportions were applied to the 2017 to 2030 fatal and serious crash injuries not avoided by active technologies to estimate the injuries remaining by road user type. The remaining fatal and serious injuries that were estimated to be light vehicle front and rear occupant injuries, were further reduced by the projected estimated effects of passive safety technology and vehicle design. The ratio of the average annual crash fleet crashworthiness rating to the average 2016 crash fleet crashworthiness rating was calculated for each projected crash year**. The product of this ratio and the remnant fatal and serious light vehicle occupant injuries gave the estimate of injuries that were not avoided by passive safety and vehicle design.** The additional injuries avoided by passive safety technology and vehicle design could then be determined by subtraction.

Crash injuries avoided by passive safety technologies or vehicle design were aggregated by crash type, crash severity, location and vehicle type.

4.9 Injuries not avoided by vehicle safety technologies and vehicle design

Crash injuries not sensitive to vehicle design, passive safety technologies or active safety technologies were aggregated by crash type, crash severity, location and vehicle type. Additionally, analysis by intersection status and speed zone was carried out.

4.10 Crash Costs

The final step involved applying monetised values (listed in section 3.4) to the injuries avoided in 2030 relative to 2016 to estimate the savings to society attributable to vehicle safety technology.

5 BASELINE TRENDS

5.1 Crash trends over 2006 to 2016

Charts illustrating the trends of interest have been placed in the appendix (A.1) for those pursuing more detail.

Over 2006 to 2016, crash numbers were found to be static or decreasing for most of the crash types. The exceptions are noted here.

There was an upturn from 2014 for fatal crashes of the following types:

- forward-moving vehicle to pedestrian (Figure 33),
- multi-motor vehicle front-to-front,
- multi-motor vehicle front-to-rear (Figure 35) and
- for multi-motor vehicle front-to-side crashes involving only medium vehicles.

Fatal crashes were observed to increase over the period for the following types:

- multi-motor vehicle front-to-side crashes involving medium SUVs and
- single vehicle front-to-object crashes involving light vehicles or medium SUVs.

Serious injury crashes where the front or side of a forward-moving light vehicle hit a bicycle/moped increased on average over the period (Figure 32).

There has been a steadily increasing trend for serious injury crashes of the following types:

- multi-motor vehicle front-to-rear (Figure 36 & Figure 37)
- rural multi-motor vehicle front-to-front (Figure 37),
- rural single vehicle front-to-object (Figure 34),
- single SUV vehicle to pedestrian and
- front-to-side crashes involving small and medium SUVs.

Trends of increasing minor injury crashes were also observed in SU vehicle crashes for the increasing serious injury crash types above. In addition, trends of increasing minor injury crashes were observed for light sized vehicle involved crashes of the types:

- single vehicle front-to-object,
- single vehicle-to-bicycle/moped and
- multi-motor vehicle front-to-rear and front-to-front crashes.

Other than the effects of these increasing trends, crash type distribution did not change markedly over 2006 to 2016. Fatal crashes were dominated by

- single vehicle crashes into objects,
- multi-vehicle front-to-side collisions and
- front-to-front collisions.

In metropolitan regions, fatal single vehicle-to-pedestrian collisions were more frequent than fatal front-to-front collisions and in rural regions fatal single vehicle overturns were almost as frequent as front-to-side fatal collisions. In remote areas single vehicle overturns were the most frequent fatal crash type.

Serious injury crashes were most frequently

- front-to-front, front-to-side and front-to-rear multi-vehicle collisions and
- single vehicle crashes into objects.

These made up between 75 and 80 percent of all fatal and serious injury collisions.

In metropolitan regions, pedestrian serious injury crashes were as frequent as front-to-front multi-motor vehicle serious injury collisions. In rural regions single vehicle overturn serious injury crashes were almost as frequent as serious front-to-front crashes. In remote areas single vehicle overturns were the most frequent serious injury crash type.

Minor injury crashes were most frequently

- front-to-side and front-to-rear multi-vehicle collisions and
- single vehicle crashes into objects.

These three crash types amounted to just under three quarters of all light vehicle minor injury crashes. In metropolitan regions, the single vehicle-to-object crashes made up about ten percent of the minor injury crashes, in rural region areas they made almost 30% and in remote areas, a little over 20%. In remote areas single vehicle overturn minor injury crashes were more frequent than single vehicle-to-object minor injury crashes.

The proportion of fatalities by crash type, and the proportion of injuries by crash type were plotted against each other (Figure 6). The resultant chart shows the crash types contributing most to injuries on the right and the crash types contributing most to fatalities at the top. Points that fall above the diagonal are crash types with the highest degree of trauma because the proportion of fatalities that the crash contributes exceeds the proportion of injuries contributed.

The most severe crash types were forward-moving single vehicle (1- 3), multi-vehicle front-to-front (11), and front-to-pedestrian (7), however their contribution to injuries overall is small because only two of these crash types contributed to more than 5% of injury crashes.

Single vehicle frontal collisions (2) and front-to-front (11) multi-vehicle crashes were responsible for the most fatalities and 3rd and 4th most injuries, as such represent the biggest road trauma burden. The less severe crash types of front-to-side (10) and rear-end (9) were responsible for the most injuries. Furthermore, pedestrian crashes (7) were a stand out contributor to light vehicle crash fatalities.

In remote regions, single vehicle overturn and single vehicle frontal collisions were the largest contributors to fatalities and injuries, and front-to-rear collisions contributed to only about 7% of injuries. In rural regions, single vehicle frontal collisions were also the crash type contributing most to fatalities and injuries. In metropolitan regions pedestrian crashes contributed the most towards fatalities. Figure 38 (in the appendix) charts the trauma contributions of crash types by region.

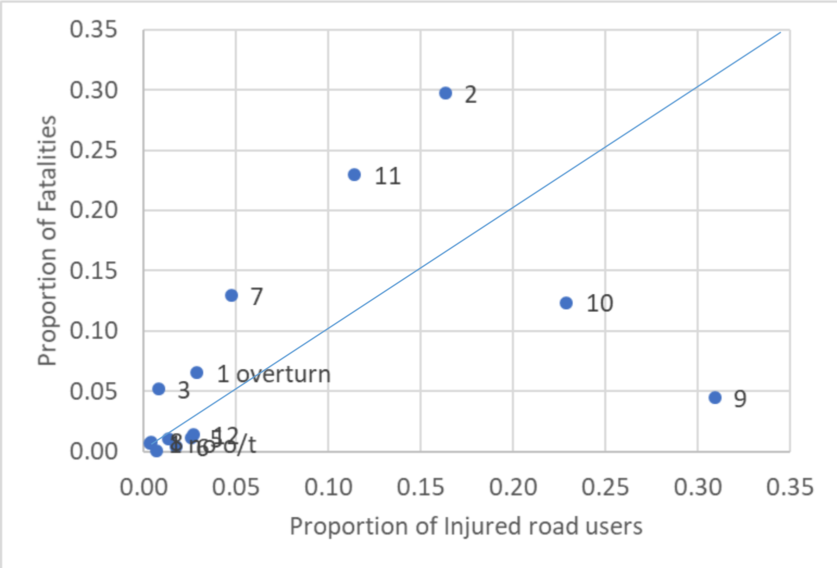


Figure 6 Proportion of injuries contributed by each crash type in 2016

Market group differences in the degree of severity observed by crash type were also observed for 2016. Points of interest are summarised by crash type.

Single vehicle frontal collisions with objects

- Injuries were less severe in large vehicle and people mover crashes and most severe in small vehicle crashes.
- Small vehicle crashes contributed to a proportion of fatalities which was noticeably more than the fleet average.
- Utilitiy crashes contributed to a proportion of injuries which was noticeably more than the fleet average.

Single vehicle side collisions with objects

- Injuries were most severe in light and large vehicle crashes.

Single vehicle overturns

- Injuries were most severe in utility, medium vehicle, people mover, small SUV and large SUV crashes.
- Utility, people mover, small SUV and large SUV crashes contributed to proportions of fatalities which were noticeably more than the fleet average.
- Utility and large SUV crashes contributed to proportions of injuries which were noticeably more than the fleet average.

Single forward-moving vehicle collisions with pedestrians

- Injuries were most severe in van, medium, small and people mover crashes.
- Vans, small, medium and people mover crashes contributed to proportions of fatalities which were noticeably more than the fleet average.

Single forward-moving vehicle collisions with bicycles and mopeds

- Injuries were most severe in van crashes where these crashes contributed to more to fatalities than the light vehicle fleet average.

Multi-motor vehicle front-to-front collisions

- Injuries were most severe in light, large and medium SUV crashes, where these crashes contributed to more to fatalities than the light vehicle fleet average.

Multi-motor vehicle front-to-side collisions

- The proportions of fatalities were never greater than the proportions of injuries for this crash type.
- Crashes involving medium vehicles, large and small SUVs and vans contributed to proportions of fatalities which were noticeably more than the fleet average.

Multi-motor vehicle side-to-side collisions

- Injuries were most severe in light (size) vehicle crashes, where these crashes contributed to a proportion of fatalities which was noticeably more than the fleet average, however, the proportions of both injuries and fatalities were very small.

Multi-motor vehicle front-to-rear collisions:

- The proportions of fatalities were never greater than the proportions of injuries for this crash type.
- Crashes with people movers, medium SUV and vans contributed to proportions of fatalities which were noticeably more than the fleet average.
- Crashes with people movers, vans and small and medium SUVs contributed to proportions of injuries which were noticeably more than the fleet average.

5.2 Trends in sensitivity to active technologies over 2006 to 2016

Trends in the distribution of sensitivity to active technologies were examined for each crash type. Some interesting trends emerged.

- Almost all single vehicle, overturn or collision with an object crash types, were sensitive to at least one active technology which was generally ESC, LDW or active headlights.
- If vehicle-to-bicycle communication technology was ignored, only a small percentage of bicycle/moped collisions were sensitive to active technologies.

- Emerging variations of AEB which target pedestrian or crossing paths crashes were significantly represented in the sensitive crashes, particularly for front-to-side and for pedestrian crashes.
- No light vehicle active technologies were able to prevent light vehicle collisions where the first event did not involve light vehicles; and no active technologies were able to prevent collisions with driverless vehicles such as when a parked car runs away. These contributed to 1% to 3% of all light vehicle crashes.

A crash was only counted once within each crash type distribution, so where a crash was sensitive to more than one technology, only the technology most effective at crash avoidance was presented. Stacked bar charts exhibiting the distribution of the most effective technologies within each crash type, crash severity and crash year may be found in the appendix (A.2). In these and subsequent charts, abbreviations are used for the active safety technologies as follows:

AEB	Autonomous Emergency Braking
AEB_Broad	This is used for crashes with lesser sensitivity to AEB
AEB_INTXN	AEB specifically configured for sensitivity to straight crossing path crashes
AEB_Ped	AEB specifically configured to detect pedestrians
BSD	Blind spot detection or lane change warning system
LDW	Lane departure warning or lane keep assist
ESC	Electronic Stability Control
BSD/LDW	Sensitivity to either LDW or BSD depending on the Intent of the vehicle movement (e.g. changing lanes).
ESC/LDW	Sensitivity to either LDW or ESC depending on the crash causation (e.g. loss of control event).
V2P	Intelligent systems that communicate between vehicle and pedestrian, facilitating detection of one to the other
V2B	Intelligent systems that communicate between vehicle and bicycle, facilitating detection of one to the other
V2P	Intelligent systems that communicate between vehicles, facilitating detection of one to the other

The injuries associated with crashes sensitive to technologies were aggregated by severity and *crash type* to determine the proportion of injuries in crashes sensitive to any active technology and highlight the crash types not being offered protection from active safety technologies. For all crash types except bicycle/moped crashes at least 80% of crashes were found sensitive to at least one technology.

5.3 Technologies best targeting fatalities

The injuries associated with crashes sensitive to technologies were aggregated by severity and *technology type* to determine both the proportion of fatalities from sensitive crashes of all crash fatalities, and the proportion of injuries from sensitive crashes of all injured road users. For each technology these two proportions were plotted against each other (Figure 7), the resultant chart shows the least sensitive technologies on the left and the least sensitive to fatal injuries at the bottom.

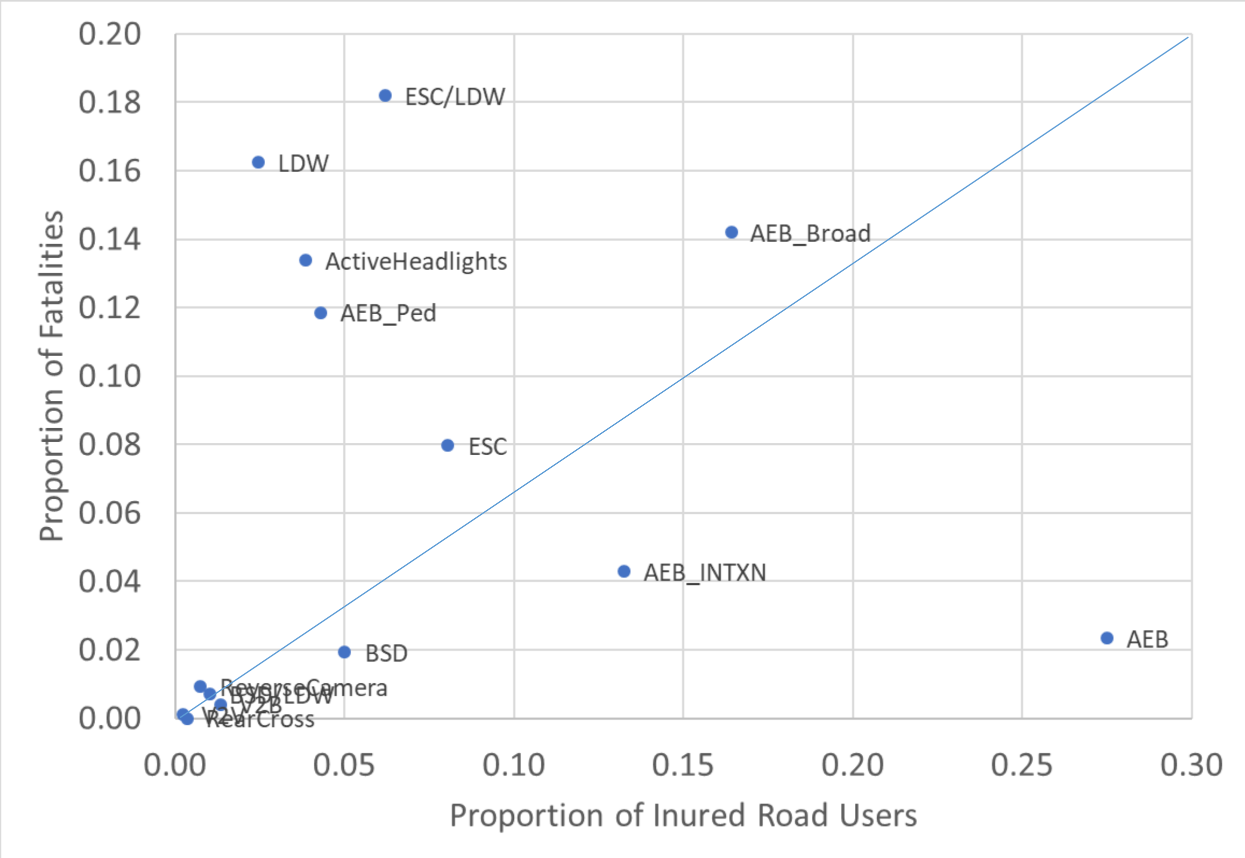


Figure 7 Rates of sensitivity by severity for active safety technologies in 2016

From this chart it is evident that more injury crashes are sensitive to AEB than any other active safety technology, however, these sensitive crashes are likely to lack severity. We also see that ESC, LDW, active headlights and pedestrian AEB are the technologies sensitive to the more severe crashes, however, they are sensitive to proportionally few injury crashes.

From this set of active technologies, the biggest future gains in injuries avoided will be from increased AEB fleet penetration and advances which increase the effectiveness of AEB; and the greatest gains in fatalities avoided will be from increased LDW fleet penetration and effectiveness.

The relationships expressed in Figure 7 were plotted for crash types, regional and market group subsets. The complete set of charts summarised in the paragraphs following may be found in the appendix (A.3).

By market group the patterns of sensitivity varied. For example, fatal crashes broadly sensitive to AEB addressed a greater proportion of fatalities than other systems for crashes involving commercial vans, people movers, medium, and large and medium SU vehicles.

For other market groups, the greatest proportion of fatalities were sensitive to ESC or LDW technologies. Furthermore, pedestrian AEB systems were second best in addressing fatalities for crashes involving people movers and vans.

In remote and rural regions and for single motor vehicle crashes (without pedestrians, bicycles and mopeds) both injury and fatal injury crashes were most sensitive to ESC/LDW technologies.

In metropolitan regions, AEB technology offered the best protection with the greatest proportion of fatalities sensitive to pedestrian sensitive AEB and the greatest proportion of injuries narrowly or broadly sensitive to general AEB systems.

Forward-moving single vehicle collisions with pedestrians, motorcycles or mopeds were most sensitive to: pedestrian AEB, V2B and V2P for frontal collisions, lane change or lane departure systems for sideswipes, and reverse cameras for reversing collisions.

For multi-motor vehicle collisions, AEB sensitivity was best for all injury and fatal injury front-to-rear and front-to-side collisions. However, if the collision was front-to-side, the AEB system was either only broadly sensitive or it was a system specific to straight crossing path intersection crashes. For sideswipes, lane change systems addressed the most injury crashes and lane departure the most fatal crashes. The greatest proportion of fatal front-to-front crashes were addressed by lane departure systems.

5.4 Penetration of technology by year of manufacture

Fitment of technologies was modelled by year of manufacture and market group and merged onto crash data. Some technologies were not projected to penetrate efficiently into the light vehicle fleet. This may have been because of poorly perceived manufacturer or consumer value, quality control issues or poor real-world performance. It is recommended that other investigations be carried out to answer the question: “What drives the natural penetration of safety technologies?”

Some interesting issues arose from analysis of the fitment models.

- Commercial vehicles consistently trailed in the projected uptake of active and passive safety systems. In many cases, the current fitment was too low to model projected uptake by individual market groups and broader groupings had to be employed. Vans fared worse in this regard. This is of concern when the high proportion of vehicle kilometres travelled by this market group is considered.
- High speed and pedestrian AEB technology uptake trailed the low speed AEB uptake. This is of concern because most injury crashes arise from forward collisions into other vehicles and higher speed and pedestrian crashes result in the greatest severity of road trauma.
- Generally side and reverse collision mitigation systems had poorer fitment projections than for forward collision mitigation. Because of poor projected fitment, crash reductions predicted from side and reverse collision mitigation systems were not modelled in this analysis.
- Other technologies not modelled in this analysis included systems which addressed speed, fatigue and inattention. These projected well only for medium and large vehicles, and overall speed technologies were projected with some of the poorest uptakes. Speed, fatigue and inattention are often used as explanations of our increasing road toll, so it is interesting that the fitment

projections were not ideal for these technologies. Perhaps the penetration lagged because of a general lack of consumer interest in technologies which have a strong emphasis on behaviour modification.

- Projections for technologies addressing pedestrian injury were poorer than for vehicle occupants. These included, Night Vision, Pedestrian AEB, Active Hoods and Pedestrian Airbags. This is of concern as pedestrians are the most vulnerable road user and pedestrian crashes were the greatest contributor to metropolitan road fatalities.

Details of penetration by year of manufacture may be found in the supporting documentation: *Fitment analysis*.

5.5 Penetration of technology by crash year

This section summarises the penetration trends observed in the projected crash data by crash year. This was observed separately for each crash severity in Figure 8, Figure 9 and Figure 10. By 2030, it is expected that the greatest penetration within the Australian light vehicle fleet will be achieved by ESC with at least 70% fitment. It is closely followed by reversing camera technology. Lane keeping, lane changing, AEB, active headlights and rear-cross systems lag behind with an expected 40-50% fitment by 2030. Relatively poor penetration of pedestrian AEB and telematics were predicted by 2030.

There were no fatal crashes deemed sensitive to rear-cross alert systems.

In these figures, AEB refers to all AEB technologies except those specifically designed for pedestrian detection.

In 2016, both active headlights and lane departure warning systems were barely present in commercial models and (Figure 59 shows that) in 2016, fatal and serious injury crashes involving commercial utilities were most sensitive to these two technologies. Thus large decreases in serious injury from light commercial vehicle crashes is possible with better future fitment of LDW and active headlights.

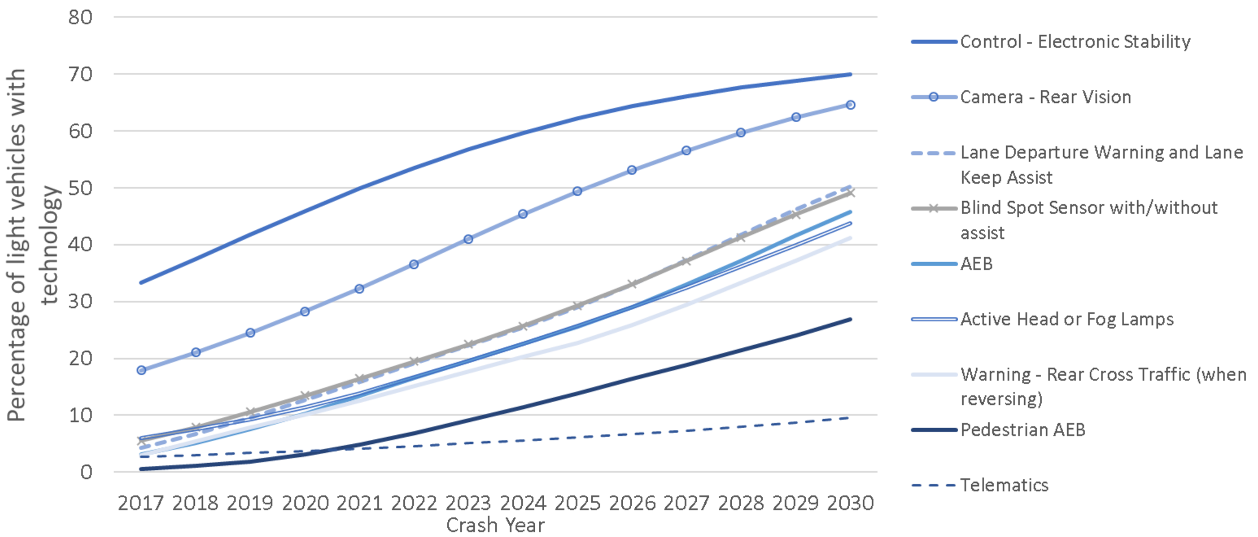


Figure 8 Penetration of active safety technologies into light vehicles of *__fatal__* *crashes*

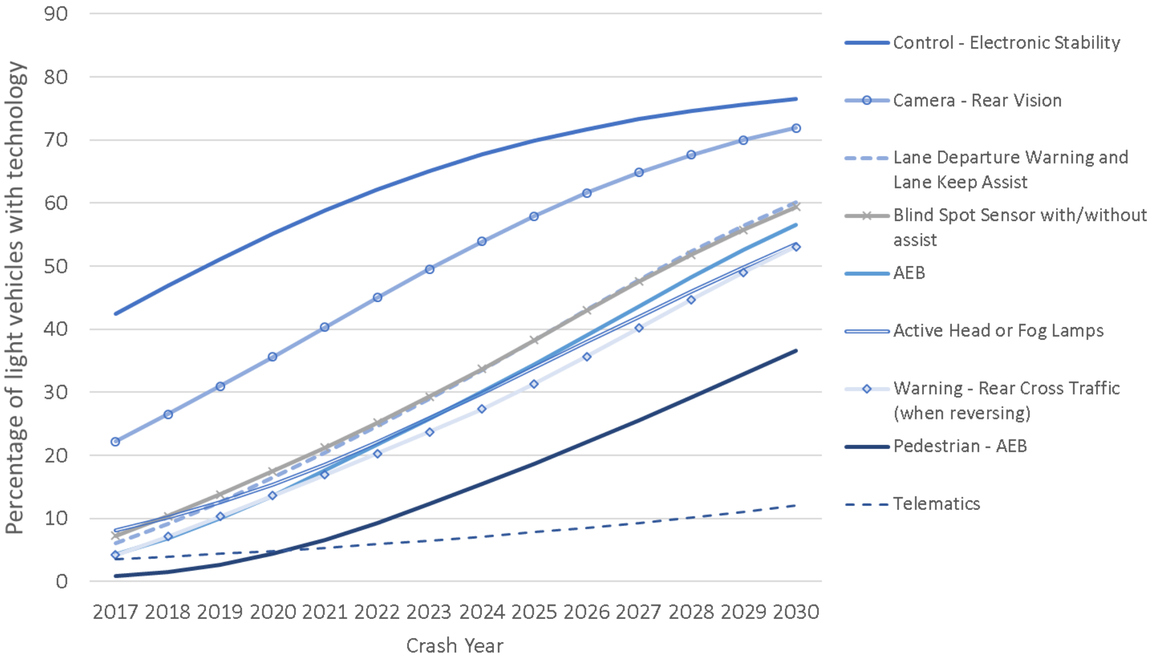


Figure 9 Penetration of active safety technologies into light vehicles of serious injury crashes

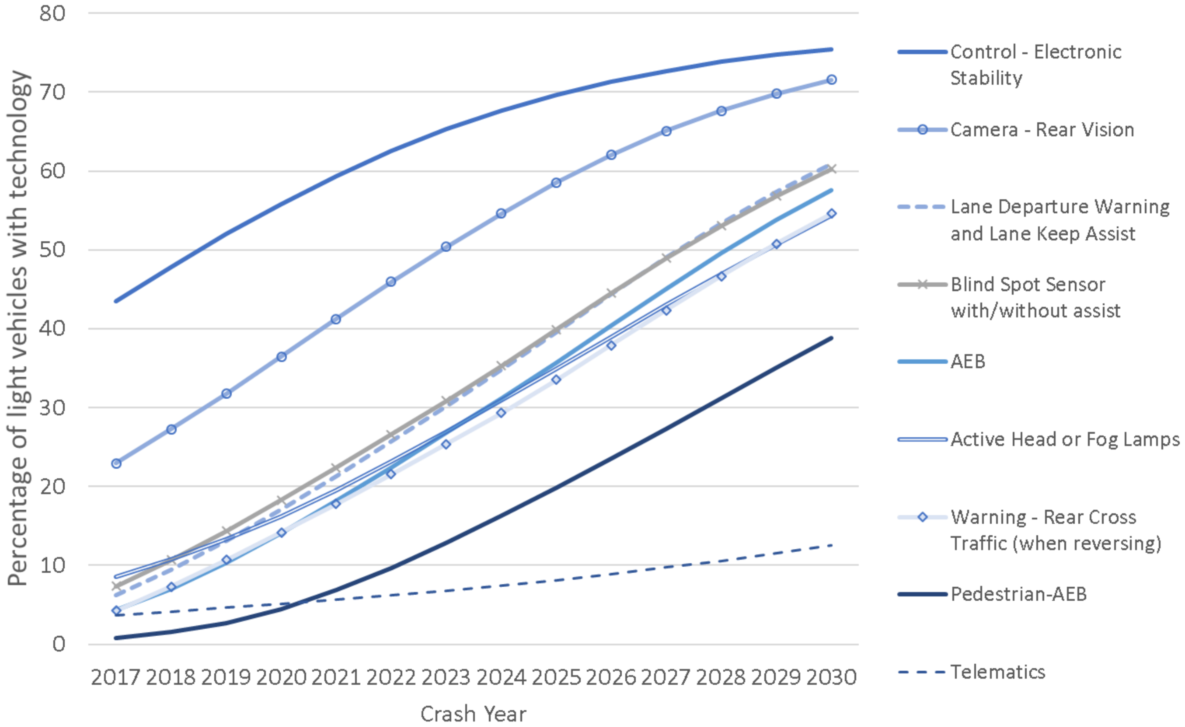


Figure 10 Penetration of active safety technologies into light vehicles of minor injury crashes

5.6 Summary of Baseline trends

5.6.1 Crash types where improvements are not being made

- Forward-moving frontal or side collisions with bicycles/mopeds.
- Forward-moving fatal and SUV non-fatal collisions with pedestrians.
- Forward-moving vehicle-to-object fatal collisions involving medium SUV or light vehicles and minor injury collisions of this type involving light vehicles.
- Multi-motor vehicle front-to-rear fatal and serious injury collisions generally, and minor injury collisions involving only SUVs or light vehicles.
- Multi-motor vehicle front-to-side fatal medium vehicle and injury SUV collisions.
- Multi-motor vehicle front-to-front fatal, rural serious injury, and minor injury collisions, where the minor injury collisions involve either light vehicles or rural SUVs.

