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POTENTIAL SAFETY BENEFITS OF EMERGING CRASH AVOIDANCE TECHNOLOGIES IN AUSTRALASIAN HEAVY VEHICLES

by

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Abstract:

This study estimates the potential crash reduction effects of fitting various emerging safety technologies to heavy vehicles in Australia and New Zealand. Technologies considered included: Electronic Stability Control, Autonomous Emergency Braking Systems, Fatigue Warning Systems and Lane Departure Warning Systems. Benefits were estimated in terms of savings of fatal, serious and minor injuries, as well as for property damage only crashes.

Estimated annual fatal and serious injuries prevented in heavy vehicle crashes by mandatory fitment of the chosen safety technologies were estimated by considering the three most recent years of available police reported crash data. The crash reduction effects of fitting all heavy vehicles with the technology were considered and converted to an annual crash saving figure.

Because of its association with the most prevalent crash types, *Autonomous Emergency Braking Systems* at all speeds was estimated to produce the biggest fatal and serious injury reductions, preventing up to a quarter of fatal crashes (which translates to $AUS187 million and $NZ62 million)

Mandated *ESC* fitment to trucks was valued with almost three times the cost saving estimate for New Zealand than for Australia, due to the greater proportion of crashes sensitive to this technology observed in New Zealand.

This report has conservatively quantified the potential of vehicle safety technology to contribute to achieving targets for road trauma reductions set out in state and national road safety strategies in Australia and New Zealand. It has made recommendations of mandatory fitment AEBS, ESC, FWS and LDWS to new heavy vehicles with compatible braking systems on the basis of these evaluations.

Key Words:
Electronic Stability Control, Autonomous Emergency Braking Systems, Fatigue Warning Systems, Lane Departure Warning Systems, Vehicle Safety, modelling, Heavy Vehicles

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Preface

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Contributor Statement

Laurie Budd	Data preparation and analysis, study design, preparation of report manuscript
A/Prof. Stuart Newstead	Project management, study concept and design and manuscript review.

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Ethics approval was not required for this project.

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EXECUTIVE SUMMARY

Vehicle manufacturers respond to both government mandate and consumer demand with an ever-increasing offering of standard and optional safety features in their vehicles, both proven and unproven in effectiveness. This report uses police reported crash data from Australia and New Zealand to estimate the potential road trauma reduction benefits of fitting the heavy vehicle fleet with some emerging safety technologies in terms of savings in fatal, serious injury, minor injury and property damage only crashes.

Over the period 2008-2013 in Australia, there has been greater growth in heavy vehicle registrations and exposure, than for passenger vehicles with recent rigid truck registrations growth more than double, and recent articulated truck exposure growth more than twenty times that for passenger vehicles. The proportion of crashed vehicles that are heavy has remained stable at 4% from 2000 to 2010, however, it is expected that given the exposure and registration growth, the proportions in 2011, 2012 and 2013 have increased, particularly for articulated trucks. In fact, an Australian trend of increasing crashes over 2002-2010 was observed for some heavy vehicle classes including road trains and observed in remote regions.

Analysis of the available data found that heavy vehicles were disproportionately involved in more severe crashes, with 13% of fatal crashes involving heavy vehicles compared with 3-4% of lesser severity crashes. Over 2008-2010, fatal heavy vehicle crashes were more likely to occur in rural regions (63%, Australia, 73% New Zealand). In addition, fatal and serious injury heavy vehicle crashes in rural and remote areas were more likely to involve articulated trucks and road trains. Amongst heavy vehicles, the fatalities per fatal crash were found to be greatest for these two heavy vehicle types.

This does not mean that there is no heavy vehicle crash issue in metropolitan regions. It was of particular concern that the majority of non-fatal heavy vehicle collisions were occurring in population dense areas, where the collision partner is generally a smaller vehicle offering less protection with a commensurately greater severity of injury resulting than would be incurred in a light passenger vehicle to light passenger vehicle collision. Metropolitan crashes are frequently at intersections; around 40% of the non-fatal heavy vehicle crashes occurred at intersections. Metropolitan heavy vehicle crashes more frequently involved rigid trucks and buses. Bus crashes in particular were found to present a 3-8 times greater risk of a pedestrian injury crash than did other heavy vehicle types.