5.6.2 Most serious crash types

- Forward-moving vehicle-to-object collisions. Vehicle types where this crash had highest severity were small and light vehicles.
- Multi-motor vehicle front-to-front. Vehicle types where this crash had highest severity were light vehicles and medium and large SUVs.
- Forward-moving collisions with pedestrians in metropolitan regions. Vehicle types where this crash had highest severity were vans, medium, small and people movers.
- Single vehicle overturns in remote regions. Vehicle types where this crash had highest severity were medium vehicles, utilities, people movers, and small and large SUVs.

5.6.3 Crash types contributing most to injury

- Forward-moving vehicle-to-object collisions contributed greatly to fatal, serious and minor injuries.
- Multi-motor vehicle front-to-side collisions contributed greatly to fatal, serious and minor injuries.
- Multi-motor vehicle front-to-front contributed greatly to fatal and serious injuries.
- Multi-motor vehicle front-to-rear collisions contributed greatly to serious and minor injuries.
- Forward-moving collisions with pedestrians contributed greatly to fatal and serious injuries in metropolitan regions.
- Single vehicle overturns contributed greatly to fatal and serious injuries in rural regions and greatly to fatal, serious and minor injuries in remote regions.

5.6.4 Crash types with poor sensitivity to light vehicle active safety technologies

Bicycle and moped collisions, crashes with no light vehicle in the first collision event and single vehicle crashes with no driver.

6 CRASHES PREVENTED BY ACTIVE SAFETY TECHNOLOGY

In 2030, 207 fatal crashes, 3,369 serious injury crashes and 8,492 minor injury crashes were projected to be avoided because of active safety technology penetration above the levels in 2016. These savings amount to $2 091 million dollars of social road crash costs.

Table 1 and Table 2, compare 2016 crashes with 2030 crashes after modelling the penetration of active safety technologies into the crashed light vehicle fleet. The tables present summaries by crash severity, location and broad market group. Table 1 additionally profiles the crashes not avoided. The remaining crashes have been divided into sensitive and not sensitive groups where '*sensitive'* refers to sensitivity to any active-safety technology. It may be seen that of the remaining crashes, most were considered to have some sensitivity to active technologies, and were *not* avoided due to no fitment or ineffectiveness, leaving room for improvements in crash avoidance beyond 2030 from increased fitment and effectiveness.

The same trends in 2016 crashes, by crashed light vehicle market groups and locations, were observed for the projected 2030 avoided crashes, with one exception. SUV crashes ranked least as a contributor to fatal crashes, but LCV crashes ranked least in fatal crashes avoided through active safety technologies. This may be explained directly by the poorer penetration of active technologies expected for the light commercial vehicle market.

Table 1 Projected 2030 injury crashes avoided through active safety technologies: overall and by region

	Fatal				Serious				Minor			
	All	Metro	Rural	Remote	All	Metro	Rural	Remote	All	Metro	Rural	Remote
Crashes (2016)	903	327	550	26	15,494	9,742	5,662	90	33,409	24,556	8,733	120
2030 projections Crashes Reduced	207	54	147	5	3,369	2,007	1,351	11	8,492	6,236	2,236	19
range	51 to 306	16 to 80	34 to 218	1 to 8	1,160 to 4,748	784 to 2,807	344 to 1,925	1 to 15	4,120 to 11,125	3,049 to 8,289	1,060 to 2,815	10 to 21
Remaining crashes in 2030	696	273	403	21	12,125	7,735	4,311	79	24,917	18,320	6,497	101
range	597 to 852	247 to 311	332 to 516	18 to 25	10,746 to 14,334	6,935 to 8,958	3,737 to 5,318	75 to 89	22,284 to 29,289	16,267 to 21,507	5,918 to 7,673	99 to 110
% reduction	23	17	27	19	22	21	24	12	25	25	26	16
range	6 to 34	5 to 24	6 to 40	5 to 32	7 to 31	8 to 29	6 to 34	1 to 17	12 to 33	12 to 34	12 to 32	8 to 18
% Sensitive and not prevented	69	69	68	79	64	63	66	79	62	62	64	72
% not prevented and not sensitive	8	14	5	2	14	16	10	9	13	13	10	12

Table 2 Projected 2030 injury crashes avoided through active safety technologies: by involved market type

	Fatal				Serious				Minor			
	small and light	PM, medium and large	SUV	LCV	small and light	PM, medium and large	SUV	LCV	small and light	PM, medium and large	SUV	LCV
Crashes (2016)	218	264	155	168	5,800	4,994	3,160	2,696	15,093	12,442	8,039	5,753
<u>2030 projections</u>												
Crashes Reduced	63	83	49	42	1,583	1,318	922	671	4,734	3,754	2,586	1,675
range	18 to 96	22 to 124	11 to 69	11 to 63	688 to 2179	516 to 1858	320 to 1241	253 to 942	2405 to 6205	1866 to 4929	1329 to 3292	811 to 2164
Remaining crashes in 2030	155	181	106	126	4,217	3,676	2,238	2,025	10,359	8,688	5,453	4,078
range	122 to 200	140 to 242	86 to 144	105 to 157	3621 to 5112	3136 to 4478	1919 to 2840	1754 to 2443	8888 to 12688	7513 to 10576	4747 to 6710	3589 to 4942
% reduction	**29**	**31**	**32**	**25**	**27**	**26**	**29**	**25**	**31**	**30**	**32**	**29**
range	8 to 44	8 to 47	7 to 44	7 to 37	12 to 38	10 to 37	10 to 39	9 to 35	16 to 41	15 to 40	17 to 41	14 to 38
% Sensitive and not prevented	63	60	58	66	62	64	60	64	60	62	60	64
% not prevented and not sensitive	8	9	10	9	11	10	11	11	9	8	8	7

Figure 11 compares the 2016 and projected 2030 distributions of types of crashes <u>not</u> avoided by active safety technology by crash severity and region. Practically no differences in crash distributions of any severity were projected for remote regions; the small observable differences could be explained by random variation given the low crash frequency in remote regions. In metropolitan and rural regions, active safety technologies were projected to noticeably decrease the proportion of single forward-moving vehicle collisions across all severities, as well as serious and minor front-to-rear collisions. Conversely the proportions of bicycle/moped, fatal pedestrian, serious and minor front-to-front, minor front-to-side and fatal and serious <u>rural</u> front-to-side and pedestrian crashes were predicted to noticeably increase.

Figure 2 compares the number of 2016 crash injuries with those avoided from projected 2030 active and passive safety technologies, by severity and region. It shows that currently rural regions contribute to most fatalities and metropolitan regions are the locations of most non-fatal crash injuries. These trends were replicated in the injuries avoided through active safety technologies. However, more serious injuries were avoided through the additional effects of passive safety technologies (on crash injuries *not* avoided through active safety technologies) in rural areas than in metropolitan regions. The greater proportions of vulnerable road user injuries in metropolitan areas offer an explanation for this trend reversal, since motorcyclist, pedestrian, bicyclist and moped rider injuries were not impacted by the methods used to estimate passive safety technology savings. In terms of proportion avoided, more than a third of fatalities and serious injuries were expected to be avoided in 2030, with the greatest proportions of both in rural regions. More than a quarter of all minor injuries were predicted to be avoided, with similar proportions in rural and metropolitan regions.

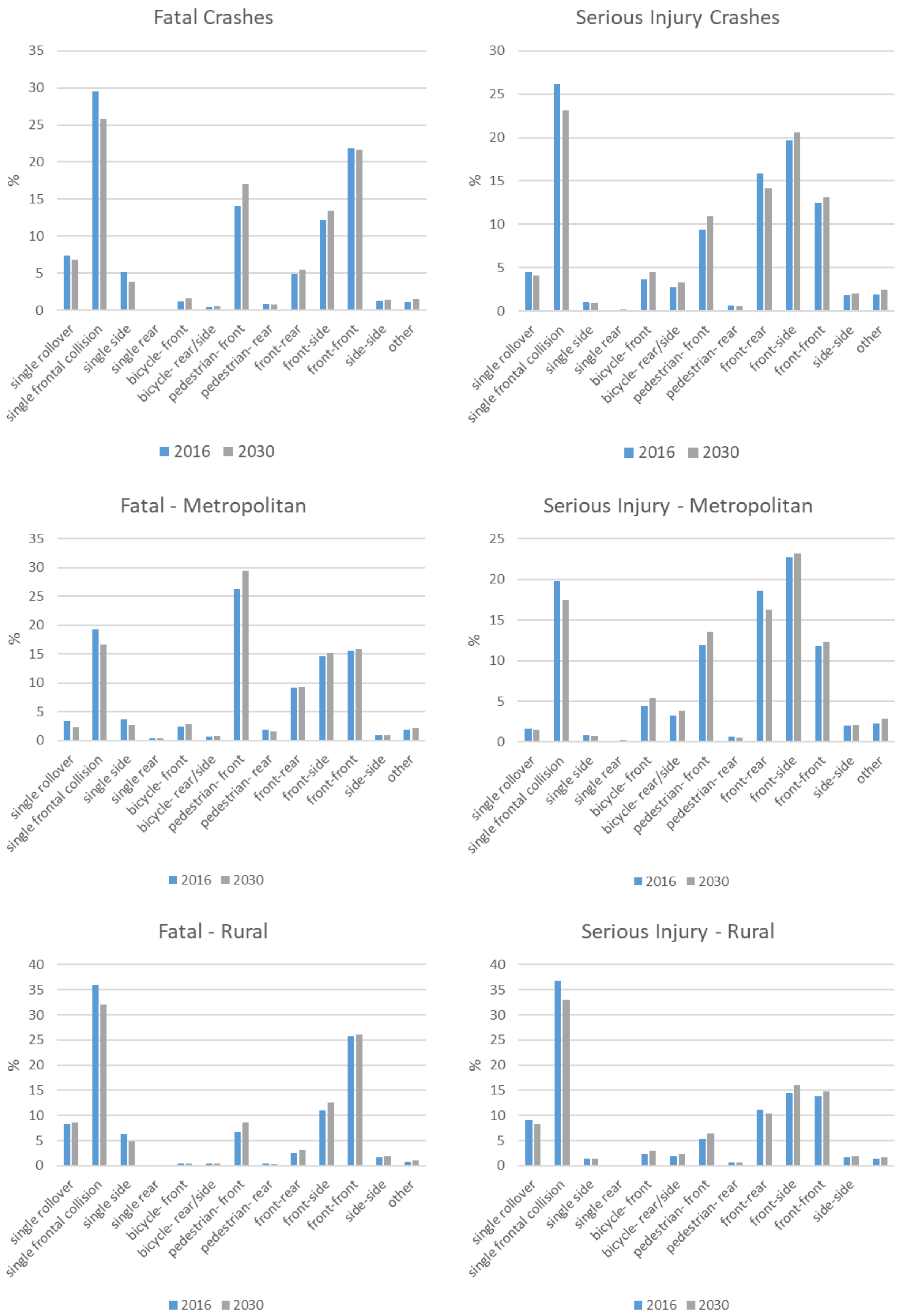


Figure 11 2016 & projected 2030 distribution of injury crash types for fatal and serious injury crashes for all crashes and by metropolitan and rural regions

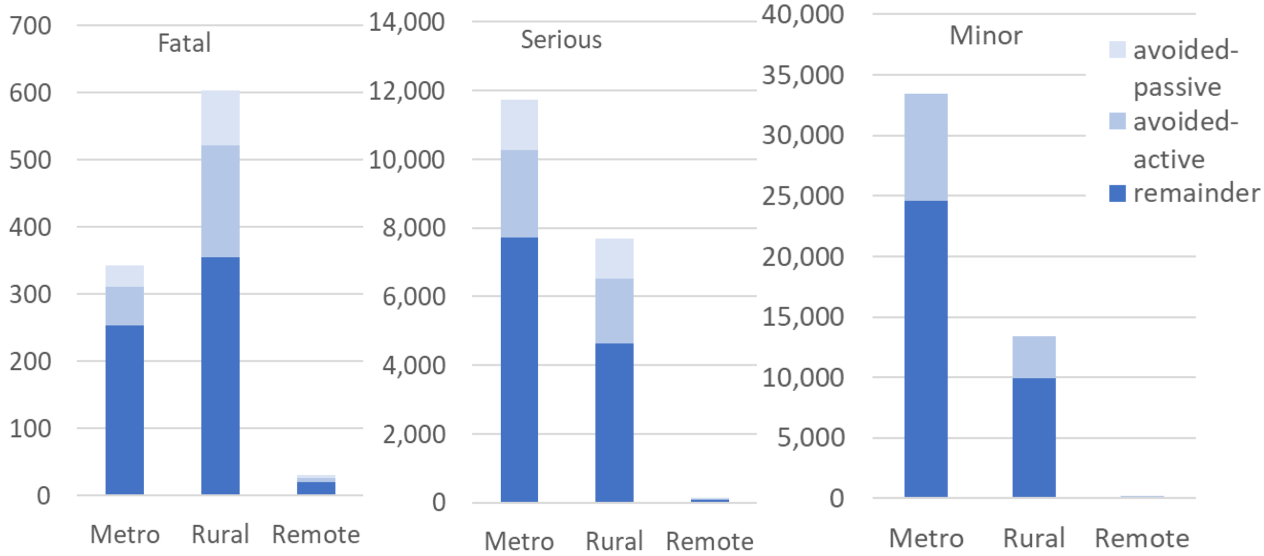


Figure 12 2016 Crash injuries by location and severity disaggregated by vehicle safety technology projections in 2030

6.1 Active vehicle technologies which best address the baseline crash trends

Given the technology penetration projections, the baseline crash trends and the most common fatal crash types, fatalities were predicted to be best addressed by LDW, ESC and active headlights; and overall injuries were predicted to be best addressed by AEB systems. In 2030, LDW and ESC systems were projected to prevent about 120 fatal crashes. ESC gave the greatest absolute benefits across severity levels, preventing in 2030, an additional 1800 minor injury crashes and 1400 serious injury crashes. However, AEB was projected to perform best for non-fatal injury crashes with projections in 2030 to prevent almost 1800 serious injury and 6000 minor injury crashes.

Single vehicle fatal crashes were greatly sensitive to ESC, LDW and active headlights. ESC was projected to be in almost 100% of all new vehicles except vans by 2020 and projected to have fitment of greater than 70% in all light vehicles by 2030, however both LDW and active headlight penetration were only expected to have 50 to 60% of the crash fleet penetration that ESC has by 2030. Furthermore, penetration was expected to lag considerably in both utilities and vans. This means that the benefits of LDW and active headlights may grow considerably beyond 2030 with potential improvements in efficacy and fitment. This is not true for ESC because ESC fitment in crashed vehicles was observed to have plateaued (Figure 8, Figure 9 and Figure 10), so the crashes prevented by ESC are not expected to rise much in the years beyond 2030. This means that large future improvements in the prevention of loss of control crashes will not be achieved with just ESC technology. ESC, lane departure warning and active headlight technologies target the most serious crash types and many of the crash types identified with increasing crash rates (5.1), so future priorities will need to address the crashes not avoided by these technologies.

The technology most sensitive to fatal multi-vehicle crashes varied by crash type; for some it was lane change or lane keeping technologies, for others it was AEB. However, AEB was the most productive in the avoidance of (any) injury crashes in forward-moving vehicles. By 2030, about half of all light vehicles were expected to be fitted with this technology.

Furthermore, of the crash types contributing most to crash injuries, most were narrowly or broadly sensitive to one of the AEB systems. The AEB fitment curves of Figure 8, Figure 9 and Figure 10 have not flattened, thus further improvements in crash prevention, from natural penetration of AEB, beyond 2030 are likely. If development of this technology continues on track, AEB effectiveness is expected to greatly improve in the near future with respect to pedestrian, 'straight crossing paths' and 'right turn across path' situations and with respect to travel speed limitations. Thus the AEB family of active safety systems are likely to continue to best address avoidance of future non-fatal injury crashes.

Figure 13 details by crash year and severity, the crashes projected to be avoided through active safety technologies from 2017 to 2030.

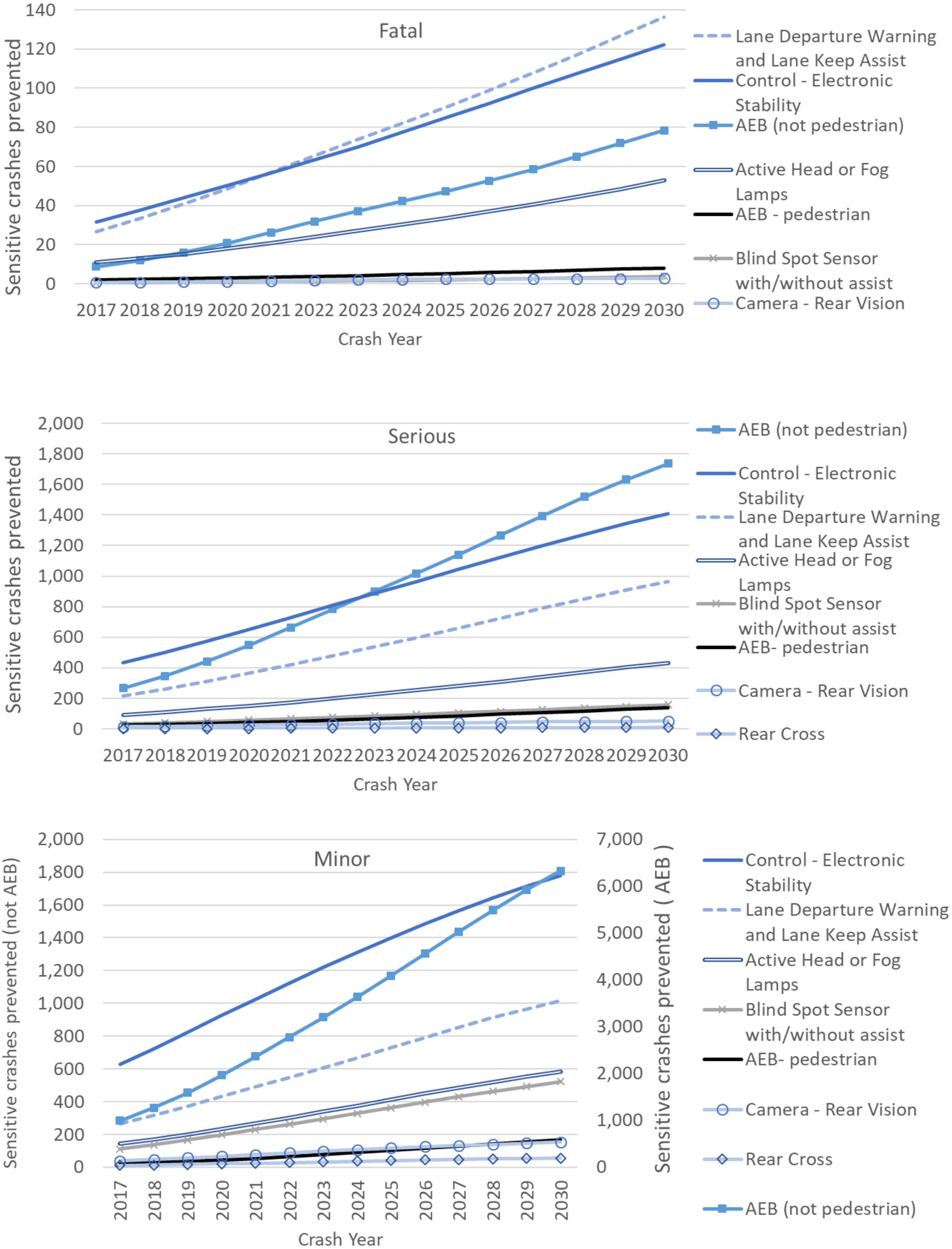


Figure 13 Crashes sensitive to active safety technologies predicted to be avoided, by crash severity

6.2 Crash types addressed by active safety technologies

Crashes avoided through active safety technologies were estimated for the crash years 2017 to 2030. These were expressed as a proportion of type by severity in Figure 15 to Figure 23.

Figure 15, Figure 16 and Figure 17 detail, by crash year, crash type and severity, the forward-moving, single-vehicle crashes projected to be avoided through active safety technologies from 2017 to 2030.

Figure 18, Figure 19 and Figure 20 detail, by crash year, crash type and severity, the forward-moving, multi-(motor) vehicle crashes projected to be avoided through active safety technologies from 2017 to 2030.

Figure 21, Figure 22 and Figure 23 detail, by crash year, crash type and severity, the reversing vehicle crashes projected to be avoided through active safety technologies from 2017 to 2030.

The 2016 distribution of crashes by severity has been provided in appendix A.4, Table 5, so that 2030 projections of absolute crash reductions may be calculated.

The greatest absolute reductions in forward-moving fatal and serious injury crashes by type were for single vehicle collisions and overturns and these crashes were projected with the greatest relative injury crash reductions; approximately a third of the 2016 crashes of this type were expected to be avoided by 2030.

Table 3 presents projected relative 2030 crash reductions from active safety technology by region, crash severity and crash type. Blank cells indicate no crashes in 2016. The multiple rows, presented for crash types 1, 6, 9 and 10, indicate additional disaggregation, usually for direction of travel. This table highlights the poorer avoidance of reversing type 4, bicycle/moped type 5 & 6, pedestrian type 7, front-to-side type 10 and side-to-side type 12 collisions, as areas for future active safety technology development. Figure 14 shows the table in graphic form. Figure 14 clearly shows that except for pedestrian and bicycle/moped crashes, most remaining fatal crashes by crash type were in rural regions and mostly from single vehicle, front-to-front and front-to-side collisions.

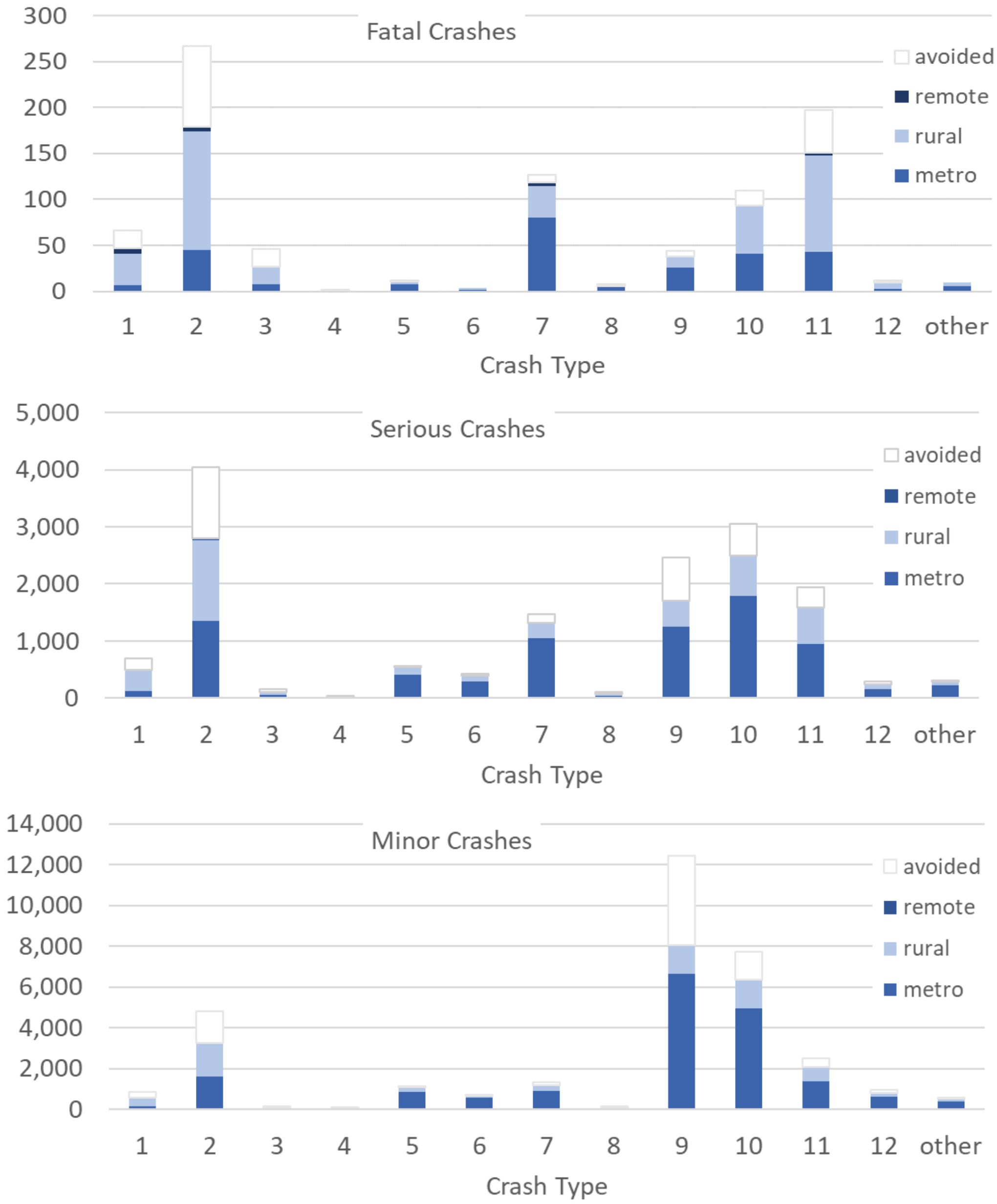
Percentage crash reductions for multi-motor vehicle crashes were generally not as great as those achieved for single vehicle crashes; by 2030 reductions of around 15% were expected for front-to-front, front-to-side and side-swipe collisions, although a quarter of fatal front-to-front crashes were expected to be avoided by 2030. Additionally, about 15% of fatal front-to rear crashes were expected to be avoided by 2030, however, for this crash type, at least an additional 20% of serious and minor injury crashes were expected to be avoided by 2030. In absolute terms, 2030 injury crash avoidance was greatest for front-to-rear crashes, however for the most part fatal front-to-rear crashes were not avoided.

Active safety technologies, over all severities, achieved the greatest proportion of avoidance with *reversing vehicle-to-pedestrian* crashes. By 2030, the avoided reversing crashes approximated 35% for pedestrian targets, 25% for other moving motor-vehicle targets, 15% for bicycle/moped targets and 10% for object (including parked vehicle) targets.

Although by 2030 much improvement was observed for reversing pedestrian collisions, further improvements for reversing crashes generally with active safety technologies appears limited. Unlike the forward-moving crash avoidance curves of Figure 15 to Figure 20, which show steady, increasing improvement over 2017 to 2030, the reversing crash avoidance curves of Figure 21, Figure 22 and Figure 23 have either plateaued or are flattening. This indicates that given current effectiveness and given projected fitment, there is likely to be only very small improvements beyond 2030 for avoidance of reversing crashes. The high levels of penetration of reversing cameras in the 2030 crashed fleet (Figure 8, Figure 9 and Figure 10) amongst crashes with a high degree of sensitivity (Figure 45, Figure 48, Figure 51) offers explanation.

Table 3 Projected 2030 injury crash percentage reduction from active safety technology: by involved crash type

		Fatal				Serious				Minor			
		All	Metro	Rural	Remote	All	Metro	Rural	Remote	All	Metro	Rural	Remote
1	Single motor Vehicle - overturns	30	48	28	22	31	29	33	19	36	34	38	28
	Single motor vehicle, no collision, no overturn	10	0	5	43	11	14	10	0	27	26	30	8
2	Single motor vehicle - front impact into parked vehicle or fixed/moving object	33	28	35	13	31	30	32	17	33	32	34	25
3	Single motor vehicle - forward moving but rear or side impact	41	39	42		28	28	27		35	33	36	
4	Single motor vehicle - reversing & impact into parked vehicle or fixed/moving object	17	17			9	9	11		11	10	12	
5	Single motor vehicle to bicycle/moped- front	1	1	0	1	4	4	3	0	5	6	4	0
6	Single motor vehicle to bicycle/moped- side	0	0	0		5	5	5	0	6	6	5	
	Single motor vehicle to bicycle/moped- reverse					15	17	11		17	17	17	
	Single motor vehicle to bicycle/moped- bicycle runs into rear	0	0			2	2	3		5	6	0	
7	Single motor vehicle to ped- forward	6	7	6	1	10	10	8	1	12	13	9	0
8	Single motor vehicle to ped- reverse	32	29	41		35	35	36		34	34	34	
9	Multi-motor vehicle - Front-to-rear forward same direction	14	16	12		31	31	29	2	35	36	33	10
	Multi-motor vehicle - rear to front reverse					30	31	29		27	28	24	
10	Multi-motor vehicle - Front-to-side	15	14	16	29	18	19	16	7	18	18	16	7
	Multi-motor vehicle - reversing right angle	5	5			20	19	33		29	29	26	
11	Multi-motor vehicle - Front-to-front	24	15	26	48	18	18	18	0	16	17	15	23
12	Multi-motor vehicle - side swipe	18	11	21		14	13	16	0	15	14	16	4
other	Multi-motor vehicle - Rear-to-rear					27	23	66		25	27	19	



1	single rollover	5	Bicycle/moped-front	9	front-rear
2	single frontal collision	6	Bicycle/moped-rear/side	10	front-side
3	single side	7	pedestrian-front	11	front-front
4	single rear	8	pedestrian-rear	12	side-side

Figure 14 2016 Injury crashes by location and severity disaggregated by active vehicle safety technology projections in 2030

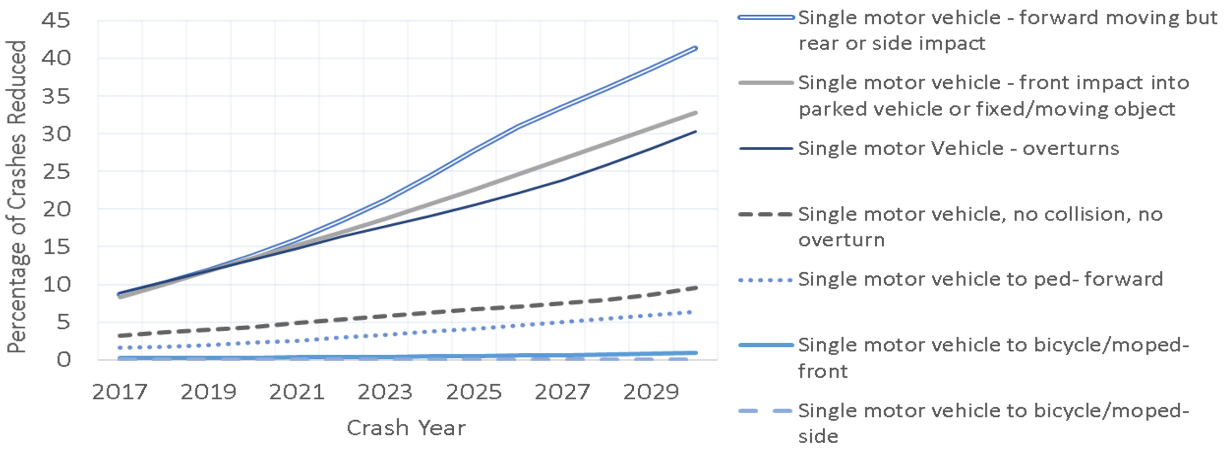


Figure 15 Percentage of fatal single vehicle forward-moving crashes avoided through additional active safety technology penetration

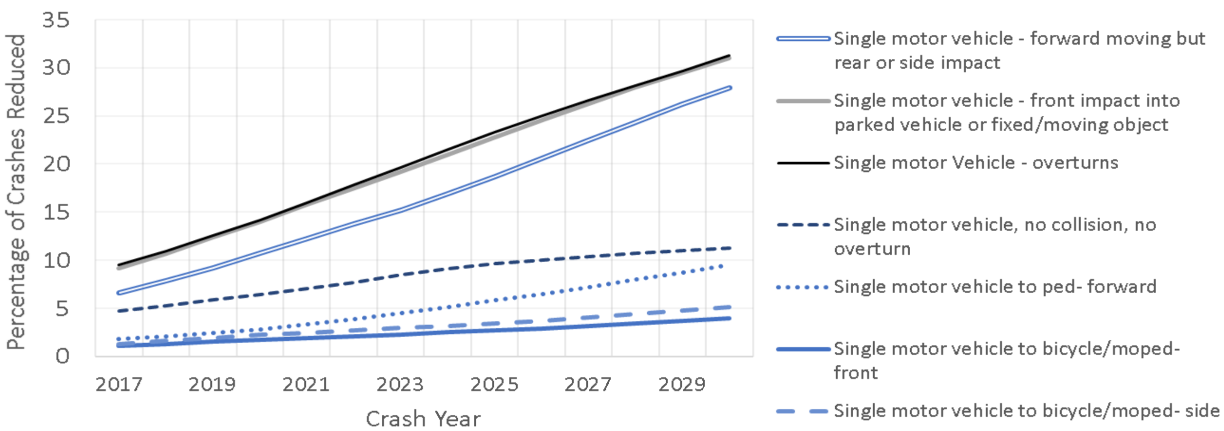


Figure 16 Percentage of serious injury single vehicle forward-moving crashes avoided through additional active safety technology penetration

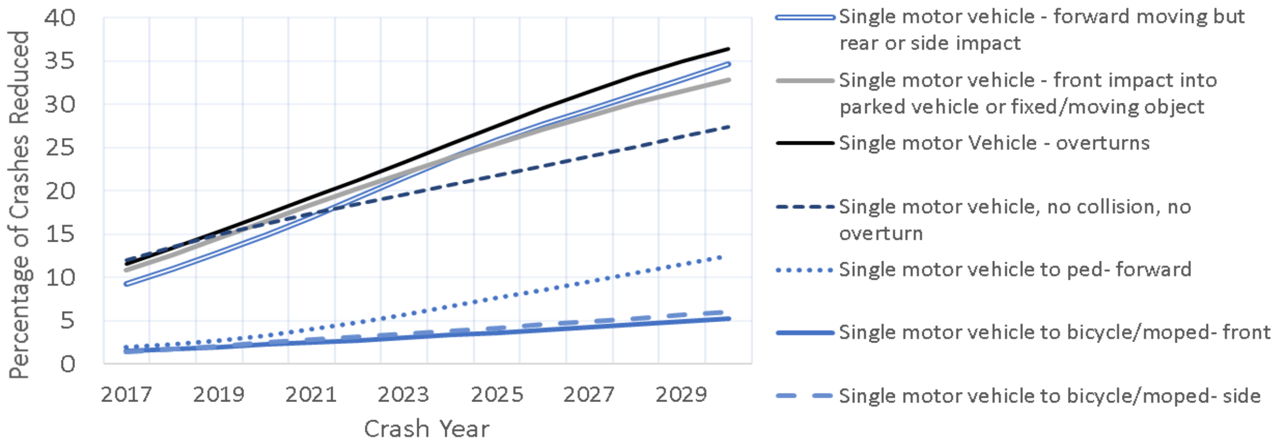


Figure 17 Percentage of minor injury single vehicle forward-moving crashes avoided through additional active safety technology penetration

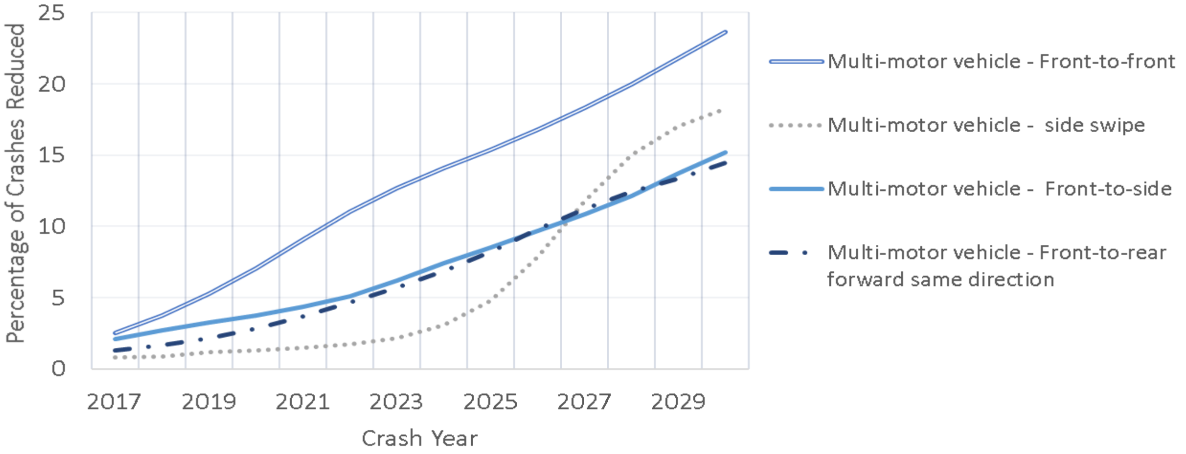


Figure 18 Percentage of <u>fatal</u> forward-moving multi-motor vehicle crashes avoided through additional active safety technology penetration

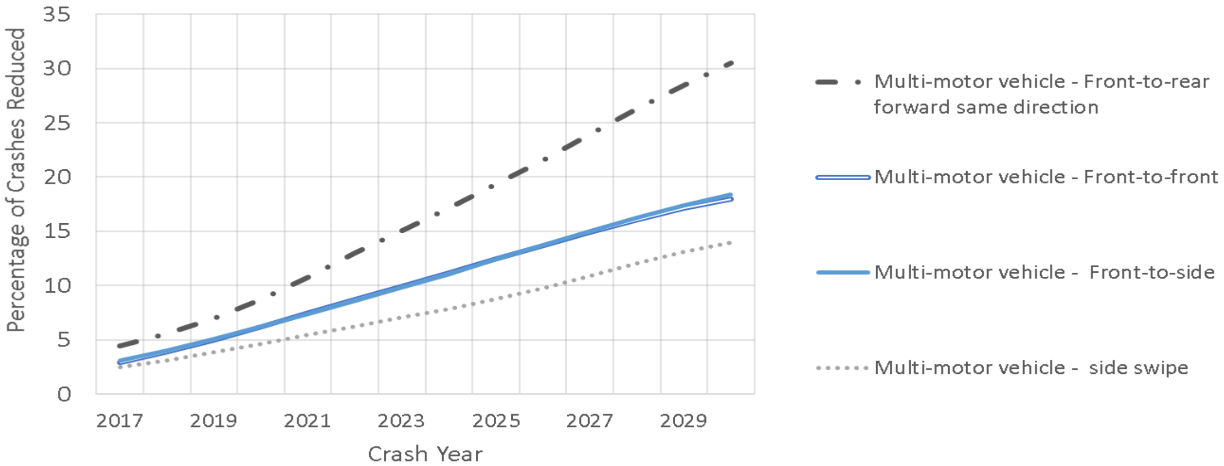


Figure 19 Percentage of <u>serious</u> <u>injury</u> forward-moving multi-motor vehicle crashes avoided through additional active safety technology penetration

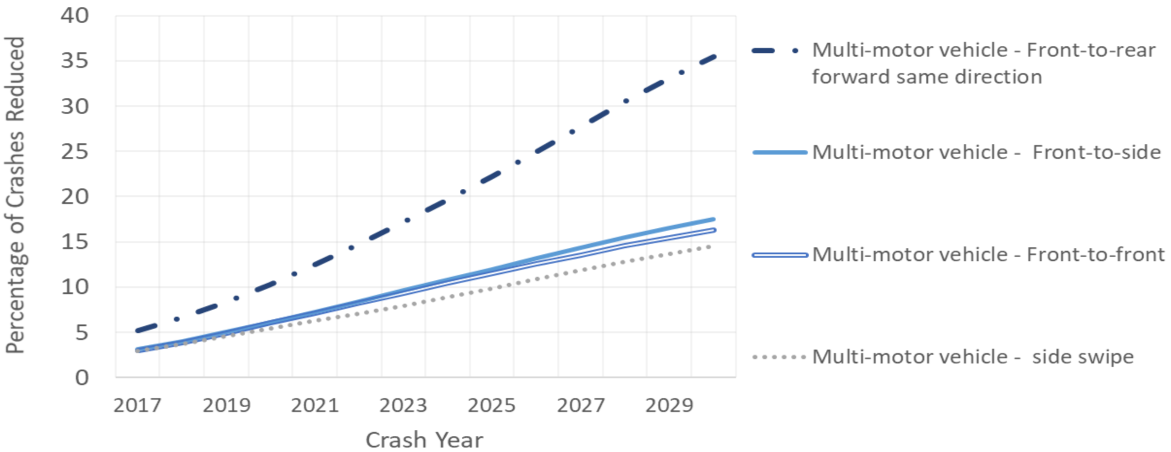


Figure 20 Percentage of <u>minor</u> <u>injury</u> forward-moving multi-motor vehicle crashes avoided through additional active safety technology penetration

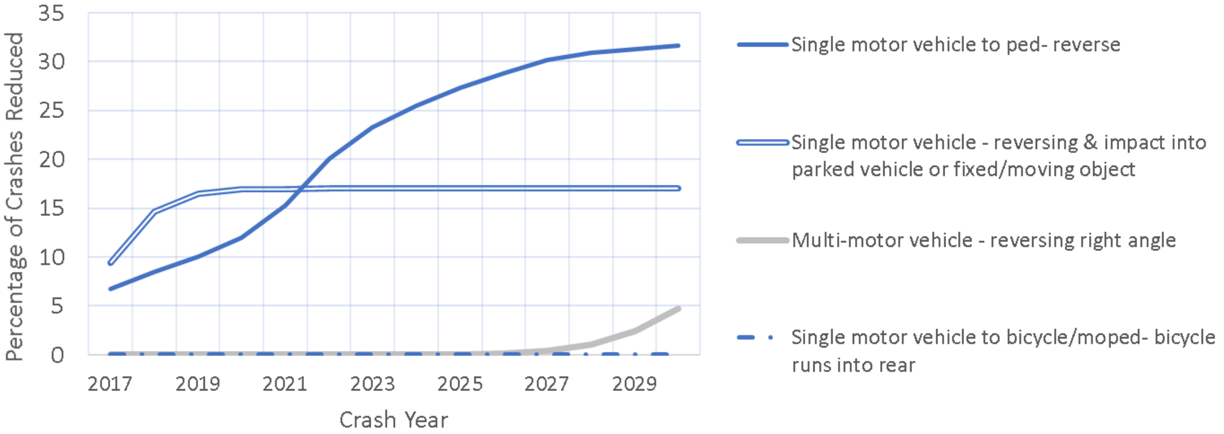


Figure 21 Percentage fatal reversing vehicle crashes avoided through additional active safety technology penetration

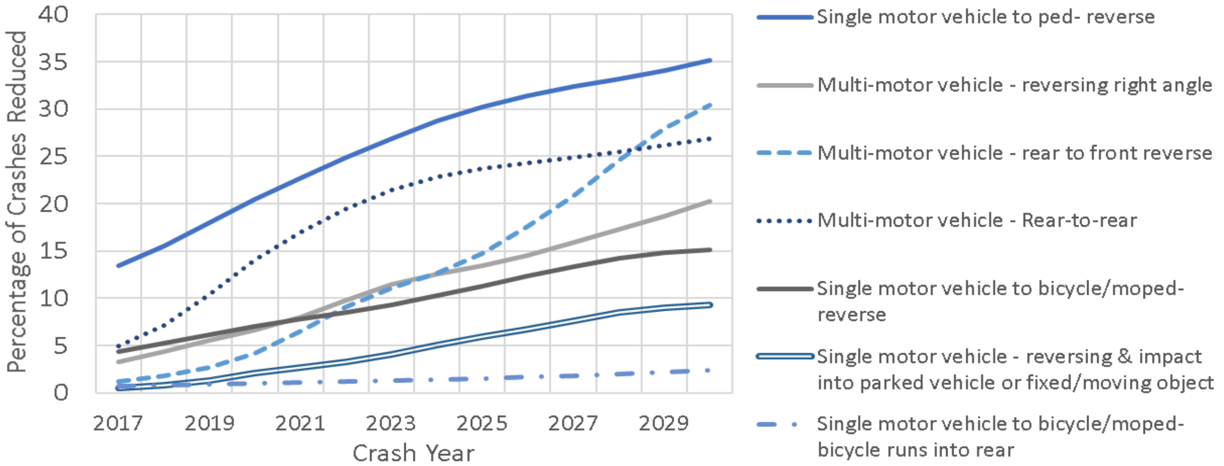


Figure 22 Percentage of serious injury reversing vehicle crashes avoided through additional active safety technology penetration

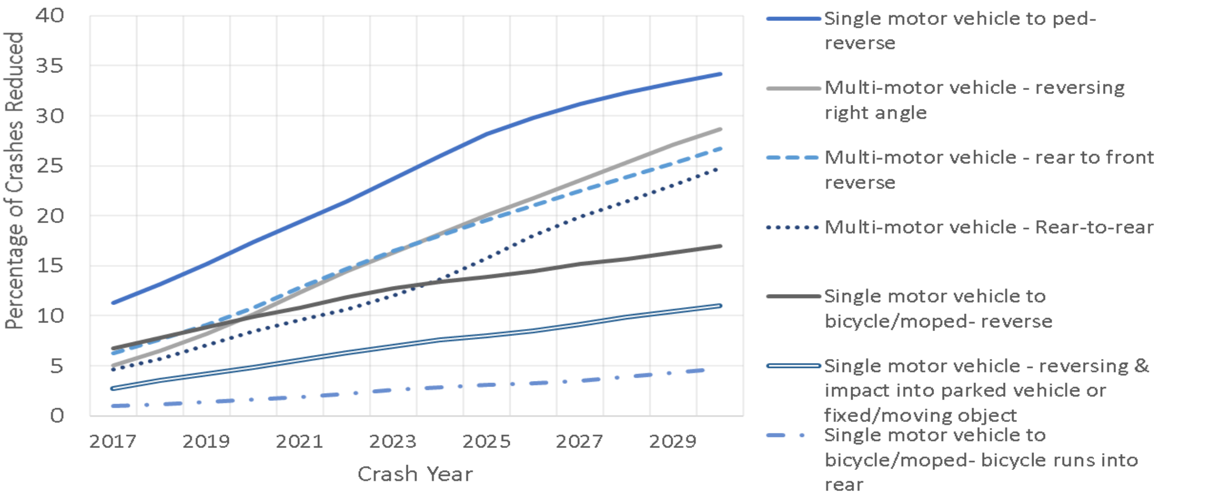


Figure 23 Percentage of minor injury reversing vehicle crashes avoided through additional active safety technology penetration

7 INJURIES PREVENTED (AND NOT PREVENTED) BY ACTIVE AND PASSIVE SAFETY TECHNOLOGY

By 2030, passive safety technologies and vehicle design were projected to act on the crashes not projected to be avoided, so that a further 12% of fatal and 14% of serious 2016 injuries could be be avoided. In 2030, 351 fatalities, 7 086 serious injuries and 12 345 minor injuries were projected to be avoided through active and passive vehicle safety technology penetration above the levels in 2016, saving a total of $3 174 million in human losses. About one third of all fatal and serious injuries were projected to be avoided through additional active and passive safety technologies. The proportion of fatal and serious injuries avoided were greater in rural regions. More than a quarter of all minor injuries were predicted to be avoided, with similar proportions in rural and metropolitan regions.

7.1 Additional injury avoidance from passive safety technology

Passive safety technologies only addressed fatal and serious injuries of light vehicle occupants. The additional injury benefit to vehicle occupants projected from passive safety technologies has been plotted, along with the active safety technology benefit, in Figure 24. Figure 11, Figure 25 and Figure 26 show additional summaries of the contribution of passive safety to injury avoidance; these include, the breakdown by location, road user type and market group.

In 2016 there were more fatalities in rural than in metropolitan regions, so it logicially followed that in 2030, more fatalities were projected to be avoided by both passive and active safety systems in rural regions. This was true both in absolute and relative terms. In 2030, 231 fatalities (24%) were projected to be avoided by active systems and an additional 120 fatalities (12%) were projected to be avoided by passive systems. And approximately 70% of these were from rural crashes. Vulnerable road user fatalities, which are mostly metropolitan pedestrians, were over-represented in the residual fatalites. Furthermore, vulnerable road user fatalities were poorly addressed by both active and passive safety technologies, such that the overall percentage of fatality avoidance in metropolitan regions was about a third less than the percentage avoided in rural regions. This means that future road safety programs and future developments in vehicle safety technologies need to specifically address vulnerable road users, particularly in metropolitan regions.

In 2016 there were fewer serious injuries in rural than in metropolitan regions, so it logicially followed that in 2030, fewer serious injuries were projected to be avoided by both passive and active safety systems in rural regions. This was true in absolute but not in relative terms; relative serious injuries avoided by both passive and active systems were 2 percent units higher in rural regions. The greater proportions of vulnerable road user injuries in metropolitan areas offers explanation for this trend reversal, since motorcyclist, pedestrian, bicyclist and moped rider injuries were not impacted by the methods used to estimate passive safety technology savings. In 2030, 4 421 serious injuries (23%) were projected to be avoided by active systems and an additional 2 665 serious injuries (14%) were projected to be avoided by passive systems. And approximately 42% of these were from rural crashes.

Additionally, trends in 2016 crash fatalities and crash serious injuries by market group were duplicated in fatalities and serious injuries avoided by passive vehicle safety. The market groups with the greatest proportion of fatalities avoided by passive sytems were the medium and large vehicle groups (18%), which were greater than the other market groups by 6 to 7 percent units. This indicated a greater expected penetration of passive safety systems in large and medium vehicles than in other market groups.

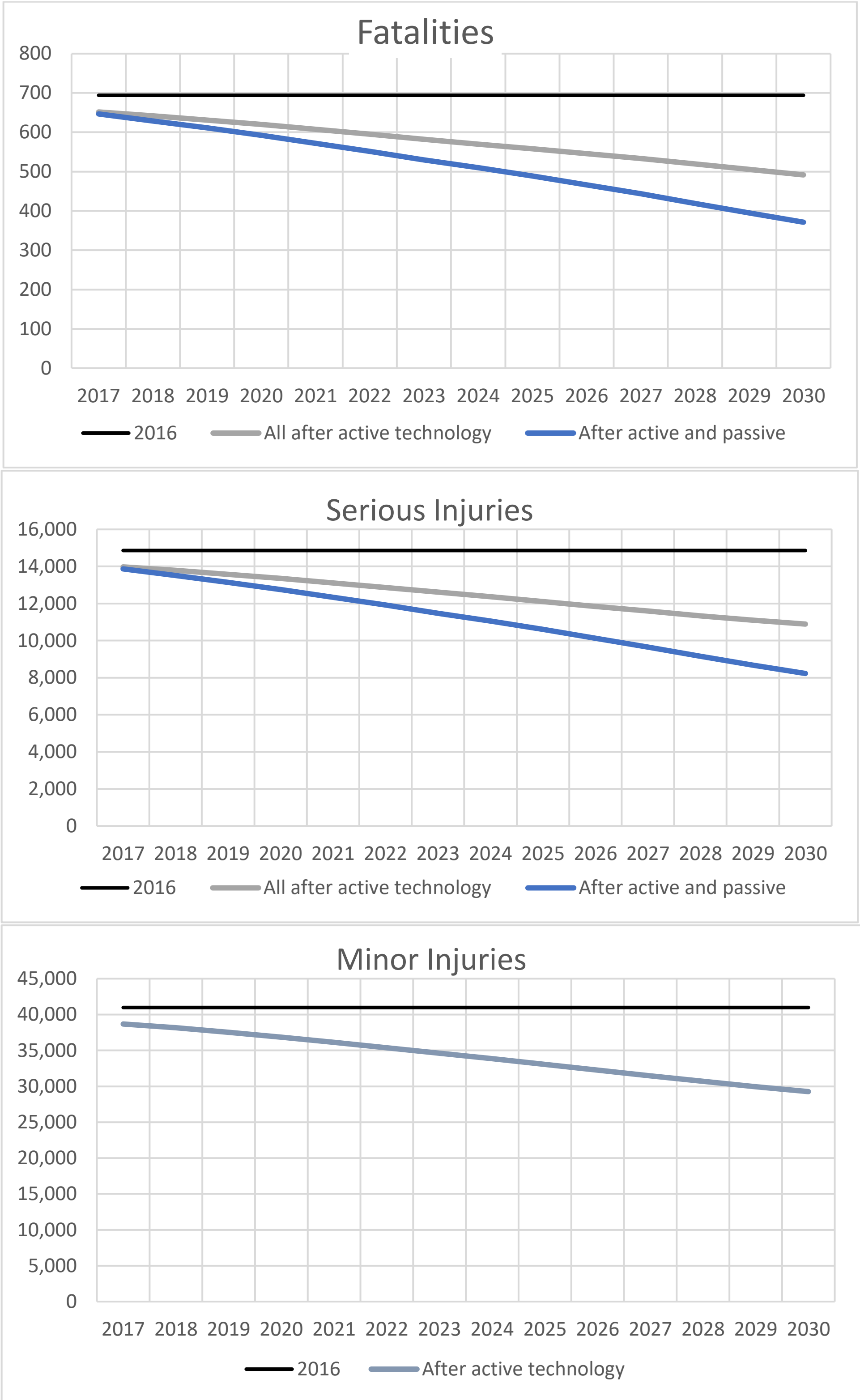


Figure 24 Light Vehicle occupant projected injuries by crash year

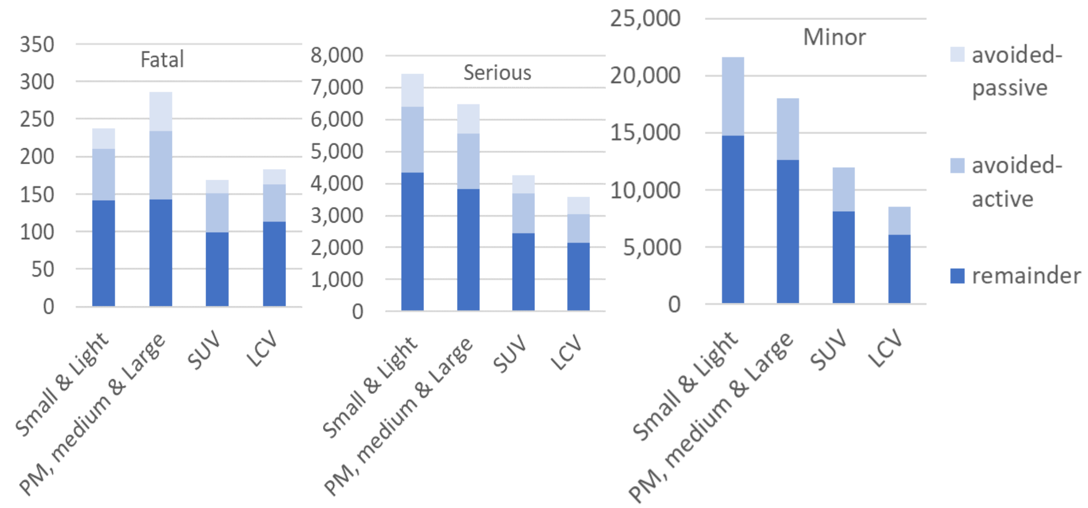
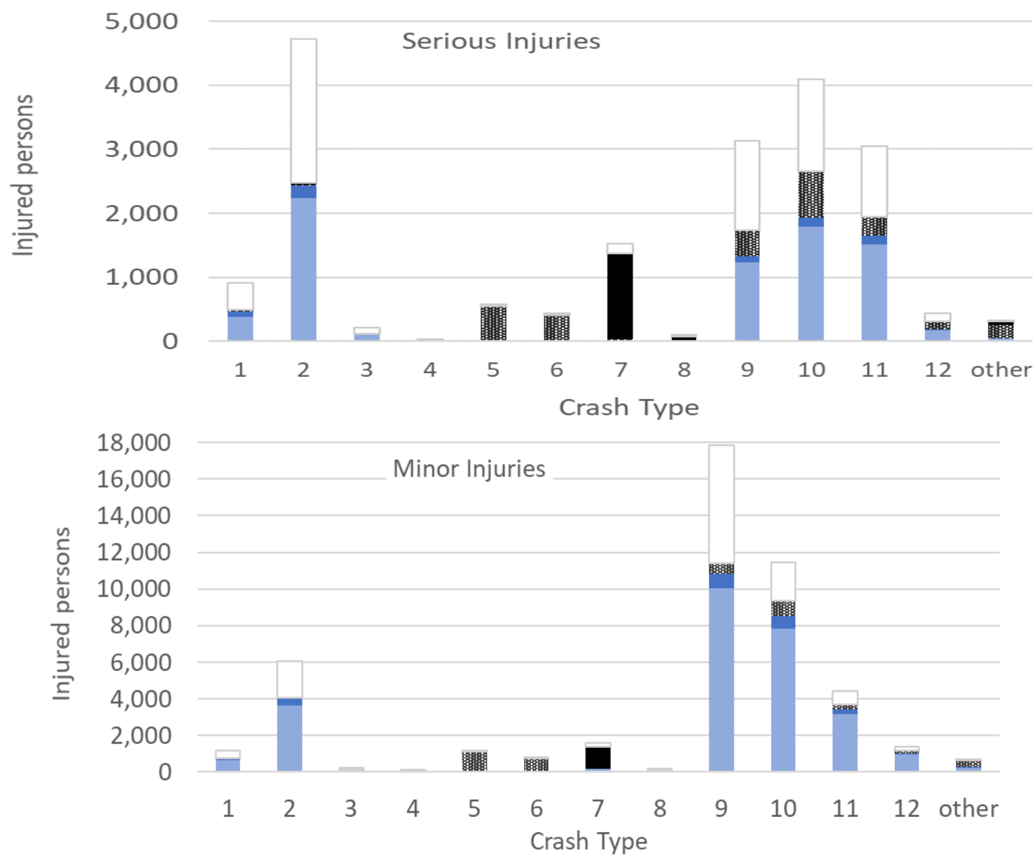


Figure 25 2016 Crash injuries by broad market group and severity disaggregated by vehicle safety technology projections in 2030



1	single rollover	5	Bicycle/moped-front	9	front-rear
2	single frontal collision	6	Bicycle/moped-rear/side	10	front-side
3	single side	7	pedestrian-front	11	front-front
4	single rear	8	pedestrian-rear	12	side-side

Figure 26 2016 Crash injuries by type, road user type and severity disaggregated by vehicle safety technology projections in 2030

7.2 Regional differences

In rural regions, the biggest contributors to road trauma are single (forward-moving) vehicle crashes and front-to-front, multi-vehicle crashes. In metropolitan regions, pedestrian collisions are the largest contributor to fatalities. In 2016, rural regions contributed the most fatalities and metropolitan regions the most to non-fatal crash injuries. Fatal crashes avoided through technology reflected these trends, however serious injuries were avoided in greater proportions in rural regions. The greater proportions of fatalities and serious injuries projected to be avoided in rural than in metropolitan regions were attributed to the fact that vulnerable road users were the greatest metropolitan contributor to severe road trauma, and were involved in crashes which were generally poorly addressed by vehicle safety technologies.