Analysis estimated the savings that would be made if specific primary safety technology fitment were mandated for heavy vehicles including; Electronic Stability Control (ESC), Autonomous Emergency Braking Systems (AEBS), Fatigue Warning Systems (FWS) and Lane Departure Warning Systems (LDWS). The savings were estimated through considering fitment to heavy vehicles of all years of manufacture crashing from 2008 to 2010 in NZ, NSW, VIC, SA and WA and from 2007-2009 in QLD and averaged to give an annual crash reduction. Annual Australian crash cost savings were calculated using the average 2006 crash costs published by BITRE (Bureau of Infrastructure Transport and Regional Economics [BITRE] 2009) indexed via CPI to 2013 dollars (Australian Bureau of

Statistics 2006). Annual New Zealand crash cost savings were similarly estimated from CPI (Statistics New Zealand) adjusted New Zealand Ministry of Transport average 2012 crash costs (Financial Economic and Statistical Analysis Team 2013). An estimation of the possible lifetime savings for a cohort of all heavy vehicles manufactured in 2010 was approximated using the cross section of crashed heavy vehicles averaged over the three years. The possible savings to society was shown without consideration of the cost involved in adding the safety technologies to the vehicles, so a Break-Even cost was provided to determine the expenditure per vehicle possible before the crash savings equal the cost of fitment. The break even cost represents the average trauma cost savings per vehicle due to fitting the technology and was calculated for both vehicles with a 2010 year of manufacture and for vehicles across all years of manufacture. The former provides the break-even cost in the first year of a vehicle's life and the latter approximates the break even cost over a vehicle's lifetime.

Because of their association with the most prevalent crash types, *Autonomous Emergency Braking Systems (AEBS)* at all speeds, in all heavy vehicles, were estimated to produce the largest percentage reduction in fatal heavy vehicle crashes. A 25% fatal crash decrease was estimated to be valued at $62-187M for Australia and $21-62M for New Zealand. In terms of lives saved annually, this translated to 67 in Australia and 14 in New Zealand. The Australian heavy vehicle type with the greatest estimated savings in fatal crashes associated with AEBS fitment were rigid trucks, however, monetary savings for prime movers was highest ranging from $24-73M (cf. $23-68M for rigid trucks). Australian AEBS break even costs, over all crash severities, in the first year of a new vehicle, amounted to, at most, only $200, however, over a lifetime, break-even costs were estimated at up to $10,300 per registered vehicle.

With 83% of Australian heavy vehicle crashes involving another vehicle which in 89% of cases was a light passenger vehicle, analysis estimated that more than half of all heavy vehicle crashes were considered sensitive to (possibly prevented by) AEBS technology; 70% for Australian fatal, 77% for New Zealand fatal and 65% for serious injury crashes. Rigid trucks were the heavy vehicle type estimated to have the greatest potential crash saving benefits from AEBS and were the most prevalent heavy vehicle type in metropolitan crashes. Growth in some of the already substantial proportions of AEBS sensitive crashes heavy vehicle crashes was also observed. In Australia this included fatal and serious injury multi-vehicle bus and road-train crashes and collisions with unprotected vehicles (bicycles and motorcycles) of all severities. When considering this growth in conjunction with the demonstrated heavy vehicle crash problem in metropolitan areas and the estimated benefits of AEBS, particularly for rigid trucks, there is a strong case for mandating AEBS in an attempt to reduce metropolitan heavy vehicle crashes and in particular, those involving more vulnerable road users.

Lane Departure Warning Systems, Electronic Stability Control and Fatigue Warning Systems if fitted to all heavy vehicles were estimated to potentially save 16, 11 and 10 and 10, 5 and 4 fatalities per year in Australia and New Zealand respectively. Each of these technologies were estimated to be able to prevent approximately 4-6% of Australian fatal heavy vehicle crashes, saving society a possible $45, $31 and $28 million respectively if mandated in all heavy vehicles. The proportion of New Zealand fatal heavy vehicle crashes that could be prevented by these technologies was higher than in Australia. Combined with higher New Zealand Crash costs, similar cost savings associated with each technology were estimated for New Zealand of $45M, 24M and $16M respectively. Australian Break-Even costs, over crashes of all severities, for each of these technologies in the first year amounted to less than $60. However, over a lifetime, the break-even costs ranged from $2,000 to $3,000 per registered vehicle.

Heavy vehicle crash data over 2002-2010 showed growth in road train crashes, in heavy vehicle exposure, in proportions of fatal heavy vehicle crashes in rural areas, and crash types potentially prevented by ESC, LDWS and FWS. It also showed large proportions of more serious crashes to be sensitive to these technologies, and particularly so for articulated trucks and road trains. Observed crash growth and relevance of each technology in preventing serious crashes suggests encouraging and ultimately mandating these technologies will assist in reducing deaths and serious injuries from crashes involving heavy vehicles..

It should be noted that the crash savings attributable to these technologies are not mutually exclusive although there is some potential synergistic benefits from combinations of the technology. Although LDWS, ESC and FWS are targeted to essentially loss of control crashes, they have different mechanisms and limitations so will act on different crashes within this general loss of control crash type. ESC is the only system that responds to yaw instability and is most efficient in low friction situations. LDWS will be most effective in higher friction situations on edge marked roads in fine conditions and at higher speeds. FWS will address some instances of lane departure in addition to those detected by LDWS, but will add detection of other fatigue related crash types not involving lane departure or prevent lane departure crashes where the LDWS may be unable to get the driver's attention in time. AEBS is effective on crashes that are generally not prevented by LDWS, ESC and FWS, and the AEBS relevant crashes are more frequently found in in areas (metropolitan) where the other technologies are less effective.

Analysis did not find LDWS, ESC and FWS to be highly cost effective over the first year of vehicle ownership although these technologies are generally installed in the vehicle for their lifetime so the lifetime cost effectiveness estimates are most relevant. It is possible crash savings estimated were conservative since the crash costs used were an average across all vehicle types. Crashes involving trucks are potentially higher cost than average due to expenses incurred to freight carriers from damaged loads and timetable disruptions which are specific to this vehicle type. With the expected growth in heavy vehicle exposure on Australian and New Zealand roads, and expected decreases in the cost of the technology as the market responds to European mandates and uptake increases, these technologies may become more cost effective.

Each of AEBS, LDWS and ESC have been shown in previous heavy vehicle studies to reduce heavy vehicle crashes of all severities, to be cost effective and to be accepted by drivers, which has led to AEBS and LDWS fitment mandates in Europe in N2, N3, M2 and M3 vehicles. This background in combination with the potential crash reduction benefits estimated in fitting these technologies to heavy vehicles in Australia and New Zealand established in this study point to a need to promote the uptake and eventual mandate of these technologies in Australasia. Results also point to the need to continue to evaluate the effectiveness of these technologies in real world application in Australasia as they become more prevalent in the fleet.

POTENTIAL SAFETY BENEFITS OF EMERGING CRASH AVOIDANCE TECHNOLOGIES IN AUSTRALASIAN HEAVY VEHICLES

1.0 INTRODUCTION

Over the period 2008-2013 in Australia and New Zealand there has been sustained growth in heavy vehicle travel. In Australia, there has been greater growth in heavy vehicle registrations and exposure, than for passenger vehicles with recent rigid truck registrations growth more than double, and recent articulated truck exposure growth more than twenty times that for passenger vehicles. Despite this growth, the proportion of crashed vehicles that are heavy has remained stable at around 4% from 2000 to 2010. However, it is expected that given the exposure and registration growth, that the number and proportion of heavy vehicle crashes may rise again in the future without further road safety programs targeted at heavy vehicles. Emerging vehicle crash avoidance technologies for heavy vehicles is an area showing potential for reducing heavy vehicle related road trauma.

Vehicle manufacturers respond to both government mandate and consumer demand with an ever-increasing offering of standard and optional safety features in their vehicles, both proven and unproven in effectiveness. Focus on the introduction in these technologies is often on the light vehicle fleet. However, such new safety technologies also have the potential to reduce road trauma when introduced into the heavy vehicle fleet. This report uses the data from the Used Car Safety Ratings research program to estimate the potential benefits of some of such emerging safety technologies in terms of savings in fatal, serious injury, minor injury and property damage only crashes involving heavy vehicles. The project aimed to quantify the annual crash savings that would be expected if specific primary safety technology fitment to heavy vehicles were mandated. Technologies considered included: electronic stability control (ESC), autonomous emergency braking systems (AEBS), fatigue warning systems (FWS) and lane departure warning system (LDWS).

1.1 Scope

This project uses the most recent available Police reported crash data to estimate injury and property damage only heavy vehicle involved crashes that would be prevented by the mandated fitment of emerging safety technologies[1]. Australian and New Zealand injury crash data were obtained from the Police reported crash data used in the aforementioned used car safety ratings project. The Australian data was aggregated from only five states: New South Wales, Victoria, Queensland, Western Australia and South Australia. Unless otherwise defined, and in the context of analysed data of this project, '*Australian'* refers to the aggregation of these five states only. It is not unreasonable to use only these five states to represent the whole of Australia when it is considered that these five states contributed to 95% of all vehicle registration (2006 and 2010) and a large proportion of the injuries and societal cost of injuries for Australian crashes. In 2006 their contributions to injury crashes were as high as 94%.

[1] Property damage only crashes were not available within Victorian and New Zealand crash data.

Heavy Vehicle Definition

For this project a heavy vehicle was defined as rigid truck with a tare weight over 4.5 tonnes, a prime mover, with or without trailer attachments, a road train or an omnibus with a seating capacity of at least 10 or a tare weight over 4.5 tonnes. Light commercial vehicles with a tare less of 3.5 tonnes or under, and other vehicles with a tare or GVM between 3.5 and 4.5 tonnes, were excluded from this analysis.

The ability to distinguish the 4.5 tonne cut point for heavy was not easily practised. With Western Australian and Queensland data, the process was simple since GVM or tare weight was mostly provided. In NSW, an indicator variable was used to inform of tare weights greater or less than 4.5 tonnes. However, in the New Zealand, South Australian and Victorian datasets, there were no variables to indicate vehicle weight. Details of methods used and assumptions made in defining heavy vehicles are provided in Appendix B.