The distribution of injuries in 2016 (initial) and in 2030 (remaining after technologies) amongst regions (and broad speed zone), by crash type, severity and road user were examined to search for regional increasing trends (Figure 27 and Figure 28). Crash types which projected with a regional shift in proportion indicated a projected relative regional growth. Notable increases in the proportion of light vehicle front occupant injuries that arose from crashes in metropolitan regions were observed for:

- fatal front-to-side crashes across all speed zones,
- single vehicle front impact crashes in speed zones less than 55 km/hr across all severities and
- fatal side-to-side crashes in speed zones greater than 70 km/hr.

Notable increases in the proportion of light vehicle front occupant injuries that arose from crashes in rural regions were observed for:

- fatal single vehicle no collision crashes across all speed zones.

Notable increases in the proportion of light vehicle front occupant injuries that arose from crashes in remote regions were observed for:

- all severity single vehicle no collision crashes across all speed zones.

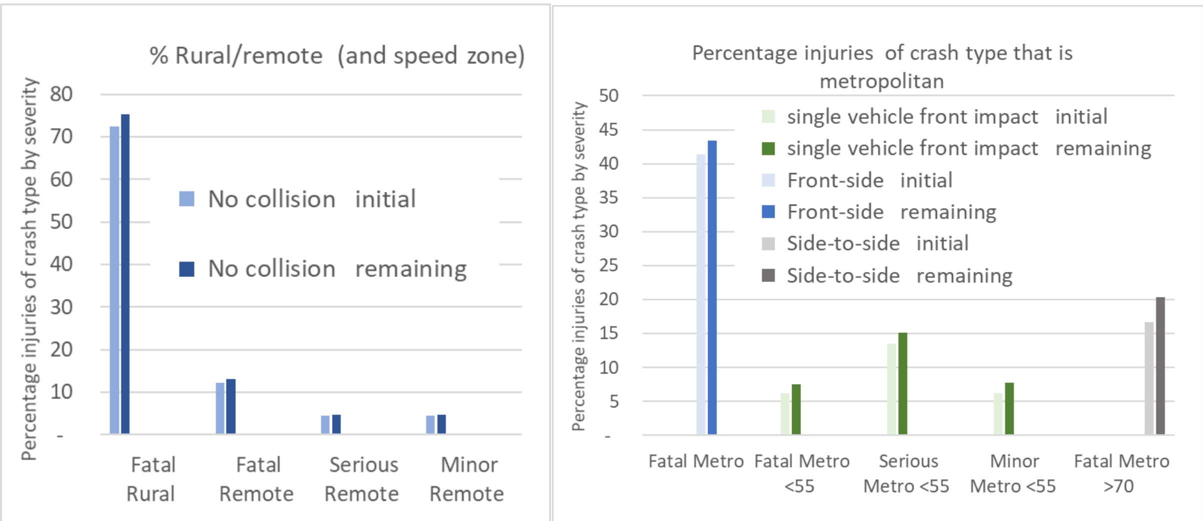


Figure 27 Regional Percentage of front occupant injuries by crash type & severity in 2016 (initial) and 2030 (remaining)

Some crash types were observed to increase within a speed zone regardless of the region. Crash types which showed a speed zone shift in proportion indicated a projected relative growth of the crash type for the zone (Figure 28). Notable increases in the proportion of light vehicle front occupant injuries that arose from crashes in low (≤70 km/hr) speed zones were observed for:

- all severity front-to-front crashes.

Notable increases in the proportion of light vehicle front occupant injuries that arose from crashes in high (>70 km/hr) speed zones were observed for:

- all severity front-to-rear crashes and
- serious and minor front-to-side crashes.

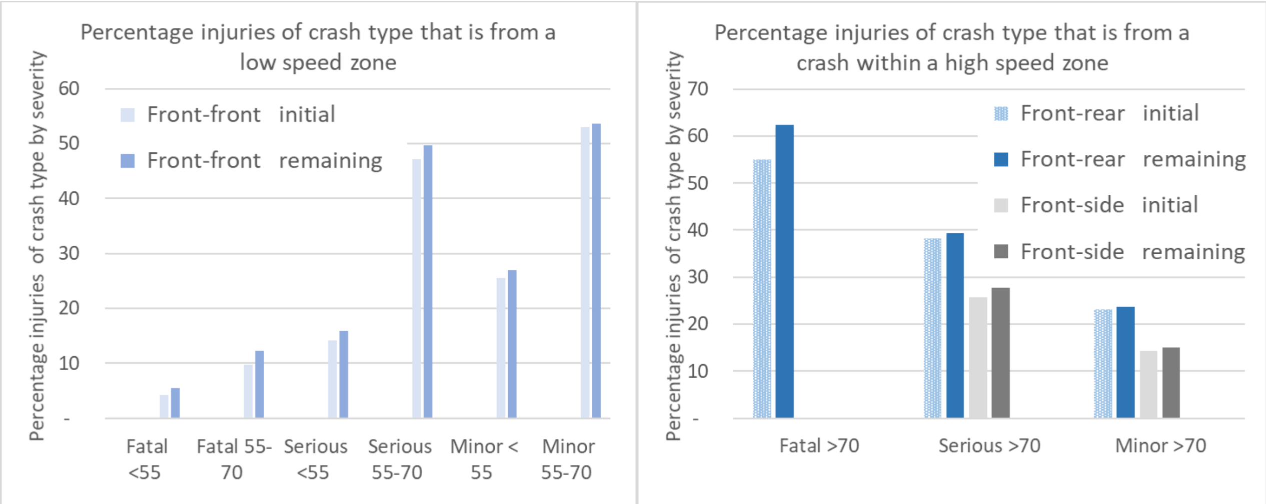


Figure 28 Percentage of front occupant injuries within a speed zone by crash type & severity in 2016 (initial) and 2030 (remaining)

7.3 Market group differences

In 2016, crashes involving large, medium and people mover vehicles contributed greatest to fatalities, however, fatal crashes were over-represented by SUVs and LCVs. 2016 fatal crash trends by market group were not observed for fatal injuries avoided through safety technologies. SUV crashes ranked least as a contributor to fatalities but LCV crashes ranked least in fatalities avoided through active safety technologies. This may be explained directly by the poorer penetration of active technologies expected for the light commercial vehicle market. The penetration of active safety techologies in the light commercial fleet was found to lag, so the potential benefits of active safety technologies in crashes invovling these vehicles was noticebly lower that for other market groups.

The pattern of reduced avoidance of crashes involving LCVs may be illustrated using market group distributions of injuries in 2016 (initial) and in 2030 (remaining after technologies), by crash type, severity and road user. Crash types which showed a shift in market group proportion indicated a projected relative market group growth. Notable increases to the injury proportion arising from LCV involved crashes were observed for front and rear occupant injuries across all severities for single vehicle crashes, front-to-rear and front-to-side crashes (Figure 29).

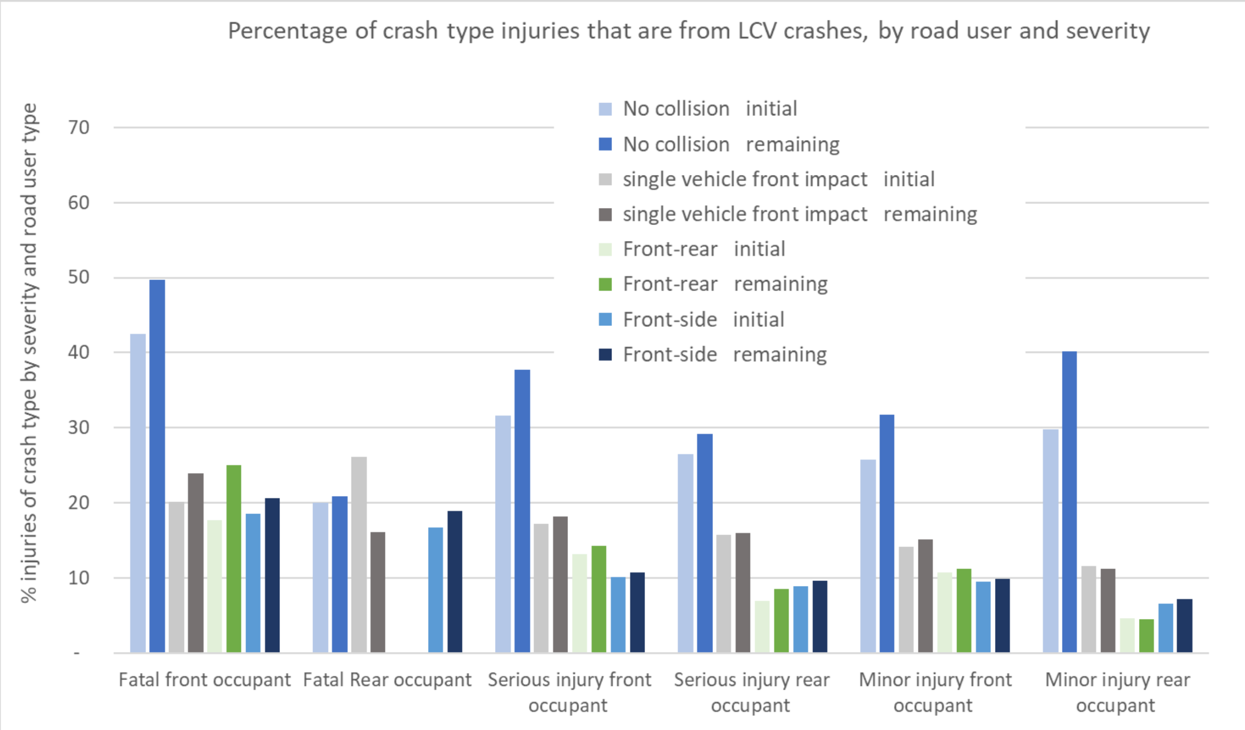


Figure 29 Percentage LCV involved crash injuries by crash type, occupant type & severity in 2016 (initial) and 2030 (remaining)

SU vehicles have been shown by the used car safety ratings to lag in the passive safety and the vehicle design features modelled within the crashworthiness ratings. This lag has translated to increases in the proportion of fatal and serious injuries arising from SUV involved crashes for specific crash types. Notable shifts were observed for front-to-rear and front-to-front crashes (Figure 30).

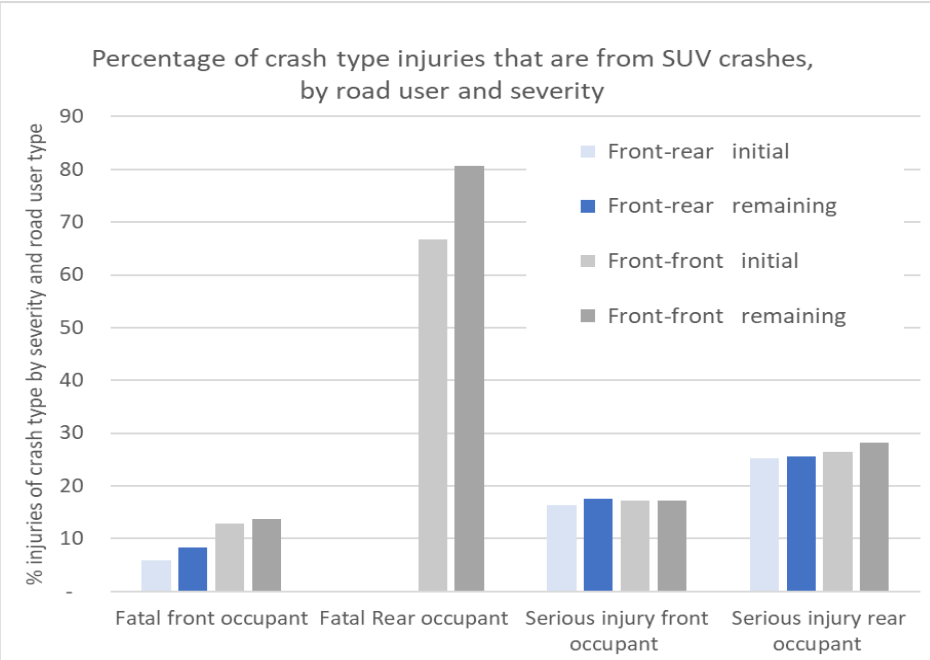


Figure 30 Percentage SUV involved crash injuries by crash type, occupant type & severity in 2016 (initial) and 2030 (remaining)

8 SUMMARY OF VEHICLE SAFETY TECHNOLOGY ANALYSIS

In order to identify future vehicle safety priority areas, the crash distributions, severity and trends in 2016 and 2030 were compared against safety technology penetration rates so that

- crash types being poorly addressed by active and passive safety technologies in 2030 could be identified,
- crash types likely to be poorly addressed by active and passive safety technologies further into the future could be identified,
- the degree of projected avoidance of more severe crash types, crash types exhibiting growth, and crash types which were high contributors to injury or severe injury could be estimated and
- it may be seen whether projected 2030 vehicle technologies were addressing crash type problem areas specific to metropolitan, rural and remote regions.

Summarising this information allowed vehicle safety priority areas to be identified.

Table 4 presents a summary comparison of crash trends of 2006 to 2016, crashes in 2016, and projected crashes in 2030. By crash type, it summarises the current situation: where improvements were not being made, which 2016 crash types contributed most to serious injuries (by location) and the vehicle types most often involved, which 2016 crash types contributed most to injuries, which 2016 crash types were more likely to be fatal and the 2016 crash distribution. For the projected year 2030, the table summarises by crash type: changes in crash distribution by severity, how much the crash type contributed to injury and severe injury, the 2030 penetration of sensitive technologies into crashed vehicles and the proportion of crashes avoided through technology. Problematic parts of the table are highlighed red, with darker colouring used to indicate issues with greater injury severity. Blue highlights were used where the 2030 distribution saw decreased proportions for a crash type, or where crashes were projected to be avoided in large proportions from the use of active technology.

8.1 Crash type being poorly addressed by vehicle safety technologies

Bicycle and moped crashes

The poorest technology sensitivity was observed for bicycle and moped crashes, which if V2B technology is discounted, showed an overall poor sensitivity to any technology. Only a small percentage of bicycle and moped crashes were sensitive to BSD and pedestrian AEB (Figure 46). V2B technology requires both the bicyclist/rider and the light vehicle to have technology which communicates, which is an unlikely current scenario. In this study, bicyclists/riders were assumed to have the technology and the telematic technology penetration was modelled for light vehicles only. It is very likely that the estimates of 5% to 6% of (forward-moving) light vehicle-to-bicycle/moped crashes avoided are even lower. Uptake of V2V may lead to future growth in crash avoidance.

Bicycle/moped crashes were found to be increasing in number over 2006 to 2016, a trend largely explained by growing exposure; the population of bicyclists and moped riders on Victorian roads is growing. They were also projected to increase in proportion (comparing 2016 with 2030), across all severities. This means that vehicle safety technologies, which poorly address bicycle and moped crashes with light vehicles, are also not addressing future growth in bicycle and moped exposure.

MONASH University

ACCIDENT RESEARCH CENTRE

Table 4 Summary of 2016 and 2030 crashes

	2006 to 2016	2016				2030								
						Residual crashes		Residual injuries (after active & passive)				% crashes avoided by active technol-ogies		
	Improvements not being made	Biggest contributor to more serious injuries and fatalities	Biggest contributor to injuries	% of crash type that are fatal	% of all crashes	%	Distribution change & severity where change is greatest	% all	% fatal	% serious	% minor		Main technology sensitivity	Penetration of main technology
Forward moving crash types														
1 single roll over/no collision		in **remote** regions. Moreso in M, CU, PM, SUVS & SUVL.	in **rural** region across fatal and serious in **remote** region across all severities	4.0	3	3		3	6	4	2	32	ESC, LDW, ADHL	Saturation almost reached for ESC. LDW in 60% of vehicles .
2 single frontal	SL or SUVM fatal & SL minor	moreso if S or SL	across all severities	2.9	18	17	decrease, all	14	23	20	12	32		
3 single side				13	0.7	0.6	decrease	0.6	4	0.9	0.4	33		
5 bicycle front	All			0.6	3	4	increase, all	4	2	4	3	5	V2B BSD Ped-AEB	V2B, V2P & ped AEB poor. BSD at about 60%.
6 bicycle side	All			0.3	2	2		2	0.5	3	2	6	V2B BSD	
7 pedestrian front	fatal or SUV non-fatal	in **metro** region. Moreso if CV, M, S or PM	in **metro** region across fatal and serious	4.3	6	7	increase, fatal	6	19	11	4	11	Ped-AEB	
9 front-to-rear	Fatal and Serious & SUV and SL minor		across minor and serious	0.3	30	26	decrease, serious and minor	27	5	14	33	35	AEB	Approaching 60%
10 front-to-side	M fatal & All injury SUV		across all severities	1.0	22	23	increase, minor in all regions, fatal and serious in rural regions	25	14	21	27	18	Broad and INTSXN AEB, BSD	See above for AEB, LDW and BSD. Intersection AEB has no penetration
11 front-to-front	Fatal, rural serious & SL & rural SUV minor	moreso if SL, SUVM or SUVL	across fatal and serious	4.2	9	10	increase serious and minor	12	22	16	11	17	Broad and INTSXN AEB, BSD	
12 side-to-side				1.0	2	3	increase	3	2	2	3	14	BSD LDW broad & INTSXN AEB	
Reversing crash types														
4 single				1.4	0.1	0.2		0.1	0.1	0.1	0.1	11	RC	Reversing camera penetration is reaching saturation. % avoided from RC is plateauing also. Rear cross is more than 50% penetrated.
6 bicycle rear				0	0.1	0.1		0.1	0	0.1	0.1	17	RC	
8 pedestrian rear				3.0	0.5	0.5		0.4	0.9	0.5	0.3	34	RC	
9 rear-to-front				0	0.2	0.2		0.2	0	0.1	0.3	27	RC, rear cross, AEB	
10 front-to-side				0.5	0.4	0.4		0.3	0.2	0.1	0.4	28	Rear cross, AEB, BSD	
other, inlcuding unknown movements, crashes with light vehicles not in the first event, rear-to-rear and bicycle into rear of forward moving				1.1	2	3	increase	2	2	3	2	2		

Pedestrian crashes

Pedestrian crashes with forward-moving light vehicles were most sensitive to pedestrian specific AEB systems. This analysis used the pedestrian AEB real-world study of Edwards, Nathanson et al. (2014) to estimate the potential additional avoidance in 2030. This study predicted the effectiveness possible in 2018 and described developments in sensors and timing. With current knowledge, it is not likely that further future developments in pedestrian-AEB technology will lead to effectiveness gains above that estimated by Edwards.

Pedestrian AEB systems were projected to have penetrated (in 2030) into about a quarter of the vehicles involved in fatal crashes. Penetration in the vehicles of non-fatal crashes was projected to be higher than into the vehicles of fatal crashes which was probably evidence of fatal crash mitigation. This technology is curently not in light commercial vehicles and was not projected to be in them, so future growth in avoidance beyond 2030 is possible just with improved fitment in this market group.

Fatal pedestrian crashes and non-fatal pedestrian crashes involving SUVs were observed to increase over 2006 to 2016. In the metropolitan regions, pedestrian crashes were one of the largest contributors to severe trauma and this crash type was also more likely to be fatal than most other crash types. In 2030, fatal pedestrian crashes were predicted to make up a larger proportion of injury crashes than in 2016. This means that active safety technologies are not adequately addressing a crash growth area, a crash type with a high contribution to trauma, a crash type that has severe outcomes and a crash type which is of specific concern in metropolitan regions. Furthermore, by definition, passive safety modelled with crashworthiness has no effect on pedestrian injury, so after applying both active and passive safety measures, this crash type was the third largest crash type contributor to both fatal and serious injuries in 2030.

Side-to-side crashes

Side-to-side crashes ranked next as poorly addressed by safety technology, however this crash type was a low contributor to overall trauma; they made up only 2% of all injury crashes and only 1% were fatal. Active safety technology was responsible for additional avoidance (in 2030) of 18% of fatal, 14% of serious injury and 15% of minor injury side-to-side crashes; proportions in rural regions were slightly higher than in metropolitan regions. Side-to-side crashes are generally sensitive to BSD, LDW and intersection AEB. Additionally some side-to-side crashes are broadly sensitive to general AEB systems. Technology effectiveness was fairly low (generally in the range of 10-20%) and difficult to assign to these crashes because driver intent (intentional lane change versus unintentional drift) often needed to be assumed. Penetration of these technologies into the crashed fleet was projected below saturation, so side-to-side crash avoidance is expected to grow beyond 2030 as the sensitive technologies continue to penetrate, however, even with growth, safety technologies are not adequately addressing this crash type.

8.2 Crash types with poor expectations for improvements in crash avoidance (through vehicle safety technologies) beyond 2030

Most crashes were actually found sensitive to active safety technologies and with the exception of crashes sensitive to reversing cameras, showed the potential for continued growth in avoidance beyond 2030. The analysis provided evidence that natural un-mandated penetration alone, for all of the active technologies studied other than reverse cameras, will lead to increased sensitive crash avoidance beyond 2030.

Reversing cameras showed evidence of being close to their full potential in 2030 and sensitive crash fitment projections for ESC showed that ESC was expected to be the next technology to reach its crash avoidance potential, however crash avoidance plots (in Figure 13) showed no evidence that avoidance limits were reached for ESC in 2030. Crash types which rely on these two active safety technologies are likely to have poor potential growth in crashes avoided beyond 2030. These crash types are single vehicle forward-moving crashes tripped by a loss of control event and reversing crashes.

Reversing Crashes

Reversing crashes were generally not identified as major contributors to trauma nor as growth types. In total, reversing crashes contributed to between 1% and 2% of all light vehicle crashes and were not projected to grow in proportion in 2030, relative to 2016. Despite these general trends, pedestrian involved reversing crashes were identified as a crash type likely to be fatal. However, pedestrian reversing crashes were found to be well served by active safety technology.

Reversing camera technologies were expected, by 2030, to allow additional avoidance of 34% of *reversing pedestrian crashes*, however these crashes contributed only a very small propotion of overall crash trauma. Unfortuneately, this technology was projected to have just about reached its potential to avoid crashes by 2030, however, further improvements in avoidance of this crash type may be achieved with reverse collision mitigation technology which has not yet penetrated the Australia crash fleet in quantities sufficient to allow projection modelling.

Given that reverse camera technology was expected to have reached its maximum avoidance potential in 2030, reverse collision mitigation may also serve as a future technology to address reversing collisions with objects, bicycles, mopeds and parked and moving vehicles. Multi-motor vehicle reversing crash types were projected to be avoided in 2030 at similar rates to pedestrian reversing crashes, however projections estimated lower rates of other single motor vehicle reversing crashes. In 2030 only 11% of vehicle-to-object and 17% of vehicle-to-bicycle/moped crashes were estimated to be avoided.

Single forward-moving crashes

Single forward-moving crashes were estimated to be best addressed by active safety technology. A third of single forward-moving (without pedestrian, moped or bicycle involvement) fatal crashes and 32% of all injury single forward-moving crashes were projected to be additionally avoided by 2030. These were amongst the most serious crash types, particularly for small and light vehicles and remote region overturns. They were also amongst the largest contributors to serious road trauma. And single vehicle-to-object crashes were projected to increase over 2006 to 2016, when serious and rural, or when certain market groups were involved. Projections showed that in 2030, avoidance of these crashes would reduce their overall proportion in the crash type distribution for all regions and severities.

Almost all of these crashes were sensitive to at least one of ESC, LDW or active headlights, and these technologies were in turrn shown to be most sensitive to crashes invovling severe trauma. Although ESC was projected to have almost reached its avoidance potential by 2030, both LDW and active headlamps were shown to have potential beyond 2030 due to poorer crashed fleet penetration in 2016; especially for light commercial vehicles which lagged severely.

In summary, across all severities and locations single forward-moving collisions are expected to be soundly addressed by the natural penetration of ESC, LDW and active headlight technologies, however, fitment in commercial vehicles was found to be lagging and future reductions may be limited by the near saturation of ESC projected by 2030.

8.3 Other crash types and their limitations

Front-to-rear crashes

Front-to-rear crashes ranked next after single vehicle crashes for crash proportions avoided by active safety technology. The less severe crashes of this type were better addressed. Active safety technology penetration was responsible for additional avoidance (in 2030) of 14% of fatal, 31% of serious injury and 35% of minor injury front-to-rear crashes; proportions in metropolitan regions were slightly higher than in rural regions. Projections also showed that relative to 2016, avoidance of non-fatal front-to-rear crashes would reduce their overall 2030 crash distribution proportion across all regions.

Rear-end crashes were one of the least severe crash types, however, injuries were more likely to be fatal if the rear-end crash involved a people mover, medium SUV or a van. Rear-end crashes were the most frequent injury crash type and were more likely to involve people movers, vans and small and medium SUVs. And front-to-rear crashes were observed to increase in recent years when fatal or serious, or when minor if the crash involved SUV or light vehicles.