In addition, where it was possible to identify, (Australian jurisdictions excluding Victoria) ambulances and fire trucks were excluded, due to the unique nature of their usage. Fire trucks could not be identified in the available Queensland data. Less than 2% of all rigid trucks, within any particular crash severity and period grouping, were excluded for this reason. Farm machinery and self-propelled plant equipment were also excluded from this analysis.

Motor vehicles of unknown type (not able to be identified as heavy) were not included because they were likely to be: a) passenger vehicles and b) small in proportion

With Australian crash data, heavy vehicles were divided into four main groups: buses, rigid trucks, articulated trucks carrying a maximum of one trailer and road trains. Road trains included B-doubles, B-triples and prime movers or rigid trucks carrying two or more trailers. Attempts were made to identify whether prime movers or rigid trucks had trailers attached. Vehicles that could not be identified into a heavy vehicle group were excluded from analysis. One hundred percent of heavy vehicles were able to be classified into vehicle types for all crash years within NSW, VIC and QLD data; and from 2004 crash year onwards for SA data, and from 2000, 2002-2004 and 2006-2009 for WA data. Heavy vehicles excluded because of unknown type made up only 0.13, 0.13, 0.08 and 0.06 % of heavy vehicles for SA crash years 2000, 2001, 2002 and 2003 respectively; and 0.04% of heavy vehicles for WA crash years 2001, 2005 and 2010.

With New Zealand crash data, heavy vehicles were only identified as trucks and buses. The tare weight was unknown; however, those light commercial vehicles that were identifiable by make, model or VIN, were excluded from the analysis.

The ability to distinguish articulated and rigid trucks varied from state to state. As a consequence, the heavy vehicle categories are blurred when combined for Australia. Discussion of this may be found in Appendix B.

Evaluated Emerging Technologies

Estimates of injury and non-injury heavy vehicle crash reductions possible with 100% fitment of some emerging safety technologies were carried out for the most recent three years of Australian and New Zealand crash data, disaggregated by heavy vehicle type. Zero percent current fitment rates were assumed, because actual fitment rates could not be known and are likely to be very low.

It was found that 83% of 2008-2010 Australian heavy vehicle crashes (2007-2009 for QLD) were multi-vehicle crashes and 26% were rear-end crashes (Section 5.5). However, rear-end crashes were found to be proportionally less represented with increased crash severity. Due to the prevalence of these types of crashes, it was expected that autonomous emergency braking systems would be a technology worthy of evaluation, with the expectation that they would prevent at least some of the more serious injury crashes from occurring.

Single heavy vehicle crashes (17%) also were shown to have moderate Australian prevalence (Section 5.5) in the same period. Single vehicle and particularly (first event heavy vehicle) roll over crashes (5%), were likely to have a serious outcome. These types of crashes often occurred when a vehicle was out of control and thus lend themselves to prevention via ESC and via fatigue and lane departure warning systems (FWS, LDWS). Head on crashes (5%) may also be caused by fatigue or an out of control vehicle. Thus, because of the injury severity associated with these types of crashes, ESC, FWS and LDWS were also evaluated in this study for their potential to reduce serious injury crashes.

The interaction of fitted technologies was not considered in this study. For example, a certain crash type may be prevented by more than one type of technology, and a vehicle may contain both (or all) of these technologies that prevent the crash type. This study considered the sets of crashes prevented by each technology to be independent of one another. The implications of this assumption are presented in Section 3.2.5.

All evaluations made in this report are costed as present value; either as 2013 AUS$ for Australian crashes, or as 2013 NZ$ for New Zealand crashes.

1.2 An overview of safety features/technologies considered

This study estimated the expected savings to Australia, New Zealand and jurisdictions, under the scenario where specific safety technologies were mandated in existing heavy vehicles. There are two ways in which safety features can reduce the burden of injury associated with vehicles. Firstly, primary safety features reduce the risk of a vehicle becoming involved in a crash. Examples of primary safety features include Electronic Stability Control, Anti-lock braking systems and Intelligent Speed Adaptation. The other way that safety features can reduce the burden of injury is by preventing injuries or reducing the severity of injuries when a crash occurs. These safety features are called secondary safety features and airbags and safety belt pre-tensioners are common examples. Therefore, primary safety features reduce crash risk, while secondary safety features reduce the severity of injuries, or reduce the risk of injury, when a crash occurs. The safety technologies examined in this report are primary safety features, and this report uses the assumption that, when present in a vehicle, they will prevent a percentage of no injury and minor, serious and fatal injury crashes.