AEB technology was found highly sensitive to front-to-rear crashes at all severities. However, AEB in some form was expected to be fitted to only about half of the crashed light vehicle fleet by 2030, and fitment was found lagging in commercial vehicles.

In summary, AEB is soundly addressing front-to-rear collisions of all severities by natural penetration, and with penetration in 2030 nearing only 50%, growth in crashes avoided is expected beyond 2030, however, in absolute terms the benefits are largely in minor crashes of metropolitan regions.

Front-to-front crashes

Ranked next for crash proportions avoided by active safety technology are the front-to-front collisions which were found to be most frequently sensitive to lane departure warnings and AEB (for right-turn across-path/ opposite direction and straight crossing path intersection crashes and crashes with broad AEB sensitivity). Almost half of remote, and just over a quarter of rural fatal front-to-front crashes were projected in 2030 to be avoided through additional active safety technologies. In metropolitan regions and for non-fatal crashes in rural and remote regions, avoidance was predicted at 15% to 23%.

Frontal collisions are not just high speed head-on collisions, although this is more likely to be true in remote regions, where LDW is likely to be the effective measure. 98% of frontal collisions in 2016 did not involve overtaking; 57% were at intersections, 50% were opposite direction (broad DCA) and 35% were adjacent direction (broad DCA group).

Frontal crashes were second to single vehicle crashes in terms of severity and were large contributors to fatal and serious injury. Fatalities were more likely if the collision involved a light, a large or a medium SU vehicle. And front-to-front crashes were observed to increase in recent years when fatal or serious and when minor injury crashes involved light or SU vehicles.

Both LDW and AEB technologies were projected to have not yet saturated the crashed vehicle fleet in 2030, and AEB has not yet reached maximum effectiveness with respect to intersection and other broadly sensitive crash types, so further improvements to this crash type are likely to occur with natural penetration of LDW and AEB technologies.

Front-to-side crashes

Ranked next for crash proportions avoided by active safety technology are the front-to-side collisions which were found to be most frequently sensitive to BSD/SVA and AEB (for right-turn across-path/ opposite direction and straight crossing path intersection crashes and crashes with broad sensitivity). 29% of remote, and 16% of rural fatal crashes were projected in 2030 to be avoided through additional active safety technologies. In metropolitan regions, and for non-fatal crashes in rural and remote regions, avoidance was predicted at 14% to 19%.

Front-to-side collisions are not just straight crossing path intersection collisions, although this is more likely to be true in metropolitan regions regions. 99% of front-to-side collisions in 2016 did not involve overtaking, 80% were at intersections, 31% were opposite direction (broad DCA), 43% were adjacent direction (broad DCA), 14% were same direction (broad DCA) and 11% were manouvring (broad DCA).

Front-to-side crashes were generally less severe crashes, but in 2016 they were of the three crash types contributing most to minor and serious injuries and fatalities. Fatal crashes were more likely if the vehicles involved included medium vehicles, vans or large and small SUVs. And front-to-side crashes were observed to increase in recent yerars when fatal and involving medium or medium SU vehicles.

Both BSD and AEB technologies were projected in 2030 to have not yet saturated the crashed vehicle fleet. Furthermore AEB has not yet reached its effectiveness limits with respect to intersection and other broadly sensitive crash types. So further improvements to this crash type are likely to occur naturally.

Location and crash approaches

The distribution of intersection location and crash DCA categories across occupant injuries by crash type and severity were examined to provide more details of multi-vehicle crashes not avoided in 2030. Fatal front occupant injuries were projected to be in greater proportions at intersections in 2030, relative to 2016 for front-to-side and front-to-front crashes: the increase was 5% and 3% units repsectively. Injuries from crashes with the DCA code for straight crossing path (adjacent cross traffic) were also projected to increase across severities for front-to-side and front-to-front crashes in 2030 (initial) relative to 2016 (remaining) (Figure 31).

This is of interest because AEB is still a developing technology with respect to the avoidance of cross path intersection crashes. These crashes are sensitive to intersection specific AEB technology which was not yet present in new vehicles in 2016. This means that although literature efficacy was available, the technology had to be modelled with no penetration in the 2030 crash fleet. Avoidance of straight crossing path crashes was modelled with only general AEB systems and broad sensitivity, which meant that given technological developments and penetration, this growing proportion of front-to-front and front-to-side crashes could be avoided with up to 8 times the effectiveness in the future. Figure 31 shows that straight crossing path crashes make up about a fifth of the injury burden of these two crash types, so there is great potential for large absolute reductions with increased intersection-AEB fitment.

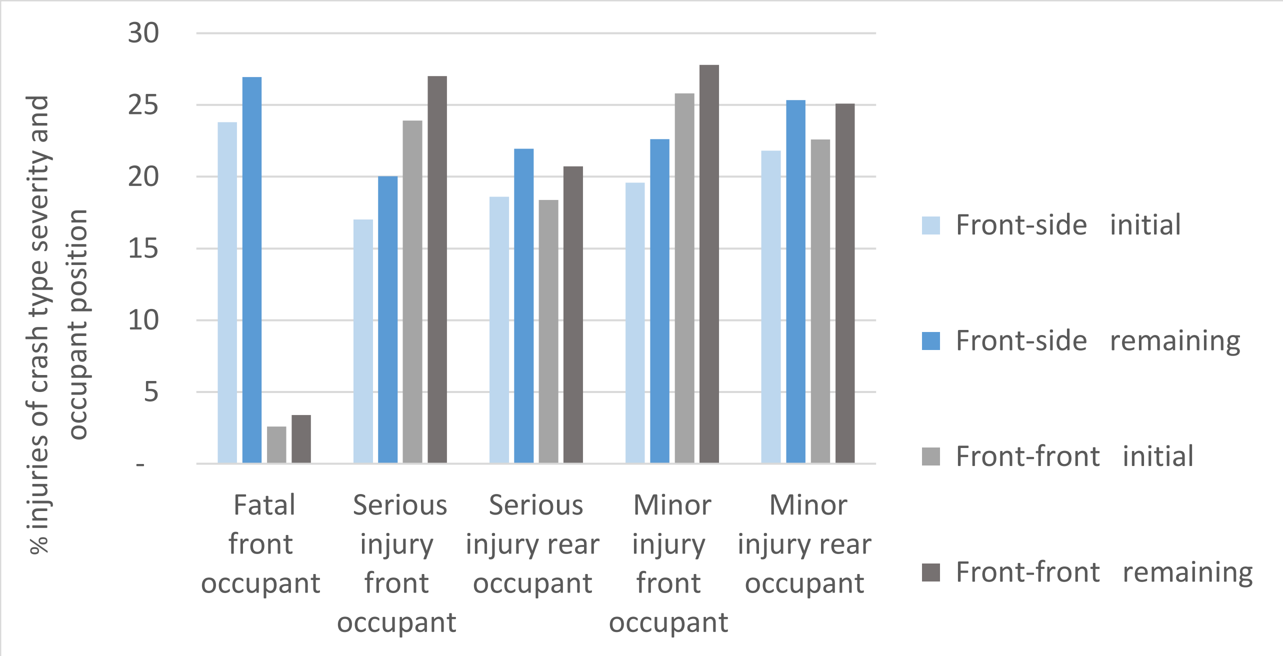


Figure 31 Percentage of light vehicle occupant injuries by position and severity from straight crossing path crashes

AEB specificity towards right turn/opposite direction crashes is also developing, however the modelled literature source provided evidence of 45% effectiveness of general systems for vehicles traveling at 40 km/hr. This still leaves room for technological advancements that improve the high-speed effectiveness. Proportions of this crash type were not projected to noticeably grow between 2016 and 2030.

9 VEHICLE SAFETY PRIORITY AREAS

This section draws together all of the information presented in this report to identify three vehicle safety priority areas.

9.1 Priority One: Fatal pedestrian crashes

Fatal pedestrian crashes and non-fatal pedestrian crashes involving SUVs were observed to increase over 2006 to 2016. In metropolitan regions, pedestrian crashes were one of the largest contributors to severe trauma and this crash type is also more likely to be fatal than most other crash types. In 2030, fatal pedestrian crashes were predicted to make up a larger proportion of injury crashes than in 2016. This means that active safety technologies are not adequately addressing a crash growth area, which is a high contributor to trauma with severe injury outcomes. It is also a crash type of specific concern in metropolitan regions. Furthermore, by definition, passive safety modelled with crashworthiness has no effect on pedestrian injury, so after applying both active and passive safety measures, this crash type was the third largest crash type contributor to both fatal and serious injuries in 2030.

Pedestrian crashes are chiefly addressed by AEB systems with pedestrian detection capability. Natural penetration rates were projected to be lagging and this technology is curently rarely present in light commercial vehicles.

As the greatest contributor to metropolitan road fatalities, pedestrian crashes are a crash type with serious outcomes. They have not been adequately addressed by vehicle safety technology despite 2030 projections of relative growth in the crash type and only 11% crash avoidance. By targetting pedestrian fatalities, reductions in non-fatal pedestrian crashes will also follow. Both relative and absolute estimated reductions in 2030 fatal crashes achieved from active and passive technologies and vehicle design, were greater for rural regions, so targetting pedestrian fatal crashes will also address this imbalance and generally improve avoidance of fatal crashes in metropolitan regions. Some suggested countermeasures are:

- Investigate what drives natural penetration to find out why pedestrian technologies are not naturally penetrating the light vehicle fleet at rates similar to other technologies.
- Encourage the increased uptake of pedestrian-AEB systems, particularly in LCVs which currently have no fitment. This may also improve bicycle and moped crash outcomes.
- Investigate the possibilities offered by vehicle-to-pedestrian and vehicle-to-infrastructure communication technology and deploy what is found to be effective. There is a great body of research on intelligent transport systems (ITS). Silla, Rämä et al. (2017) esimated that almost half of pedestrian-to-vehicle crash injuries could be avoided with vehicle-to-pedestrian technology. ITS systems may be as simple as interacting mobile phone technology with vehicle telematics so that both drivers and pedestrians are alerted to impending collisions.
- Encourage vehicle design improvements or the uptake of pedestrian technology such as night vision and active hood / windshield A-frame airbags. Fredriksson, Shin et al. (2011) estimated the latter to decrease AIS 3+ pedestrian injury risk from 85-100% to 20%. This is pertinent for SU vehicles which demonstrated an increasing baseline trend of pedestrian crashes.

- Install infrastructure which enhances pedestrian safety. This document suggests that prior research into the relevance and effectiveness of such structures be carried out. Suggestions of infrastructure to investigate further may include traffic island safety zones, improved lighting near community centres which are active at night (such as scout halls, sporting facilities, TAFEs, clubs and bars), footpath fencing to minimise jay walking, and installations of zebra or controlled crossings.
- Deploy interactive programs which target pedestrian behaviour such as walking while distracted. This document suggests that prior research into the relevance and effectiveness of such programs be carried out.
- Deploy interactive programs which target driver behaviour such as speed reduction in high foot traffic zones and driver education on pedestrian awareness. This document suggests that prior research into the relevance and effectiveness of such programs be carried out.

9.2 Priority Two: Single vehicle frontal crashes with fixed objects

Single vehicle frontal crashes with fixed objects were estimated to be best addressed by active safety technology, however this crash type was projected to make up 21% of all injury crashes in 2030 and two thirds of these crashes were projected to not be avoided by vehicle safety technologies in 2030.

These were amongst the most serious crash types, particularly for small and light vehicles and remote region overturns. They were also amongst the largest contributors to serious road trauma. Single vehicle-to-object crashes were observed to increase over 2006 to 2016, for serious and rural crashes, or when certain market groups were involved.

ESC, LDW and active headlamps were the main technologies addressing single vehicle forward-moving fatal crashes modelled in this analysis. ESC was found to have almost saturated the crashed vehicle fleet so has no more to offer in crash avoidance beyond 2030. Just over half the crashed light vehicle fleet were fitted with LDW or active headlights in 2030. Both LDW and active headlamps were shown to have potential beyond 2030 due to poorer crashed fleet penetration in 2016; especially for light commercial vehicles which lagged severely. Just over half the crashed light vehicle fleet were fitted with LDW or active headlights in 2030.

Some suggested countermeasures are:

- Investigate what drives natural penetration to find out why systems which address fatigue, speeding and inattention are not naturally penetrating the light vehicle fleet at rates similar to other vehicle safety technologies. Single vehicle forward-moving crashes are often the result of speeding, driver inattention and driver fatigue. The fitment analysis found poor projected uptake of speed, fatigue and inattention systems such as speed zone reminder, speed alert, speed limiter, driver fatigue warning, driver attention detector. The limitations of crash data prevented the inclusion of these technologies in this analysis, however with such poor fitment rates, their contribution to crash avoidance was likely to be poor.
- Investigate what drives natural penetration to find ways to enhance the natural penetration of LDW and active headlights, especially within the light commercial market group.
- Investigate what drives natural penetration to find ways to enhance the natural penetration of relevant passive safety technologies, especially within the light

commercial market group which are severely lagging: e.g. front passenger head airbag, all rear airbags and rollover protection (which is also lagging in SUVs).

- Deploy programs targetted at enhancing driver acceptance of lane departure warning systems, especially for professional drivers. Reagan and McCartt (2016) found LDW systems to only be switched on 33% of the time.
- Increase the proportion of roads with edgelines. LDW currently rely on edgelines and does not function where there are no lanemarkings. Increasing the proportion of lanemarkings on roads where fatigue, speeding and inattention are likely will increase the real-world effectiveness of LDW.
- Investigate ways to improve injury outcomes in small and light vehicle single vehicle crashes. This may involve vehicle design or encouraging uptake of passive safety systems such as rollover protection, active headrests, and the various airbags currently availabe. Small and light vehicles were found to have poorer outcomes in these crash types.
- Investigate ways to improve injury outcomes in remote locations as remote single vehicle crashes were found to have poorer outcomes. Such a way could be to encourage uptake of automatic crash notification systems or to educate remote region drivers about them. Automatic crash notification systems are an emerging safety technology designed to notify emergency responders that a crash has occurred and provide its location. This not only speeds up the response, but may be the only way that some crashes are detected before fatalities occur.
- Deploy appropriate additional infrastructure, such as signage to warn of approaching hazzards with suggested speeds, improvements to shoulders and road surface improvements.

9.3 Priority Three: Front-to-front vehicle crashes both at intersections and midblocks and front-to-side impacts at intersections including straight crossing path and right turn across path crash types

37% of crashes in 2030 were projected to be front-to-side or front-to-front crashes. In 2016, 57% of front-to-front collisions were at intersections and 35% came from adjacent approaches. In 2016, 80% of front-to-side were at intersections and 43% came from adjacent directions. Serious and fatal front-to-side crashes were projected to increase in proportion in rural areas. Both front-to-side and front-to-front are significant contributors to road fatalities and injury crashes generally and more than 80% of these two crash types were not projected to be avoided in 2030. These crashes generally only have broad or low speed sensitivity to general AEB systems. Intersection-AEB systems which target straight crossing path crashes have not yet been commercialised. Some suggested countermeasures are:

- Investigate what drives natural penetration to find out why ITS, high speed AEB systems and intersection-AEB technologies are not naturally penetrating the light vehicle fleet at rates similar to other technologies. Intersection AEB systems which target straight crossing path collisions are likely to be able to prevent around 40% of straight crossing path crashes and if AEB systems could improve speed range sensitivity both generally and specifically for *right turn/other direction* crashes more fatalities could be avoided. Furthermore, an increased speed range in general AEB systems could aid avoidance of high-speed front-to-rear crashes.

- Investigate what drives natural penetration to find ways to enhance the natural penetration of relevant passive safety technologies, especially within the light commercial market group which are severely lagging: e.g. front passenger head airbag and all rear airbags.
- Investigate the possibilities offered by vehicle-to-vehicle and vehicle-to-infrastructure communication technology and deploy what is found to be effective. There is great body of research on intelligent transport systems (ITS). It is possible for intelligent intersection infrastructure to warn drivers of approaching vehicles from cross directions.
- Continue to expand red light speed camera programs. These have proven effectiveness (Budd, Scully et al. 2011) on these crash types (44% casualty crash reduction).

10 REFERENCES

Anderson, R.W.G., Hutchinson, T.P., Linke, B. and Ponte, G. (2010). "Analysis of crash data to estimate the benefits of emerging vehicle technology." Univeristy of Adelaide Centre for Automotive Safety Research, Adelaide.

Australian Bureau of Statistics (2019). "Comsumer price index australia - september quarter 2019." Australian Bureau of Statistics, Canberra, Australia (Document Number:6401.0). https://www.abs.gov.au/ausstats/abs@.nsf/7d12b0f6763c78caca257061001cc588/fd16e5cfb4db3a4aca25737d00222911!OpenDocument.

Automotive Data Services Pty Ltd (2014). "Redbook, vol 2014".

Budd, L., Keall, M. and Newstead, S. (2015). "Retrospective and prospective chages in secondary safety of the australian and new zealand vehicle fleets and the potential influence of new vehicle safety technologies." Monash University Accident Research Centre, Clayton, Australia (Document Number:329). https://www.monash.edu/__data/assets/pdf_file/0006/1057236/muarc329.pdf.

Budd, L., Scully, J. and Newstead, S. (2011). "Evaluation of the crash effects of victoria's fixed digital speed and red-light cameras." Monash University Accident Research Centre,(Document Number:307).

Budd, L., Stephens, A. and Newstead, S. (2019). "The potential benefits of autonomous emergency braking in australia." Monash University Accident Research Centre, Melbourne.

Bureau of Infrastructure Transport and Regional Economics [BITRE] (2009). "Road crash costs in australia 2006." Bureau of Infrastructure, Transport and Regional Economics [BITRE], Canberra (Document Number:118). https://bitre.gov.au/publications/2010/files/report_118.pdf.

Cicchino, J. (2017). "Effectiveness of forward collision warning and autonomous emergency braking systems in reducing front-to-rear crash rates." Accident Analysis and Prevention **99**: 142-152.

Cicchino, J. (2017). "Effects of rearview cameras and rear parking sensors on police-reported backing crashes." Traffic Injury Prevention **18**(8): 859-865.

Cicchino, J. (2018). "Effects of blind spot monitoring systems on police-reported lane-change crashes." Traffic Injury Prevention **19**(6): 615-622.

Cicchino, J. (2018). "Effects of lane departure warning on police-reported crash rates." Journal of Safety Research **66**: 61-70.

Cicchino, J. (2019). "Real-world effects of rear cross-traffic alert on police-reported backing crashes." Accident Analysis & Prevention **123**: 350-355.

Corben, B., Logan, D., Fanciulli, L., Farley, R. and Cameron, I. (2009). "Strengthening road safety startegy development 'towards zero' 2008 - 2020 - western australia's experience scientific research on road safety management swov workshop 16 and 17 november 2009." Safety Science **10**(48): 1085-1097.

Doecke, S., Grant, A. and Anderson, R.W.G. (2015). "The real-world safety potential of connected vehicle technology." Traffic Injury Prevention **16**(sup1): S31-S35.

Elvik, R. (2009). "An exploratory analysis of models for estimating the combined effects of road safety measures." Accident Analysis & Prevention **41**: 876-880.

European Commission (2016). "Advanced driver assistance systems 2016." European Commission. https://ec.europa.eu/transport/road_safety/sites/roadsafety/files/ersosynthesis2016-adas15_en.pdf.

Fredriksson, R., Shin, J. and Untaroiu, C.D. (2011). "Potential of pedestrian protection systems- a parameter study using finite element models of pedestrian dummy and generic passenger vehicles." Traffic Injury Prevention **12**(4): 398-411.

Jermakian, J.S. (2011). "Crash avoidance potential of four passenger vehicle technologies." Accident Analysis & Prevention **43**: 732-740.

Keall, M., Fildes, B. and Newstead, S. (2017). "Real-world evaluation of the effectiveness of reversing camera and parking sensor technologies in preventing backover pedestrian injuries." Accident Analysis & Prevention **99**: 39-43.

Keall, M. and Newstead, S. (2015). "Development of a method to rate primary safety of vehicles using linked new zealand crash and vehicle licensing data." Traffic Injury Prevention **17**: 151-158.

Kusano, K.D. and Gabler, H.C. (2014). "Comprehensive target populations for current active safety systems using national crash databases." Traffic Injury Prevention **15**(7): 753-761.

Newstead, S., Keall, M. and Watson, L. (2011). "Rating the overall secondary safety of vehicles from real-world crash data: The australian and new zealand total secondary safety index " Accident Analysis and Prevention **43**: 637-645.

Newstead, S., Watson, L., Keall, M. and Cameron, M. (2018). "Vehicle safety ratings estimated from police reported crash data: 2018 update australian and new zealand crashes during 1987-2016." Monash University Accident Research Centre, Melbourne.

NHTSA (2016). "Vehicle-to-vehicle communication technology for light vehicles." Preliminary regulatory impact analysis NHTSA, Office of Regulatory Analysis and Evaluation, National Center for Statistics and Analysis, Washington, DC, U.S.A (Document Number:FMVSS No. 150).

Ostling, M., Lubbe, N. and Jeppsson, H. (2019). Passenger car safety beyond adas: Sefining remaining accident configurations as future priorities. The 26th International Technical Conference on the Enhanced Safety of Vehicles (ESV), Eindhoven, Netherlands.

Reagan, I.J. and McCartt, A.T. (2016). "Observed activation status of lane departure warning and forward collision warning of honda vehicles at dealership service centres." Traffic Injury Prevention **17**(8): 827-832.

Risbey, T., Cregan, M. and De Silva, H. (2010). Social cost of road crashes. Australasian Transport Research Forum, Canberra, Australia, Planning and Transport Research Centre.

Scanlon, J., Sherony, R. and Gabler, H.C. (2017). "Injury mitigation estimates for an intersection driver assistance system in straight crossing path crashes in the united states." Traffic Injury Prevention **18**(sup1): S9-S17.

Scully, J. and Newstead, S. (2010). "Followup evaluation of electronic stability control effectiveness in australasia." Monash University Accident Centre, Monash University (Document Number:306).

Silla, A., Leden, L., Rämä, P., Scholliers, J., Van Noort, M. and Bellet, T. (2017). "Can cyclist safety be improved with intelligent transport systems?" Accident Analysis & Prevention **105**: 134-145.

Silla, A., Rämä, P., Leden, L., Van Noort, M., De Kruijff, J., Bell, D., Morris, A., Hancox, G. and Scholliers, J. (2017). "Quantifying the effectiveness of its in improving safety of vrus." Institution of Engineering and Technology (IET) Intelligent Transport Systems **11**(3): 164-172.

Sternlund, S. (2017). "The safety potential of lane departure warning systems-a descriptive real-world study of fatal lane departure car crashes in sweden." Traffic Injury Prevention **18**(sup1): S18-S23.

Strandroth, J. (2015). "Validation of a method to evaluate future impact of road safety interventions, a comparison between fatal passenger car crashes in sweded 2000 and 2010." Accident Analysis and Prevention **76**: 133-140.

Strandroth, J., Lie, A. and Rizzi, M. (2017). Real-world benefits of adaptive headlights on passenger cars in sweden. The 25th International Technical Conference on the Enhanced

Safety of Vehicles (ESV), Detroit, Michigan USA, Federal Office of Road Safety & U.S. Dept. of Transportation, NHTSA.

Toshiyuki, Y. and Yukou, T. (2017). Estimation of the effect of autonomous emergency braking systems for pedestrians on reduction in the number of pedestrian victims. The 25th International Technical Conference on the Enhanced Safety of Vehicles (ESV), Detroit, Michigan USA, Federal Office of Road Safety & U.S. Dept. of Transportation, NHTSA.

APPENDIX A

A.1 Charts which illustrate crash trends over 2006 to 2016

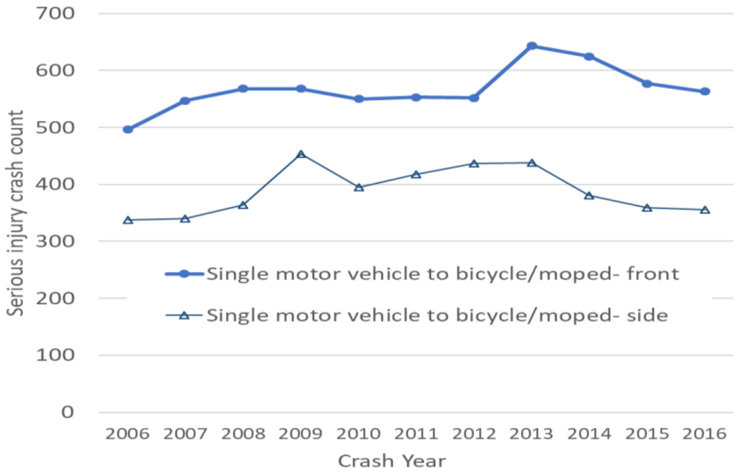


Figure 32 Serious injury crash count over 2006 to 2016 for bicycle and moped crashes

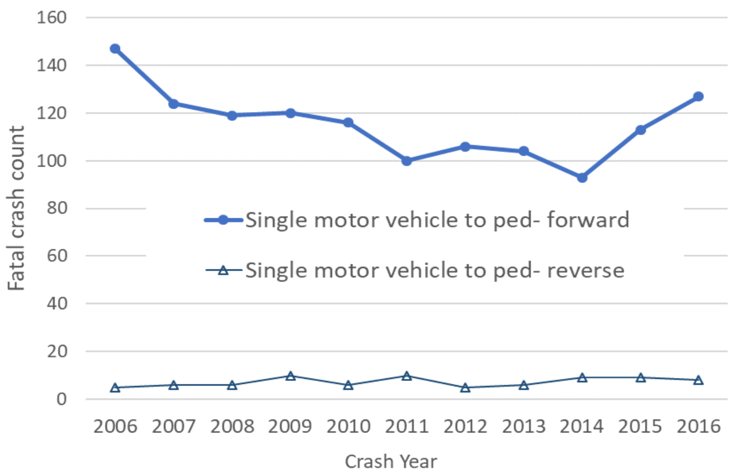


Figure 33 Pedestrian fatal crash count over 2006 to 2016

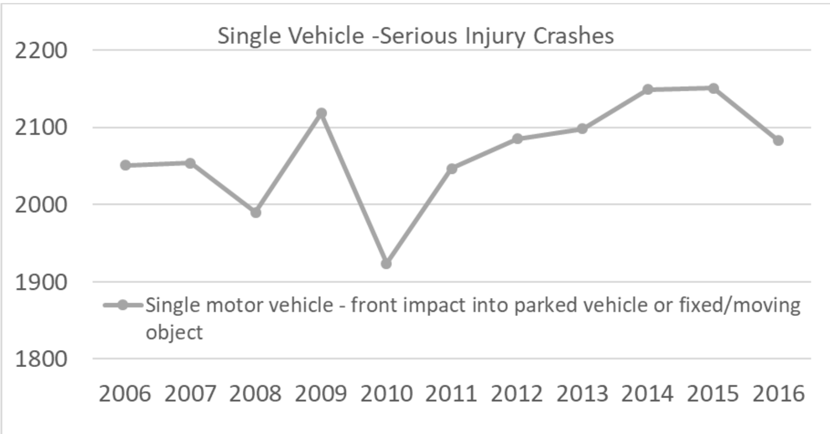


Figure 34 Rural single vehicle into object, serious injury count over 2006 to 2016

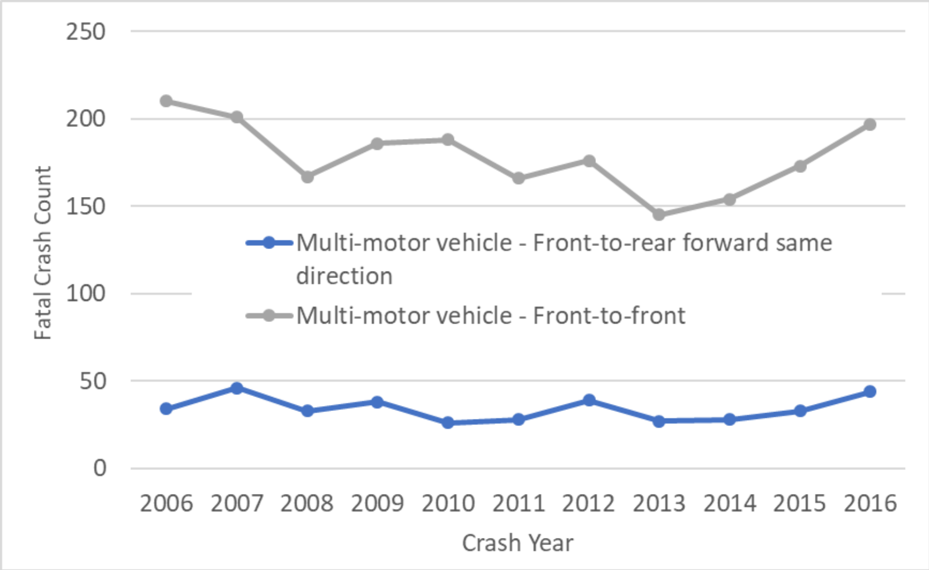


Figure 35 Recent increasing fatal crash count over 2006 to 2016 for multi-vehicle crashes