There are three factors that must be known in order to model the effectiveness of the chosen technology at reducing crashes or injuries within this study: the types of crashes where the technology is effective, the expected or measured crash or injury reduction for the type of crash, and the fitment rate of the technology within the population of crashed vehicles. Different primary and secondary safety features will be effective in different types of crashes. For example, side airbags will not provide any additional protection to occupants in head-on impacts, but they will provide decreased risk of serious injury in side impacts or rollover crashes. In this study crash types sensitive to the emerging technologies have been selected following techniques described in the literature which evaluated efficacy, and current and past fitment rates for safety technologies in heavy vehicles were unknown; they were considered so low as to be zero.

There is good scientific evidence of the effectiveness of Electronic Stability Control (ESC) (Barickman 2009, Brown 2009, Murray 2009, Pearson 2011, Wang , Woodrooffe 2011, Park 2012, Elsasser 2013, Markkula 2013), Lane Departure Warning Systems (LDWS) (Visvikis 2008, Houser 2009, Robinson 2010) and AEBS,(Battelle 2007, Fitch 2008, Grover , Woodrooffe 2009, Rakha 2010, Robinson 2010) in specific heavy vehicle types, however the effectiveness within other heavy vehicle types and the effectiveness of the other safety features (FWS) were determined using the assumptions of equivalency or the generic estimates of Anderson (2011)[2].

The remainder of Section 1.2 describes the safety technologies considered in this study. The descriptions are summarised from literature (Grover 2008, Houser 2009, Robinson 2010, Anderson 2011, Pearson 2011, Anderson 2012, National Highway Traffic Safety Administration 2012, Austroads 2013). The details of how crashes sensitive to the technologies were identified are in Section 3.2 and Appendix B.

1.2.1 Lane Departure Warning Systems (LDWS)

This technology targets unintentional departure from a lane. It uses forward and side viewing cameras to identify reflective lane markings to establish a vehicle's position within a lane, and to determine the road alignment and the vehicle's speed and direction of travel. It determines the intention of the driver from information on steering angle and indicator use. If the system decides that the lane departure is unintentional and the driver has taken no corrective action, the system responds first with a warning sound and light flash, and later with a steering wheel shudder (if the first warning is ignored). Some systems go as far as taking corrective action usually in the form of applying braking to a single wheel to correct the path of the vehicle.

LDWS work well with Autonomous Emergency Braking Systems (AEBS) and help prevent fatigue related crashes. The lane departure crashes prevented by LDWS include, single-vehicle roadway departure crashes and same direction and opposite direction lane departure multi-vehicle crashes. These crash types include side-swipes, rollover and head-on crash outcomes. Robinson (2010) assumed a LDWS effectiveness of 20-60% reduction

[2] As fatigue related crashes are not accurately identifiable in Australian crash databases, the approach of Anderson (2011) was used to estimate fatigue warning system efficacy. It was assumed in this study that efficacies in specific types of heavy vehicles may be applied to all heavy vehicle and bus (>4.5 t GVM) types.

in all severity injuries resulting from LDWS sensitive crashes. Houser (2009) assessed efficacy (in large trucks) in reducing the LDWS sensitive crashes as: 23-53 % for single vehicle roadway departure collisions, 24-50 % for single vehicle roadway departure rollovers, and 23-46 % for same direction lane departure and other direction lane departure over-the-lane-line multi-vehicle collisions. The lower figure of the range was evaluated from a Mack field operation test studying single vehicle run-off road crashes and rollovers not caused by an impact. The upper figure resulted from motor carrier information. These efficacies were applied equally crashes of all severities. Since Houser's range of values is almost the same for each crash type, for simplicity, this study used the modest efficacy range of 23-50% on all sensitive crashes equally.

Delineation must be present, and of sufficient quality, for the system to work; LDWS systems are of little use to off-road vehicles. The LDWS work at a typical minimum tracking speed of 60 km/h, and do not provide warnings below this speed, so their effectiveness is limited in urban areas. Because they are optical based systems, their limitations are not restricted to vehicle speed (and delineated roads). Weather may cause reflective interference and snow may cover the delineation. In this study only roads with speed zones of at least 80 km/hour were considered, as it is often the case that 60 km/h roads do not have edge lines. In addition, only highways and freeways (or when unable to identify, divided roads) were assumed to have well maintained edge lines. 14% of the relevant LDWS sensitive crashes were found to occur in wet, snowy or dusty conditions in the most recent three years of Australian crash data.

LDWS are available to heavy vehicles fleets as an after-market product. An economic analysis of LDWS for large trucks performed in the USA by the Federal Motor Carrier Safety Administration (FMCSA) in 2009 over a five year crash period (Houser 2009) found LDWS to have a cost benefit ranging from 1.37 to 6.55 depending upon the system efficacies, distances travelled by a vehicle and system purchase prices. Furthermore, a European study (Robinson 2010) of crashes in N2, N3, M2 and M3 (Australian NB, NC, MD and ME) vehicles (goods vehicles with GVW>3.5t and buses with >8 seats per person) averaged over four years, found LDWS to be cost effective over a wide range of model assumptions; their benefit to cost ratio was even found to be greater than 1 for off-road and urban vehicles.