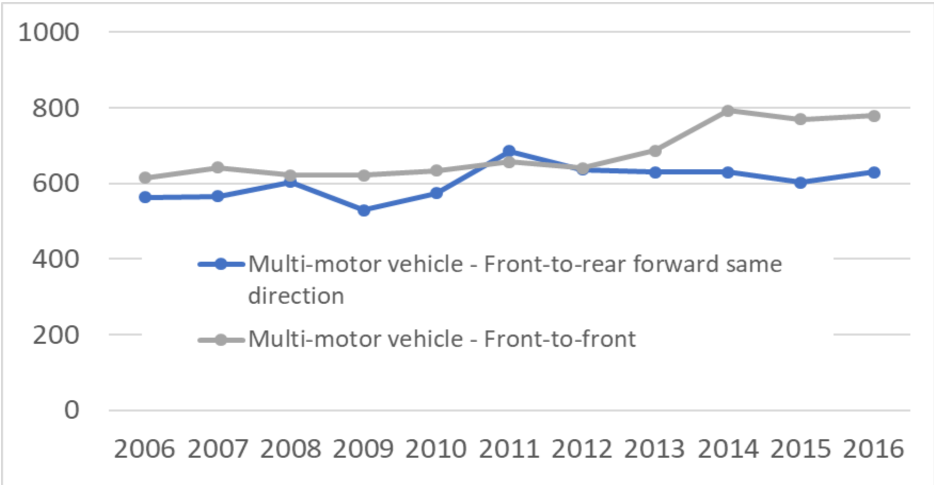


Figure 36 Increasing serious injury crash count over 2006 to 2016 for rural multi-vehicle crashes

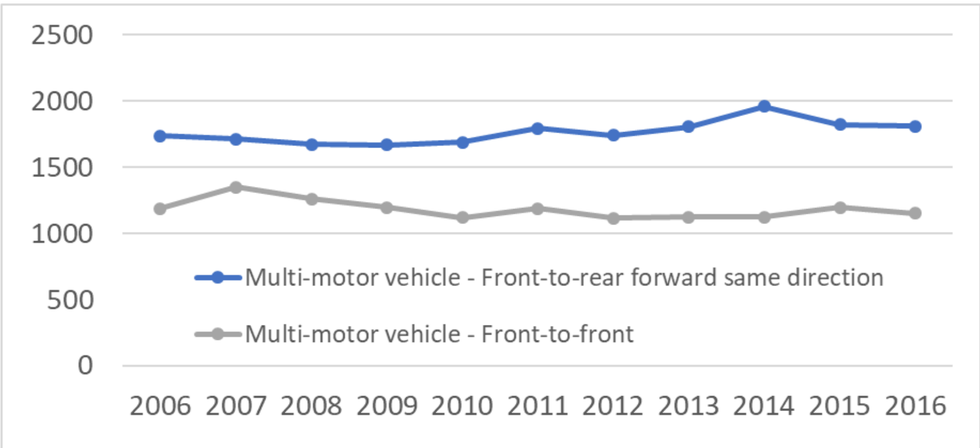


Figure 37 Increasing serious injury crash count over 2006 to 2016 for metropolitan multi-vehicle crashes

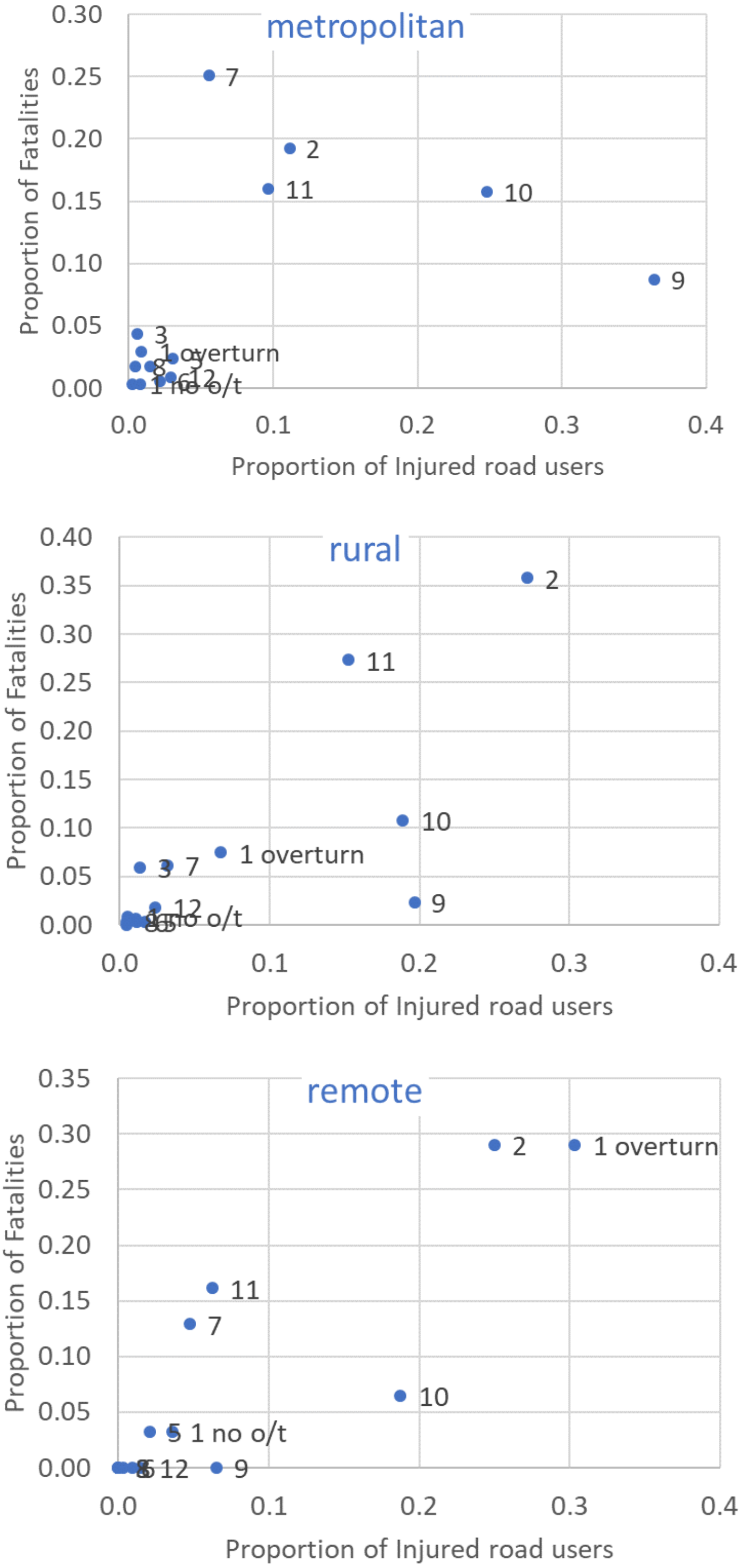


Figure 38 Proportion of injuries contributed by each crash type in 2016 by region

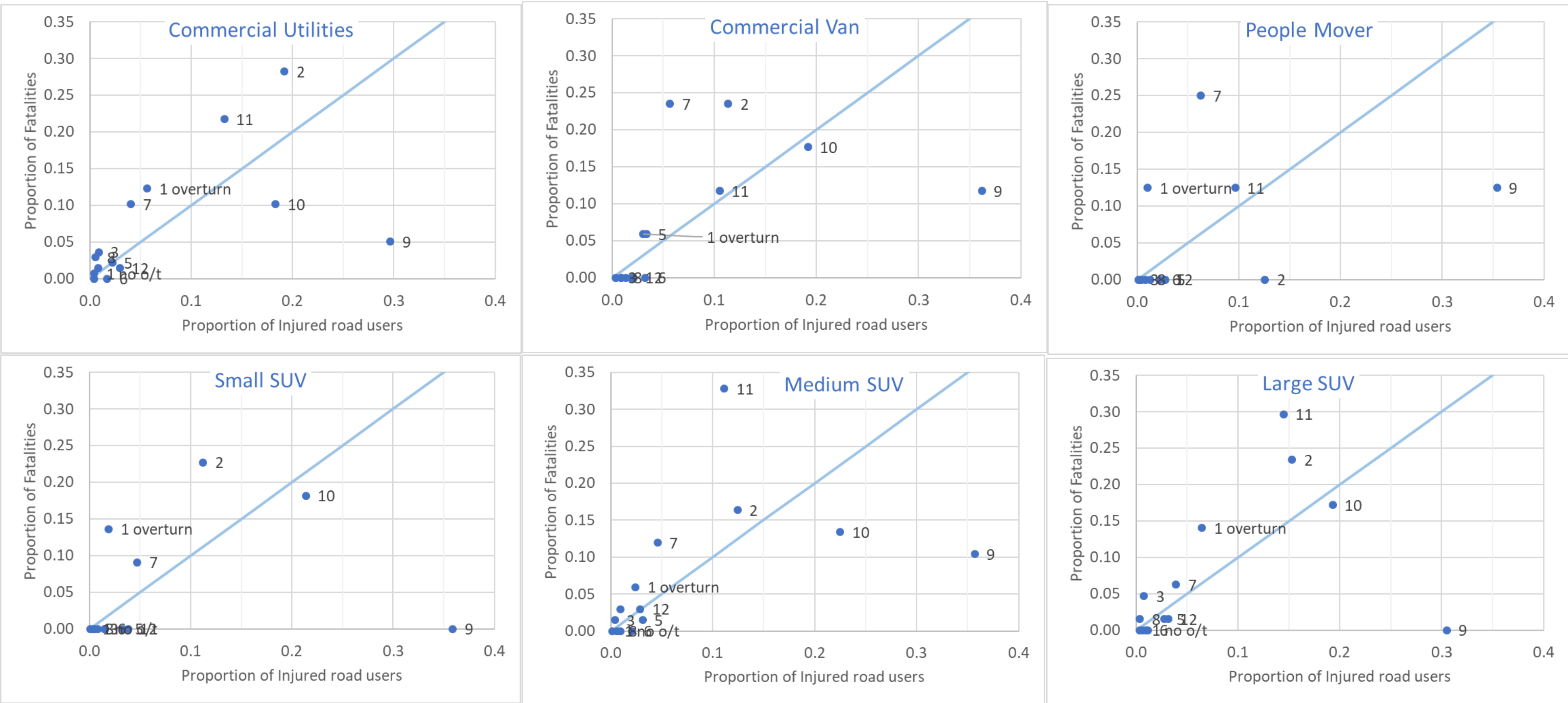


Figure 39 Proportion of injuries contributed by each crash type in 2016 by market group crash (I)

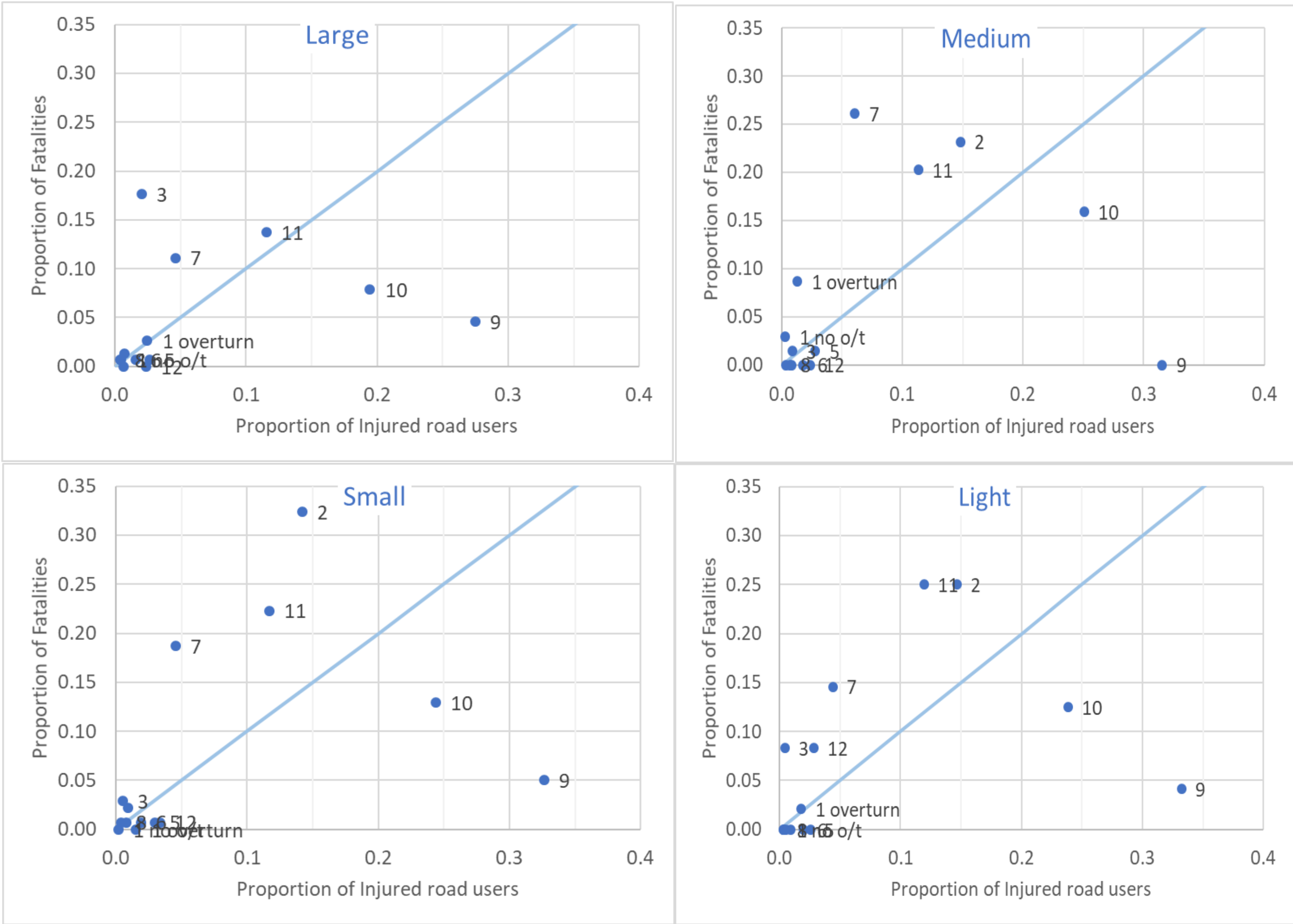


Figure 40 Proportion of injuries contributed by each crash type in 2016 by market group crash (II)

A.2 Charts demonstrating the distribution of sensitivity to active technologies, by crash type over 2006 to 2016

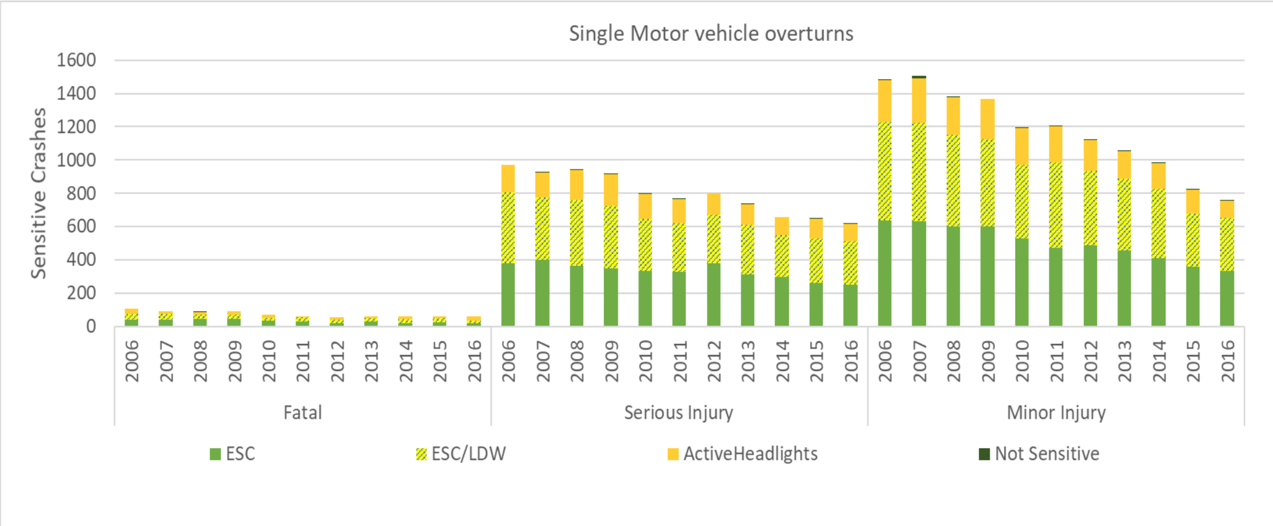


Figure 41 The distribution of technology sensitive crashes by severity and crash year for type 1 crashes with overturn

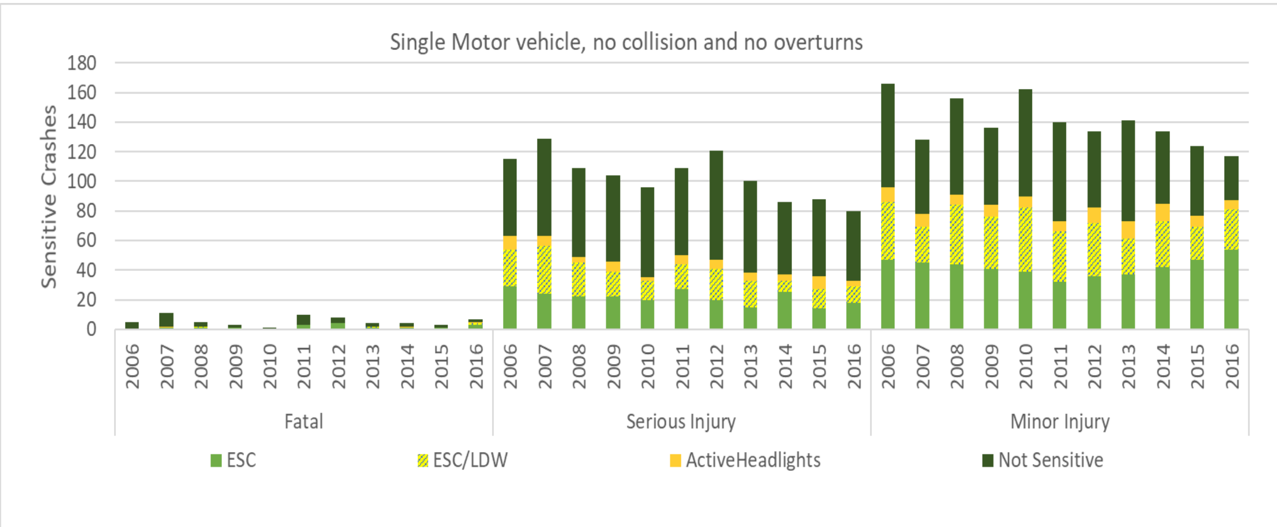


Figure 42 The distribution of technology sensitive crashes by severity and crash year for type 1 crashes with no overturn

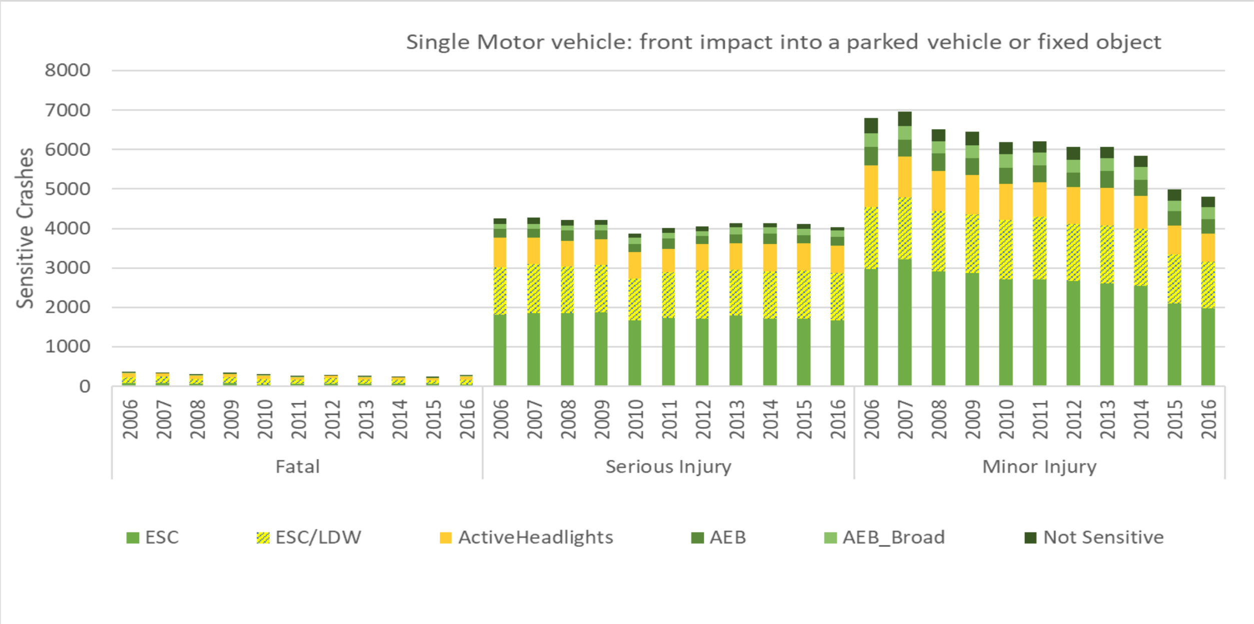


Figure 43 The distribution of technology sensitive crashes by severity and crash year for type 2 crashes

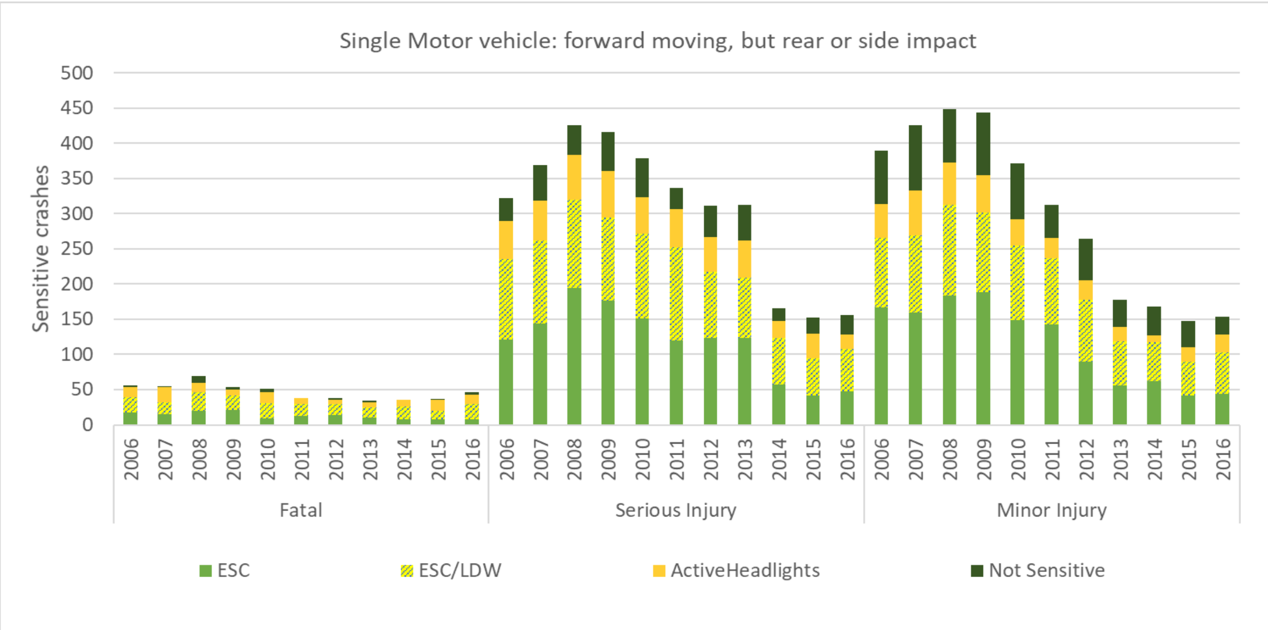


Figure 44 The distribution of technology sensitive crashes by severity and crash year for type 3 crashes

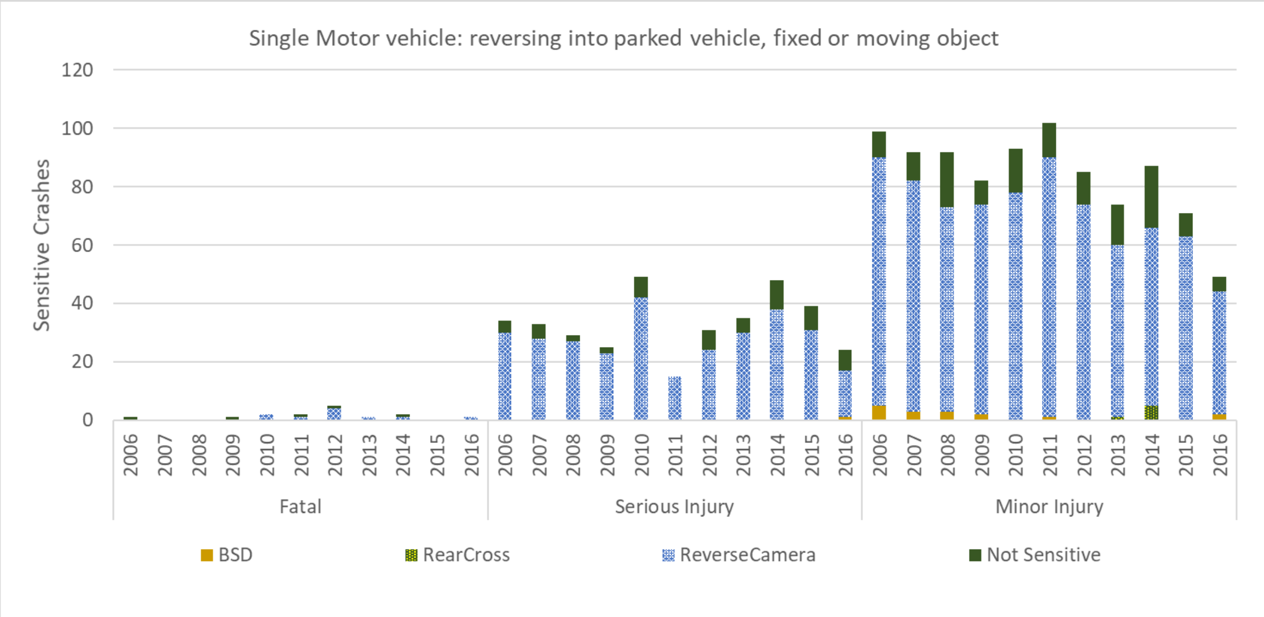


Figure 45 The distribution of technology sensitive crashes by severity and crash year for type 4 crashes

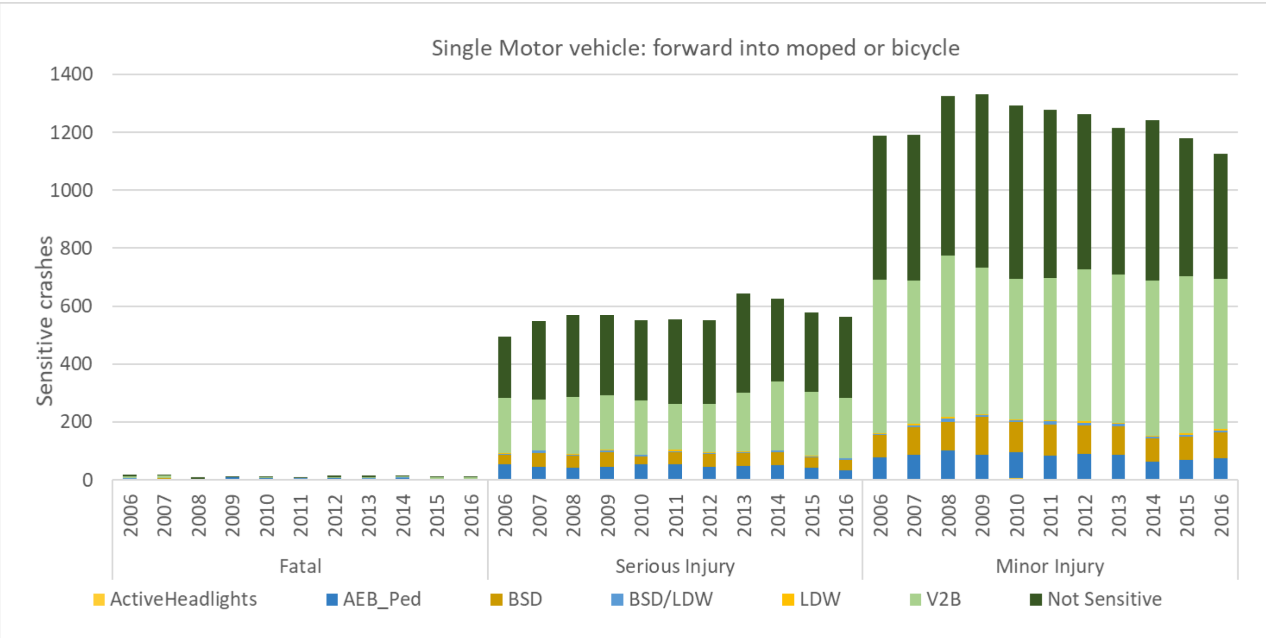


Figure 46 The distribution of technology sensitive crashes by severity and crash year for type 5 crashes

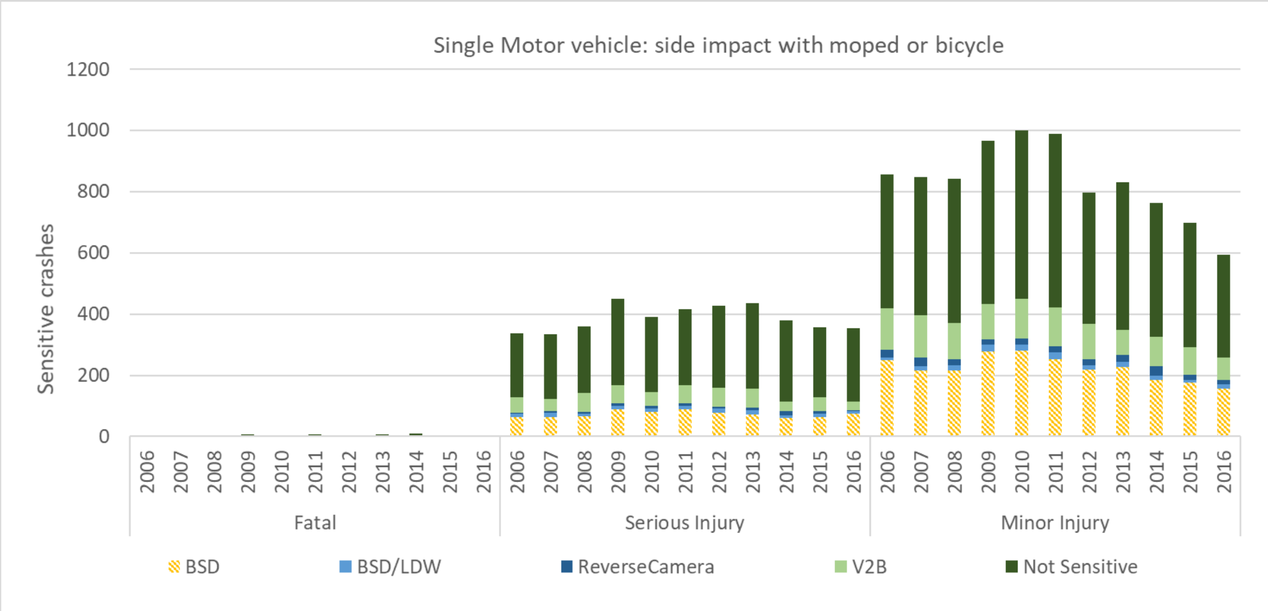


Figure 47 The distribution of technology sensitive crashes by severity and crash year for type 6 crashes with side impact

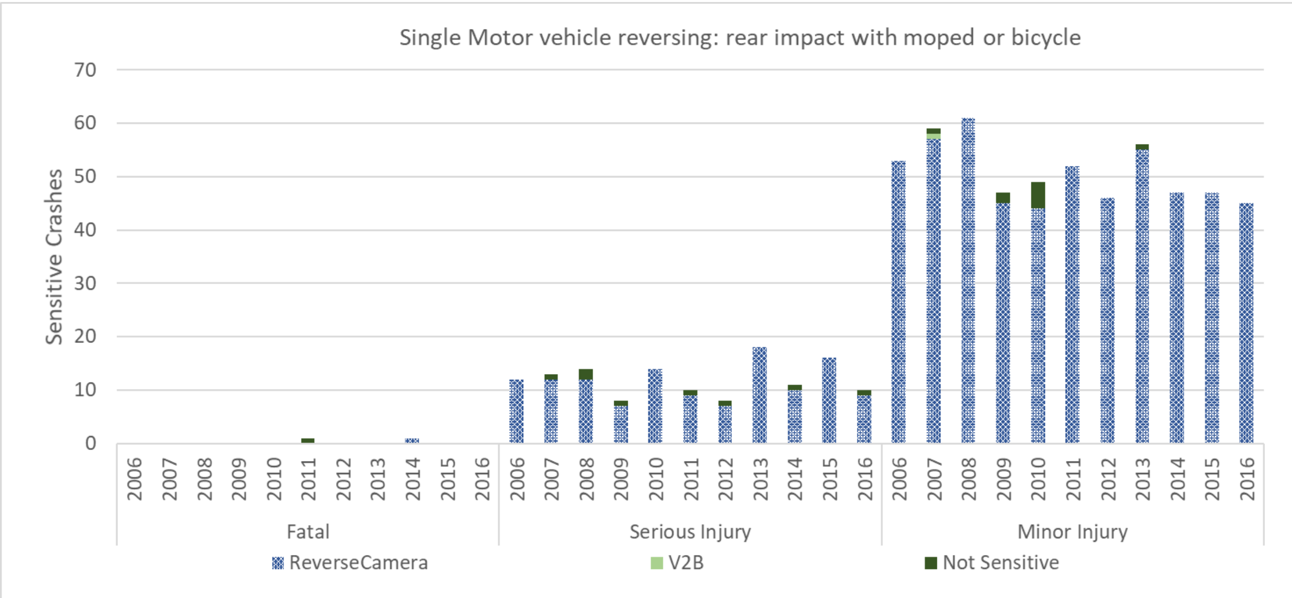


Figure 48 The distribution of technology sensitive crashes by severity and crash year for type 6 crashes with motor vehicle reversing

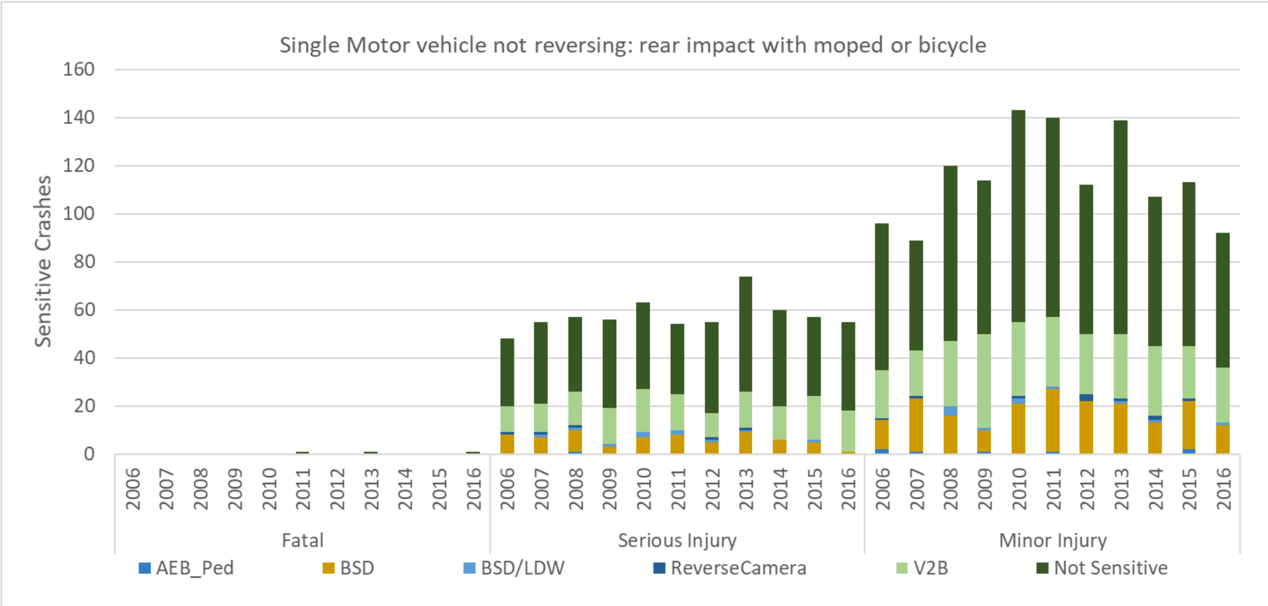


Figure 49 The distribution of technology sensitive crashes by severity and crash year for type 6 crashes with bicycle/moped running into rear of vehicle

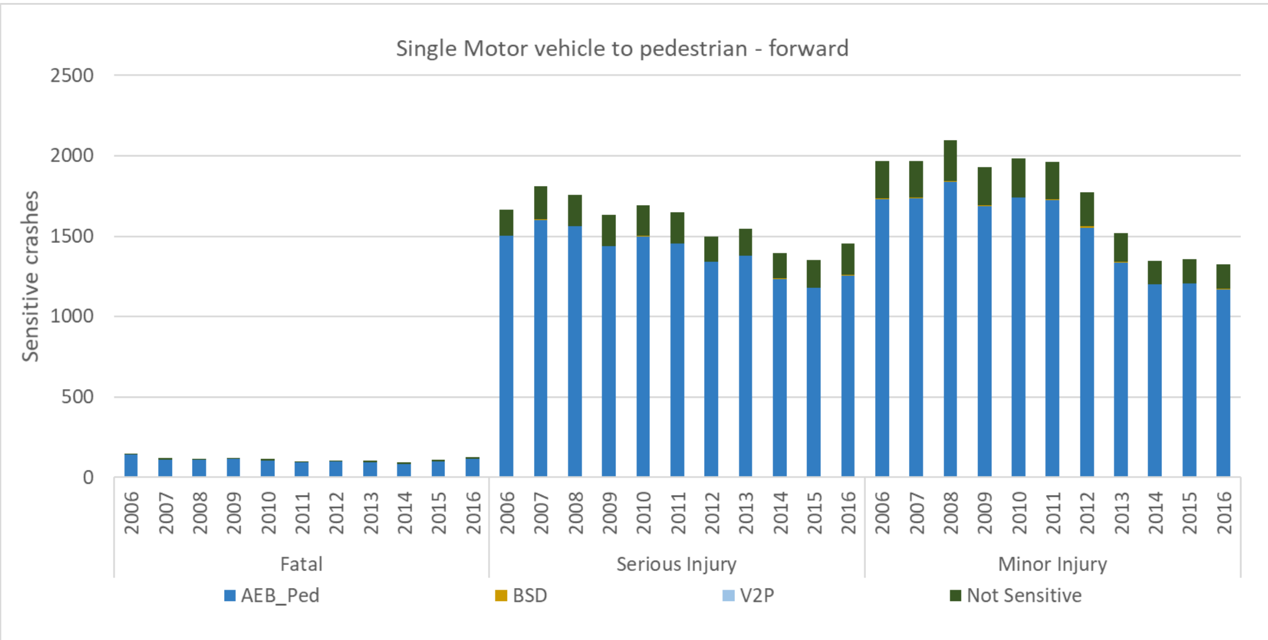


Figure 50 The distribution of technology sensitive crashes by severity and crash year for type 7 crashes

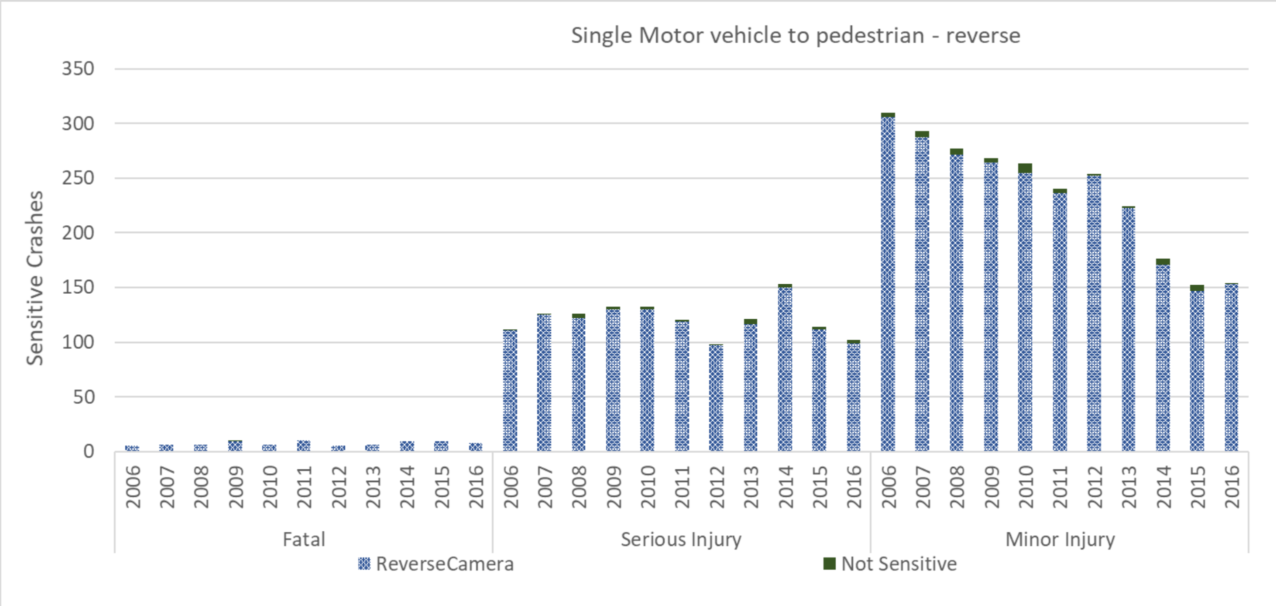


Figure 51 The distribution of technology sensitive crashes by severity and crash year for type 8 crashes

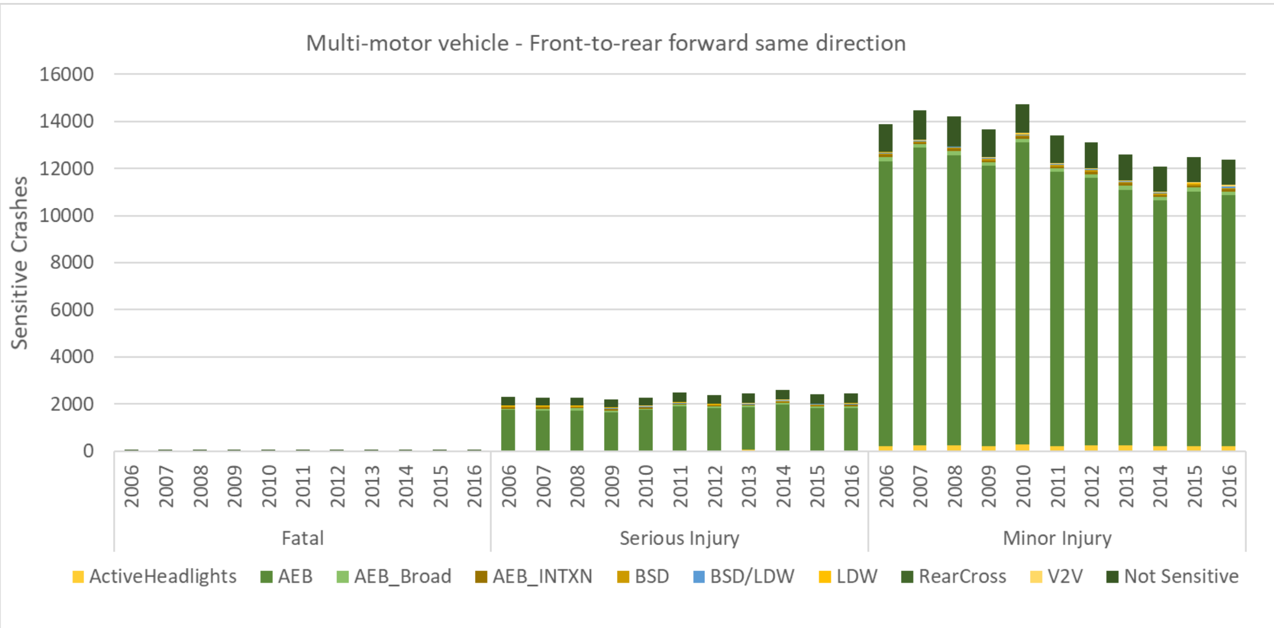


Figure 52 The distribution of technology sensitive crashes by severity and crash year for type 9 crashes: forward moving

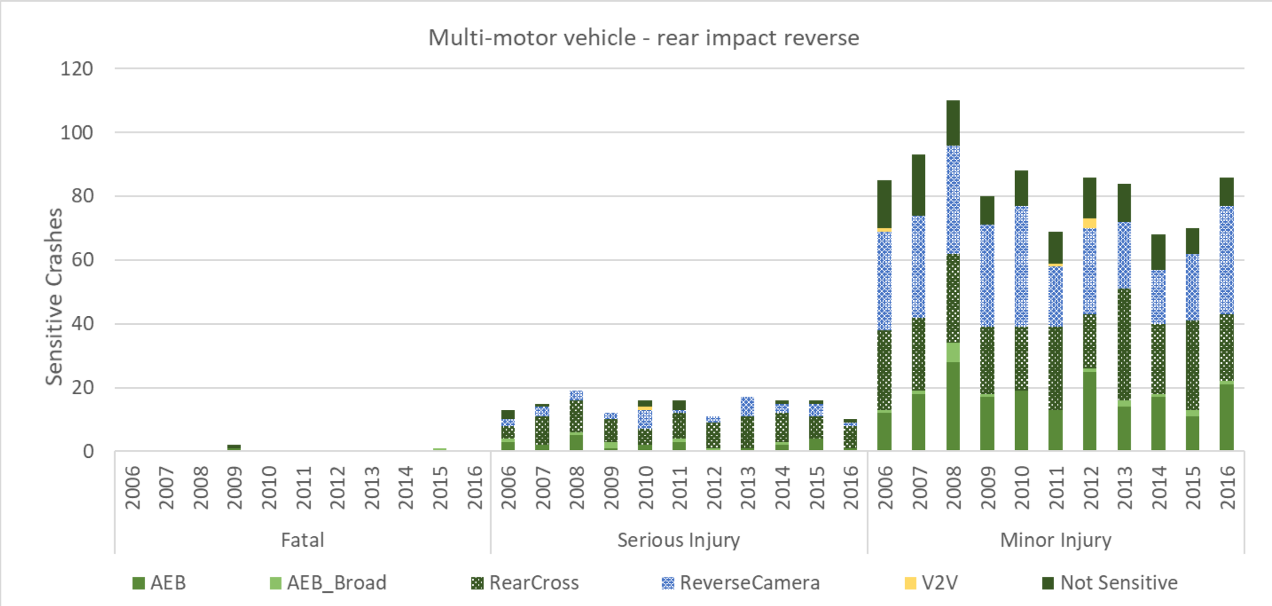


Figure 53 The distribution of technology sensitive crashes by severity and crash year for type 9 crashes: reversing

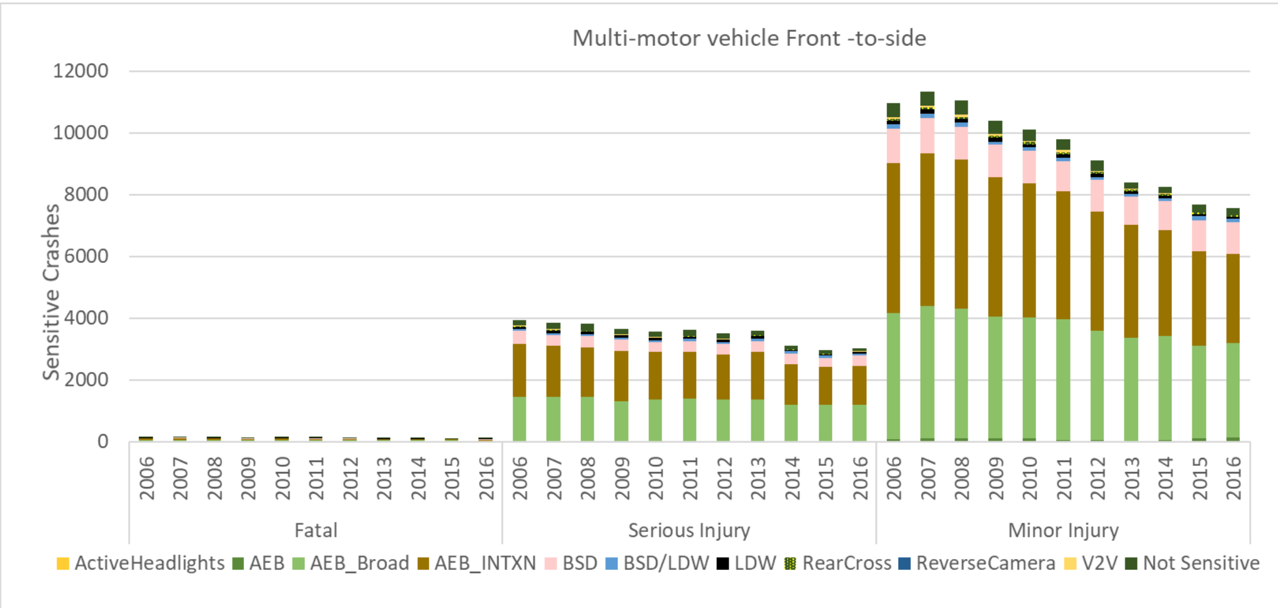


Figure 54 The distribution of technology sensitive crashes by severity and crash year for type 10 crashes: forward moving

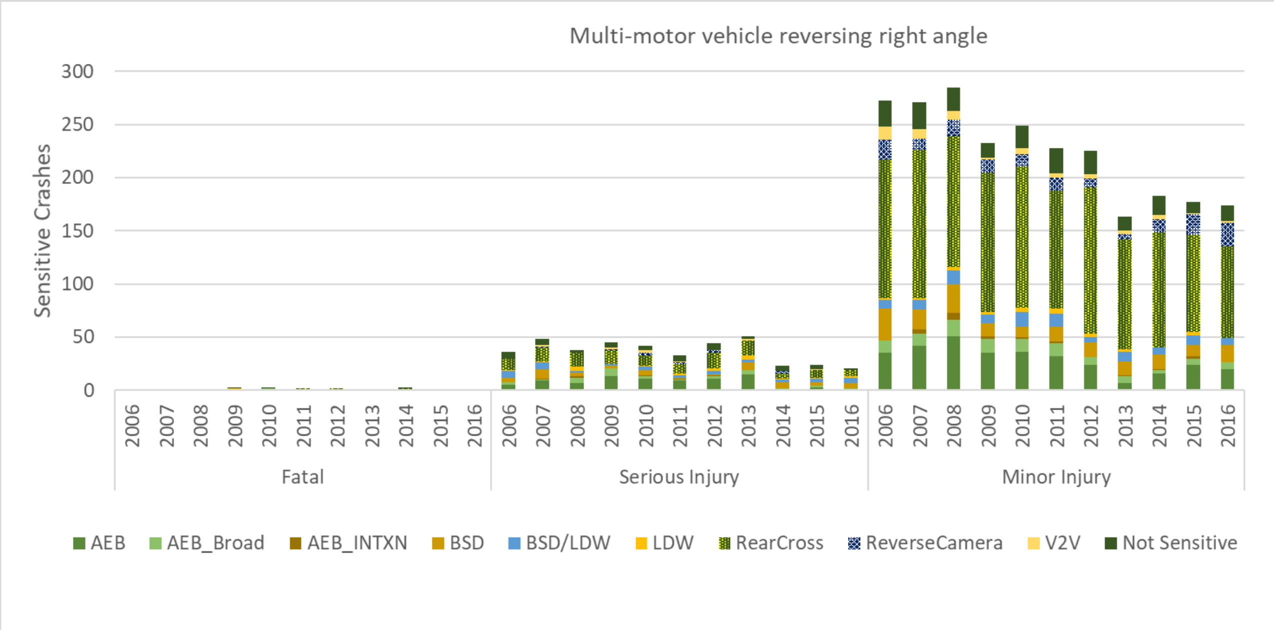


Figure 55 The distribution of technology sensitive crashes by severity and crash year for 10 crashes: reversing

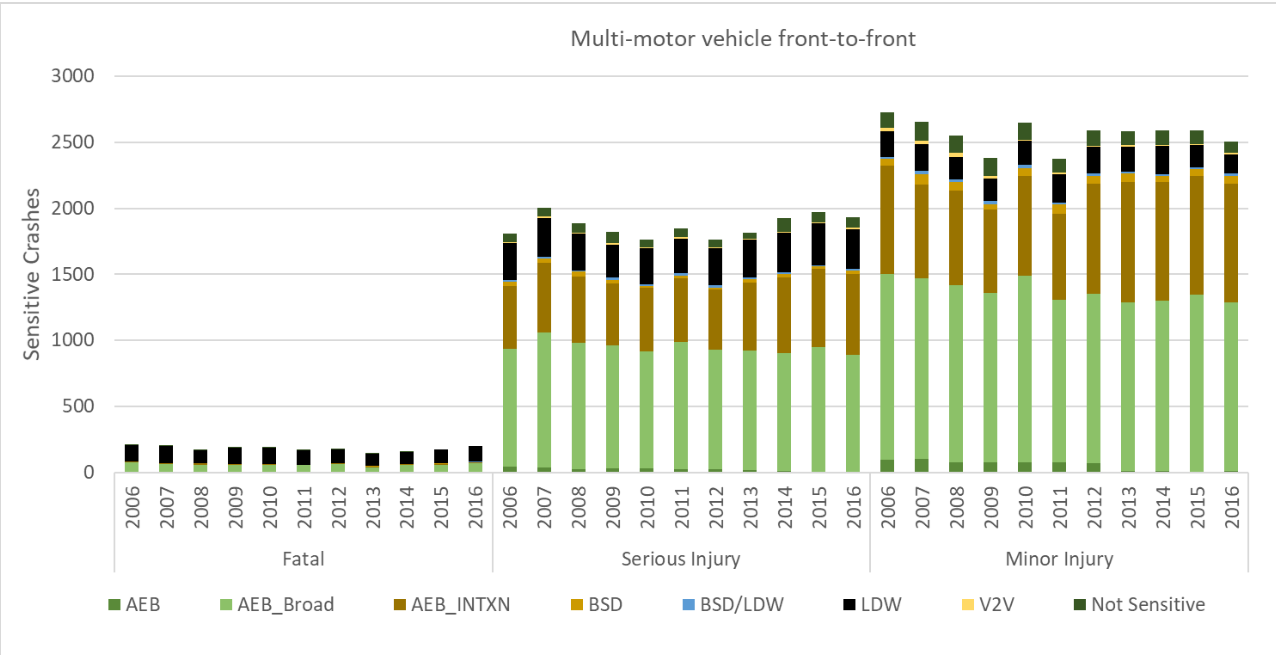


Figure 56 The distribution of technology sensitive crashes by severity and crash year for type 11 crashes