The cost of purchasing and installing a LDWS in 2009, in the USA, into a large truck, was estimated at US$1,000 to $1,500 (Houser 2009).

The EuroFOT study (Kessler 2012) found that truck drivers found LDWS systems useful when fatigued but otherwise irritating, despite the system being found to improve lateral control, slightly increase indicator usage and decrease lateral crash events. This study did not find an increased traffic or environmental efficiency associated with LDWS systems.

Europe has mandated LDWS in the vehicles of the Robinson (2010) study. A National Road Safety Strategy November 2012 progress report (Department of Infrastructure and Transport 2012) informed that mandating LDWS in heavy vehicles in Australia is under consideration.

1.2.2 Autonomous Emergency Braking Systems (AEBS)

Forward Collision Warning Systems (FCWS) use laser, radar, infra-red, ultrasonic, visual imaging or mm Wave sensors, sometimes in combination, with cameras to monitor the distance to and the speed of objects directly in a vehicle's path and alerts the driver of danger. It is left to the driver to respond appropriately to the warning without intervention. Forward Collision Detection and Intervention (also known as autonomous emergency braking) targets rear-end crashes by taking the forward collision warning a step further with the inclusion of an autonomous braking intervention by the vehicle. The system can also warn the driver and prime the braking system. Some systems only work at lower speeds (up to 30km/h or 50 km/h) whilst others work at higher speeds using a combination of short and long range radar technologies. A range as large as 10-180km/h has currently been claimed as effective in light vehicles for targets moving in the same direction; the effective range is 0-70km/h for stationary targets. The AEBS systems which were mandated in Europe for heavy vehicles were expected to be effective at vehicle speeds from 20km/h (Robinson 2010).

AEBS responses may be adjusted to below maximum levels to allow tyre grip to be available for making directional changes, however it is of greater advantage for heavy vehicles to maximise braking because of the added risk of roll-over produced by directional change in emergency situations and because of the unlikely availability of manoeuvring space. Production places the autonomous deceleration maximum typically at 4 m/s^2.

AEBS may be coupled with other systems. AEBS and FCWS are often coupled with LDWS and/or Adaptive Cruise Control (ACC), which actively controls acceleration and braking of the vehicle to maintain set distance (up to 200m) headway to a preceding vehicle. ACC generally works at vehicle speeds between 60km/h and 180 km/h. To avoid trailer swing when braking severely, it is also advisable that Anitlock Braking Systems (ABS) is used in conjunction. ABS has been mandated in new models of medium to heavy goods vehicles and buses with less than 4 axles from July 1 2014 (Department of Infrastructure and Regional Development 2013). AEBS may also be coupled with traction control, electronic brake force distribution and brake assist technologies.

Grover (2008) states that heavy vehicle braking systems are different from light vehicle braking systems in that they are typically either fully pneumatic or electronically controlled pneumatic (EBS) braking systems. The response time for a pneumatic brake system is longer than for a hydraulic system, however EBS response times are faster than those of fully pneumatic systems. EBS also has the advantage of more balance in braking. In combination with AEBS, EBS braking systems maintain these advantages with the advantage of easily integrating the autonomous control of the already electronic system. Fully pneumatic braking systems are not as easily controlled autonomously and fitment of AEBS to vehicles with this braking system has generally not been considered feasible.

Another issue of fitment is incompatibility of braking systems between a prime mover and its trailer. If a prime mover fitted with AEBS was pulling a trailer with a fully pneumatic braking system and no AEBS, the prime mover would respond faster than the trailer causing instability which would be exacerbated by the ABS on the prime mover. Possibly wheel lock of the trailer would result. However, test data has shown that the risks are no greater in this situation than from rapid driver applied brakes.

Whilst originally developed to avoid, mitigate or warn of collisions with other vehicles or fixed objects, these systems have now been adapted to prevent pedestrian crashes. Forward collision warning, mitigation or avoidance systems specifically reduce severity or prevent rear-end collisions with moving vehicles directly in path, collisions with stationary objects on-path, and run-off road crashes at the end of a road or T-intersection. They may work on curved roads depending upon line of site and road-side clutter. Because they detect objects in the path of a vehicle or generally reduce braking distance, they are expected to reduce the frequency or injury severity of some other crash types which may involve a vehicle or object passing in front of the vehicle with the forward collision avoidance system. For example: collisions with unprotected road users on the carriage way, intersection collisions, collisions with vehicles travelling in the opposite direction and collisions with objects falling from other vehicles.

The AEBS are limited by the ability of the sensor to sense objects. Heavy precipitation and heavy build-up of debris may deactivate the system by blinding the sensors. Another limitation is the inability to sense and react in certain situations such as: when a vehicle "cuts-in" suddenly, when the vehicle in front is too close to give time for a reaction, when the object is too small or too far to the side relative to the active vehicle or when traffic is merging.

Benefits in terms of casualty crash reductions have been difficult to measure due to the limitations of the available crash databases. Robinson (2010) assumed a 20 to 50% effectiveness at reducing all injuries from AEBS fitted heavy vehicle rear-end crashes with stationary or moving vehicles (not unprotected road users). This range was based on applying the reductions used by Grover (2008) which were disaggregated by injury severity: 25-75% of fatalities became serious injury casualties, 25-75% of those seriously injured became minor injured and 0-10% of minor injuries were avoided. Grover (2008) considered the injuries from all vehicles but only considered single and two vehicle rear-end crashes involving heavy vehicles of the European types: N2, N3, M2 and M3. A more recent, large scale European field operational study of trucks on motorways (Kessler 2012) found that FCW + ACC systems contributed to an overall 0.2-0.6% reduction in motorway injury crashes: 0.33-0.85% of fatal crashes and 0.18-0.45% of other injury crashes.

In this study, injury reductions to narrowly sensitive crashes[3] were calculated using the ranges of Grover; and the minor injury reduction rate was applied to property damage only narrowly sensitive crashes. For crashes only broadly sensitive to AEBS, the range limits were reduced by two thirds, in a manner similar to that used by Anderson (2011) in allocating efficacies to crashes of broad and narrow sensitivities. In addition to fatalities becoming serious injuries and serious injuries becoming minor injuries; in this study, minor injury crashes, (estimated, by jurisdiction using the proportion of minor injuries that

[3] Crashes narrowly sensitive to AEBS crashes are rear-end crashes and single vehicle crashes into objects. Broadly sensitive crashes include those where the target vehicle or object passes across, or travels in the opposite direction of the colliding vehicle. See Sections 3.2 and 3.2.2 for a more detailed explanation.

are from minor injury crashes and the ratio of minor injuries from minor injury crashes to minor injury crashes), were assumed to become PDO crashes (This acknowledges that a proportion of minor injuries are from more severe crashes). PDO crashes were assumed to be prevented completely and at the same reduction rate as applied to minor injury reductions. The exception to this was for New Zealand and Victorian crashes, where PDO crashes were not recorded. In these two jurisdictions, minor injury crash reductions were only assumed to be prevented because PDO crashes were not considered.

Many AEBS systems are co-fitted with FCWS, and together they contribute to reducing the same crash types. It is difficult to measure the separate crash reduction contribution of the two systems. Batelle (2007) separated the effects of FCW (forward collision warning) and ACC (adaptive cruise control) with an advanced electronically controlled braking system in a study of 100 Volvo prime movers. It was found that the FCW was the main contributor to rear-end crash reduction effects; the effects of the ACC with the electronic braking system were statistically insignificant. Batelle (2007), Fitch (2008) and Rakha (2010) found a 21% reduction in rear-end heavy vehicle crashes from FCW, although statistical significance was only achieved in the Fitch and Rakha studies. The advantage was attributed to the finding that drivers in heavy vehicles with FCWS adopted following distances 4.6m longer. This finding was supported by Kessler (2012) where FCW + ACC systems were found to increase headway time by 5% for trucks on motorways in Europe.

Grover (2008) found AEBS (without FCWS) to be highly likely to provide a cost effective reduction in casualties with further technical developments and reductions in unit cost. In 2010, the Robinson European study of crashes in N2, N3, M2 and M3 vehicles (goods vehicles with GVW>3.5t and buses with >8 seats per person) averaged over four years, found AEBS to be cost effective in some situations over a wide range of model assumptions; the mid-range benefit cost ratio was close to one for all heavy vehicle classes with one exception. Fitment to N2 tractor units under 7.5 GVW was not found to be cost effective. Kessler (2012), in a large scale field operational test, gave FWC + ACC systems a benefit cost ratio of 3.9-5.2.

A typical AEBS system in 2008 was found to cost as little as €200-€250 (around A$300-400) per vehicle (including fitment) for exiting first generation technology and as much as €1,000 - €6,000 (A$1600-9000) per vehicle for future technology.

The EuroFOT study (Kessler 2012) of 53 drivers of MAN and Volvo trucks, over 603 km (for treatment group) of motorway, found positive drive acceptance of ACC and ACC+FCW. It also found that usage was associated with a 2% reduction in fuel consumption from improved traffic flow and driving behaviour such as the 37% reduction in harsh braking manoeuvres and the 36% reduction in kinematic related incidences.

Europe has mandated AEBS in the vehicles of the Robinson (2010) study. Mandated AEBS in heavy vehicles is currently not under consideration in Australia. Exemptions from the European mandate are being sought on the grounds that AEBS is not effective in vehicles without rear-end suspension. In these vehicles, changes in load change the chassis height and may put the target vehicle for the AEBS out of the sensor view.