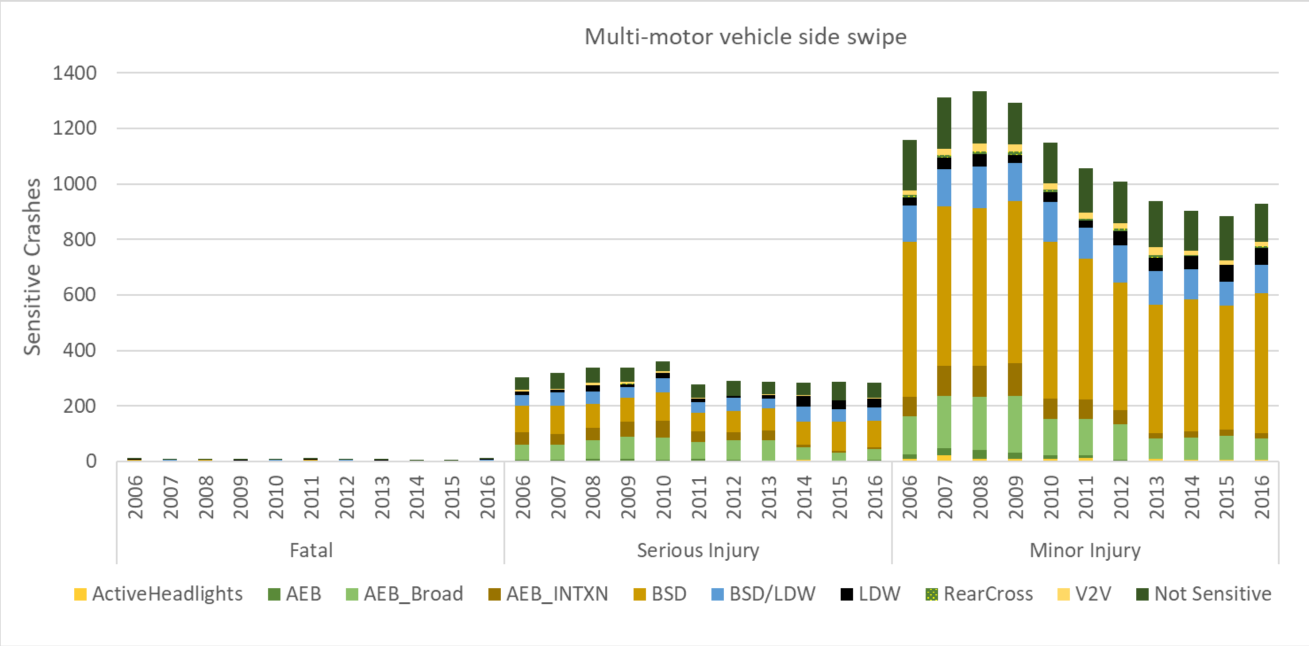


Figure 57 The distribution of technology sensitive crashes by severity and crash year for type 12 crashes

A.3 Charts demonstrating the proportion of injuries in crashes sensitive to a technology in 2016 by region, market group

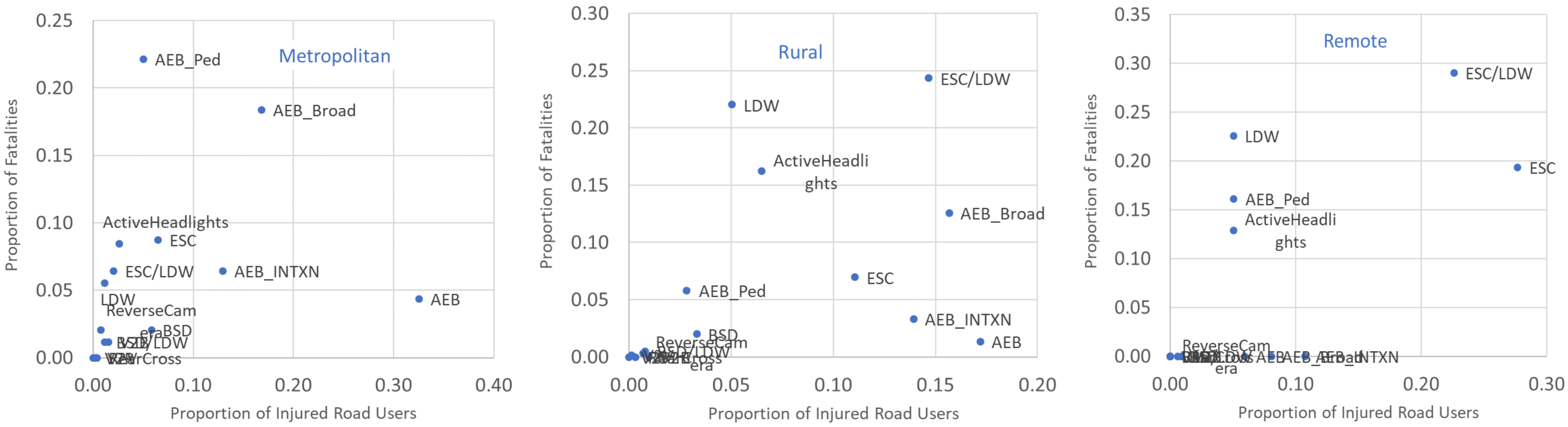


Figure 58 Rates of sensitivity by severity for active safety technologies in 2016 by Region

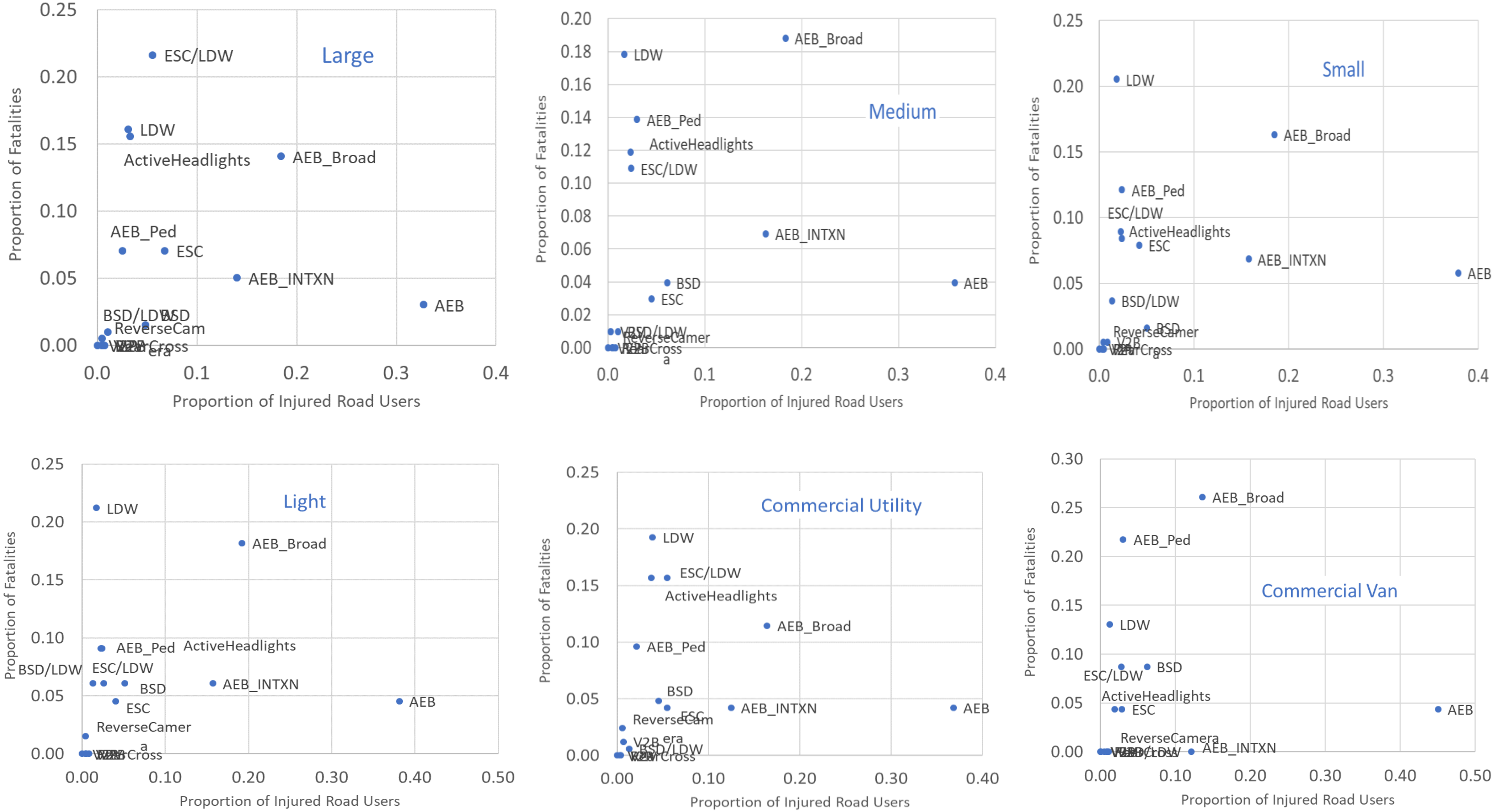


Figure 59 Rates of sensitivity by severity for active safety technologies in 2016 by Market Group (I)

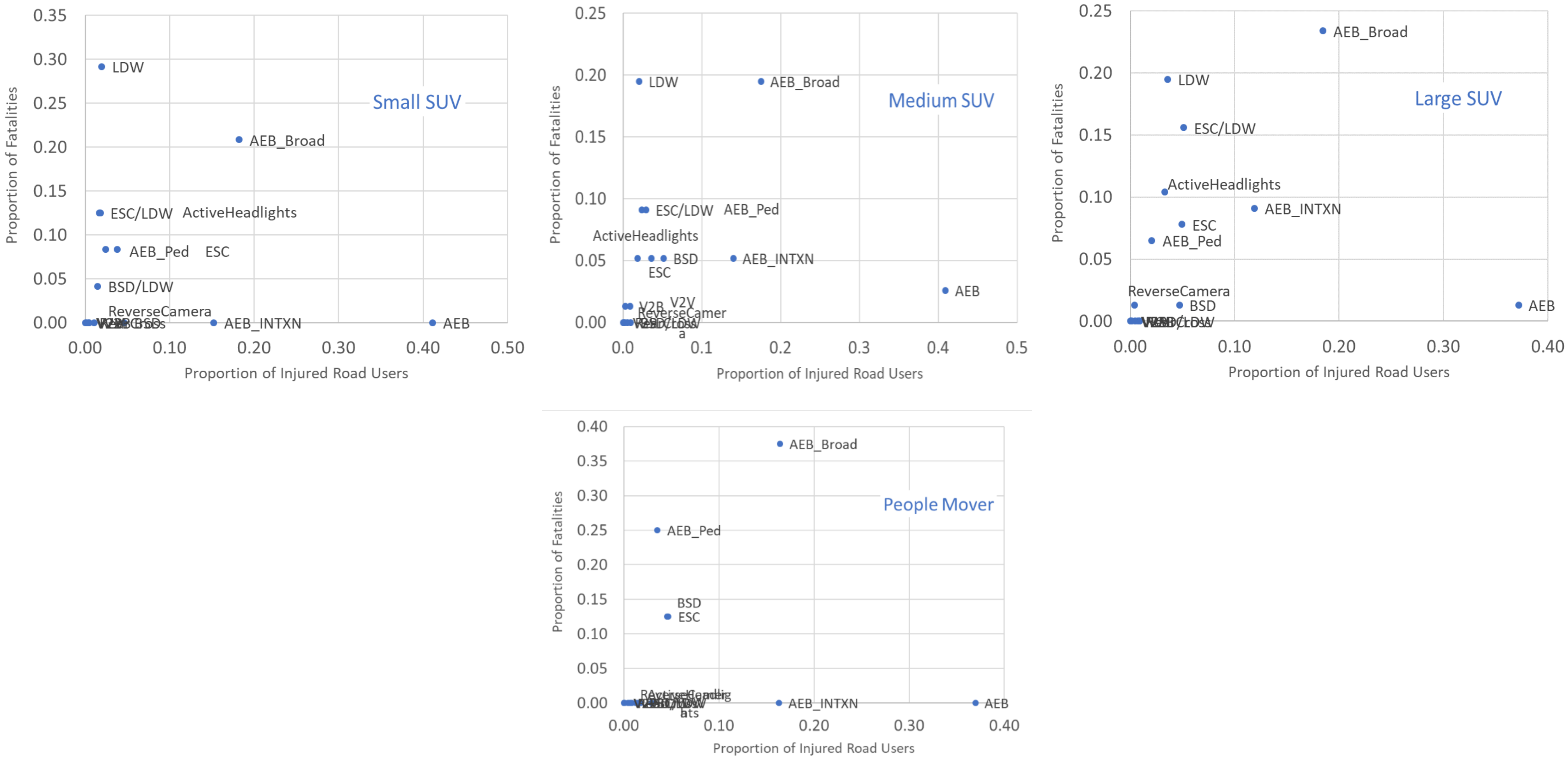


Figure 60 Rates of sensitivity by severity for active safety technologies in 2016 by Market Group (II)

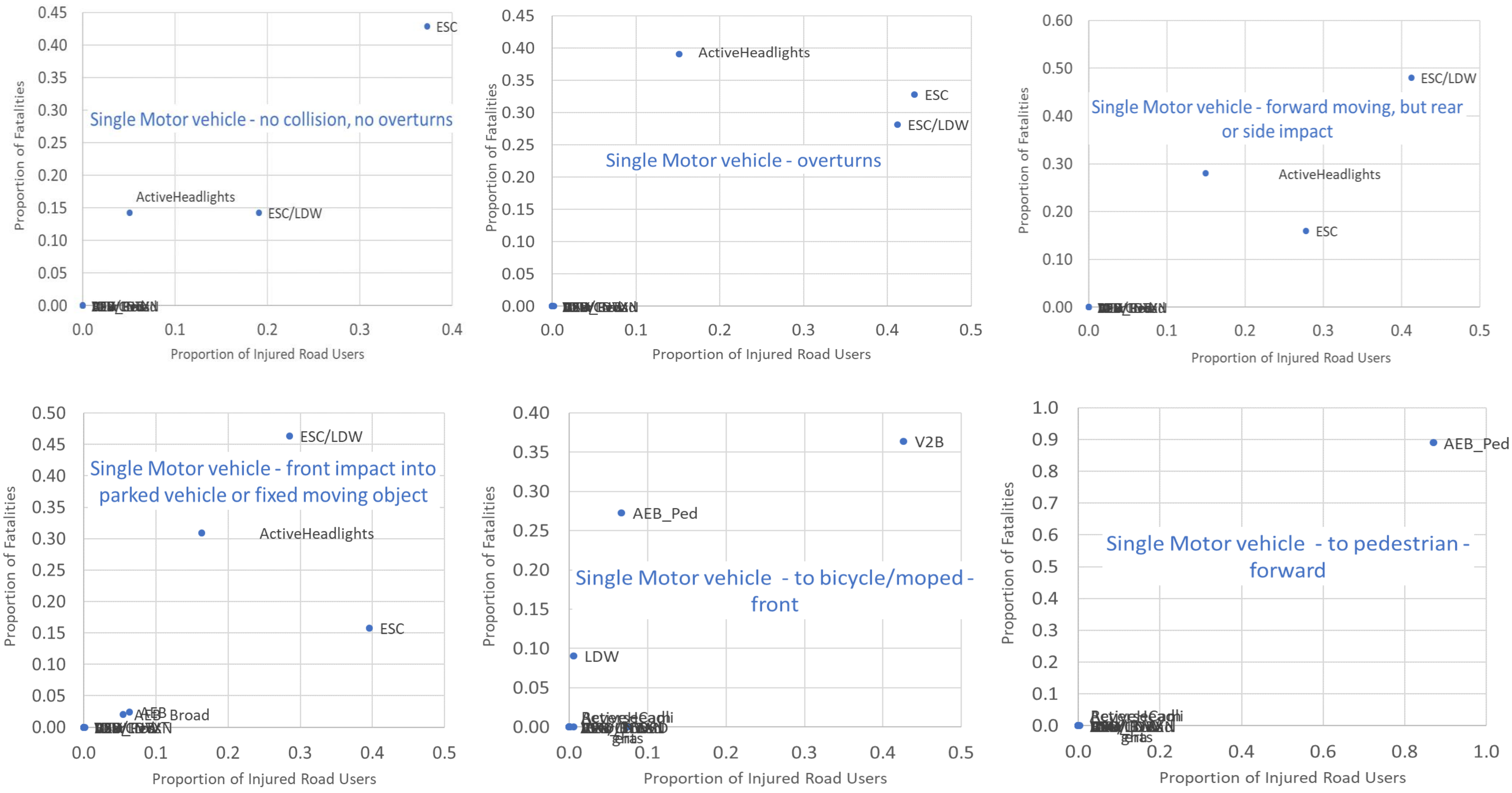


Figure 61 Rates of sensitivity by severity for active safety technologies in 2016 by Crash Type (I)

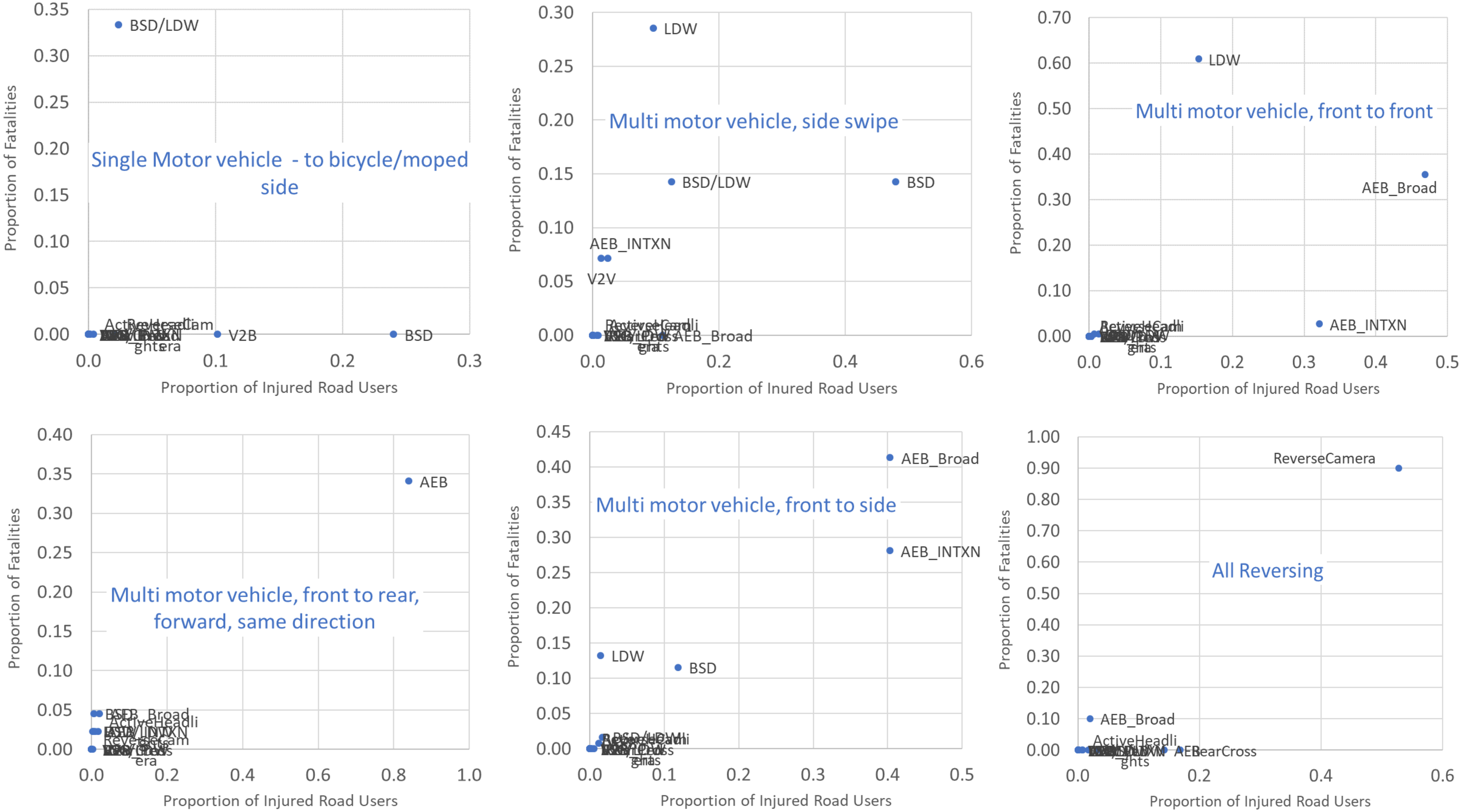


Figure 62 Rates of sensitivity by severity for active safety technologies in 2016 by Crash Type (II)

A.4 2016 crash counts by severity and crash type

Table 5 2016 crashes by crash type and crash severity

		2016 Crashes											
		Fatal				Serious				Minor			
	Crash Type	All	Metro	Rural	Remote	All	Metro	Rural	Remote	All	Metro	Rural	Remote
1	Single motor Vehicle - overturns	59	10	41	8	619	116	480	23	758	162	563	33
	Single motor vehicle, no collision, no overturn	7	1	5	1	80	39	37	4	117	54	59	4
2	Single motor vehicle - front impact into parked vehicle or fixed/moving object	267	63	198	6	4,044	1,930	2,083	31	4,822	2,348	2,450	24
3	Single motor vehicle - forward moving but rear or side impact	46	12	34	0	156	77	79	0	153	68	85	0
4	Single motor vehicle - reversing & impact into parked vehicle or fixed/moving object	1	1	0	0	24	16	8	0	49	34	15	0
5	Single motor vehicle to bicycle/moped- front	11	8	2	1	563	431	131	1	1,126	906	216	4
6	Single motor vehicle to bicycle/moped- side	3	1	2	0	356	269	86	1	597	507	90	0
	Single motor vehicle to bicycle/moped- reverse	0	0	0	0	10	7	3	0	45	37	8	0
	Single motor vehicle to bicycle/moped- bicycle runs into rear	1	1	0	0	55	37	18	0	92	74	18	0
7	Single motor vehicle to ped- forward	127	86	37	4	1,463	1,159	298	6	1,335	1,052	277	6
8	Single motor vehicle to ped- reverse	8	6	2	0	102	65	37	0	154	107	47	0
9	Multi-motor vehicle - Front-to-rear forward same direction	44	30	14	0	2,445	1,811	630	4	12,372	10,321	2,039	12
	Multi-motor vehicle - rear to front reverse	0	0	0	0	10	7	3	0	86	58	28	0
10	Multi-motor vehicle - Front-to-side	109	47	60	2	3,030	2,194	819	17	7,570	5,909	1,636	25
	Multi-motor vehicle - reversing right angle	1	1	0	0	21	19	2	0	175	155	20	0
11	Multi-motor vehicle - Front-to-front	197	51	142	4	1,933	1,153	778	2	2,508	1,648	854	6
12	Multi-motor vehicle - side swipe	12	3	9	0	285	189	95	1	930	721	205	4
	Multi-motor vehicle - Rear-to-rear	0	0	0	0	10	9	1	0	54	38	16	0
other	Crash with only light vehicles not in first event	8	5	3	0	250	192	58	0	356	274	81	1
	Movement unknown, light vehicles in first event	2	1	1	0	38	22	16	0	110	83	26	1

A.5 Active technology published effectiveness

Table 6 Effectiveness used in estimating potential crashes avoided

Technology	Source	Target	Fatal Crashes	Serious Injury Crashes	Minor Injury Crashes
ESC	Scully and Newstead (2010)	All causes as per Table but all LCV, SUVS & SL were included Car & LCV	24 (-29, 41)	24 (-29, 41)	23 (12, 32)
		SUV	57 (-52, 82)	57 (-52, 82)	64 (52, 74)
FCW + AEB	Cicchino (2017)	Table Front-to-rear	56 (24, 74)	56 (24, 74)	56 (24, 74)
AEB		Table Front-to-rear (and LTAPOD ≤60kph speed zone as proxy for 40 kph travelling speed)	45 (40, 48)	45 (40, 48)	45 (40, 48)
AEB-Intersection	Scanlon, Sherony et al. (2017)	Straight crossing path	38-79	38-79	25-59
LDW/LKA	Sternlund (2017)	Table head on and single vehicle)- no cause required	53 (11,..)	53 (11,..)	53 (11,..)
	Cicchino (2018)	Table side-swipe with no intentional lane change & no pedestrian or bicycle collisions	21 (-2,38)	21 (-2,38)	21 (-2,38)
BSD/SVA	Cicchino (2018)	Proportion of table with intentional lane change	: 23 (-6, 44)	: 23 (-6, 44)	: 23 (-6, 44)
ADHL	Strandroth, Lie et al. (2017)	Single vehicle only, as per table, not required to be on curve	39 (11, 59)	39 (11, 59)	39 (11, 59)
	Jermakian (2011)	As per table (dark, curve)	88	91	91
Rear cross-traffic alert	Cicchino (2019)	As per Table	32 (0,54)	32 (0,54)	32 (0,54)
Reversing camera	Keall, Fildes et al. (2017)	Pedestrian-car as per table	41 (12,61)	41 (12,61)	41 (12,61)
	Cicchino (2017)	Reversing cars to any road user	17 (7,25)	17 (7,25)	17 (7,25)
V2V	Kusano and Gabler (2014)	TIP/SD	20	20	20
V2V (IMA)	NHTSA (2016)	Straight crossing path aka perpendicular crossing path (at non-signalised intersections)	43-55	43-55	43-55
V2V (LTA))		LTAP/OD	37-63	37-63	37-63
V2V +AEBS	Doecke, Grant et al. (2015)	All other tabled V2V	37-86	37-86	37-86

Table 7 Effectiveness used in estimating potential injuries avoided

Technology	Source	Target	Fatal Injuries	Serious Injuries	Minor Injuries
AEB-Ped	Toshiyuki and Yukou (2017)	Pedestrian crashes	5	12	20
AEB less sensitive	Budd, Stephens et al. (2019)	As per Table	10 (3,17)	10 (3,17)	10 (3,17)
AEB (general system on pedestrian)		Pedestrian crashes	-	-	28 (3, 47)
V2B	Silla, Leden et al. (2017)	Cyclist crashes	~45%	~47%	~47%
V2P	Silla, Rämä et al. (2017)	Pedestrian crashes	~45%	~47%	~47%

GLOSSARY

"**Crashworthiness ratings (CWR)**" assess the risk of fatal or serious injury to the driver of a vehicle involved in a crash (where the vehicle is damaged enough to be towed away, or some injury occurs in the crash).

"Aggressivity (AGG)" is a measure of the risk of injury or serious injury that a vehicle poses to road users other than its own occupants (including other vehicle drivers, pedestrians, motorcyclists and bicyclists) (Newstead, Keall et al. 2011).

"Total Secondary Safety Ratings (TSS or TSS or TSI)" encompasses crashworthiness and aggressivity, by assessing the risk of a fatal or serious injury in a crash (where the injured party may be an occupant of the vehicle, or another road user). Total Secondary Safety Ratings are used interchangeably with Total Secondary Safety Indices.

"Primary safety ratings (PSR or PSI)" provide a measure of the vehicle's ability to enable the driver avoid a crash (Keall and Newstead 2015). Primary Safety Ratings are used interchangeably with Primary Safety Indices.

"**Active safety systems"** are vehicle safety systems which prevent crashes from occurring. They include both warnings and automated systems which actively steer or brake. These may also be called **primary safety systems.**

"**Passive safety systems"** are vehicle safety systems which prevent or mitigate injury produced by a vehicle crash. They include seat belts, airbags, and crumple zones. These may also be called **secondary safety systems.**

MONASH University

ACCIDENT
RESEARCH
CENTRE

Further information

Associate Professor Stuart Newstead
Monash University Accident Research Centre
21 Alliance Lane
Monash University Clayton Campus
Victoria 3800
Australia

T: +61 (0)3 9905 4364
E: stuart.newstead@monash.edu

monash.edu.au