1.2.3 Electronic stability (ESC) and Roll Stability (RSC) Control

ESC and RSC are two stability systems designed to mitigate roll-over and loss of control crashes in heavy vehicles. There are RSC systems that can be fitted to trucks, prime movers and trailers and there are RSC systems only available to trailers (Trailer Roll Stability Systems). ESC systems may not be fitted independently to trailers. ESC includes the functions of RSC to mitigate first-event un-tripped roll-over crashes and in addition, stabilizes yaw moments to mitigate loss of control crashes primarily by preventing over and under steering.

Roll-over thresholds are set for a critical speed determined where the wheel speed, lateral differences in weight distribution, lateral acceleration and air suspension pressures have been determined to induce a roll-over event. ESC and RSC systems respond when the (RSC and ESC) roll-over or (ESC only) loss of directional control thresholds are approached.

To stabilise the vehicle, ESC applies individual brakes at the corners of a vehicle, whereas RSC typically applies all of the drive axle brakes at a uniform pressure. During a hard cornering event, an RSC system prevents the roll-over by responding with braking to the detected lateral acceleration. However, on a slippery road surface, insufficient traction may mean that lateral acceleration is not detected by the RSC system resulting in loss of control. In situations like this, an ESC system will intervene and maintain control by automatically applying selective brakes to generate a yawing moment that helps the driver maintain directional control. These differences lead ESC systems to be more effective at preventing loss of control (LOC) crashes. ESC systems were also found to be more effective than RSC at preventing jack-knives (Brown 2009) and 8% more effective than RSC systems (Woodrooffe 2011) at reducing costs associated with 5 axle heavy vehicle roll-over events.

Both ESC and RSC have been found to be effective at reducing heavy (prime mover and trailer) vehicle rollover events (Barickman 2009, Brown 2009) resulting from tight curve negotiating. Brown (2009) found these two systems were able to adapt to different combinations of equipment and loads. However, Barickman, (2009) concluded that ESC and RSC were capable of sensing or estimating the load but not estimating the centre of gravity of the load.

ESC and RSC systems will likely have different efficacy and cost benefits in different types of heavy vehicles. Cost benefits differ because the cost of fitment varies as does the cost of the crash. ESC is tuned according to features specific to a heavy vehicle such as steering features, height, weight, centre of gravity and wheel base. Thus the differences in efficacy when the system is properly tuned will be related to how well ESC can do its job. This is not likely to be greatly different in vehicles that manoeuvre in a similar way. In fact, the performance of ESC systems in motor coaches (with 16 or more seats) was evaluated as preventing target rollover and LOC crashes in a similar manner to prime movers when an identical set of test manoeuvres were performed (National Highway Traffic Safety Administration 2012, Elsasser 2013).

Within a trailer-truck combination, performance will vary according to what combinations of EBS, ABS, RSC and ESC are involved. Trailer Roll Stability Control (TRSC) Systems have no interaction with the towing vehicle and thus no ability to reduce engine torque in the prime mover (Barickman 2009). Because both RSC and ESC work on the prime mover, they have a faster response (because lateral forces are experienced at the prime mover before the trailer) and they have a stronger braking torque than TRSC systems (Barickman 2009). Advantages over TRSC include the better mitigation of wheel lift under test procedures (Barickman 2009). ESC systems fitted to both the trailer and prime mover do communicate, but the delay in receiving information from the trailer through the flexible coupling may reduce the efficacy of roll mitigation (Pearson 2011). If a prime mover with ESC is coupled with a trailer without ESC the risk of trailer lock up is increased unless the trailer has a load sensing or electronic brake system (Pearson 2011).

TRSC, ESC and RSC are typically integrated with anti-lock braking systems (ABS); some are even integrated with AEBS. ABS also work to reduce loss of control crashes, however ABS targeted crashes are caused by wheel lock-up rather than by steering manoeuvres. Thus the mandating of ABS does not make ESC systems redundant because the two systems address different crash causes.

Recent efficacy studies have been carried out for single unit trucks (Woodrooffe 2011), as well as for five axle prime mover semitrailer combinations and heavy vehicles with a GVW of 12 tonnes and greater, in un-tripped first event rollover and loss of control crashes, using computer simulation results due to the lack of ESC and RSC market penetration (Woodrooffe 2009). The following table, taken from (Wang 2011) summarises targeted crash reduction rates from ESC and RSC fitment .

Table 1 : Effectiveness rates for ESC and RSC in heavy vehicles (>=12t) by target crashes

Technology	Overall	Rollover	Loss of Control
ESC	28-36[3]	40-56[2,3]	14[2,3]
RSC	21-30[3]	37-53[1]	3[2,3]

1 (Murray 2009)

The high end of this range was due to rollovers on curved roadways at excessive speeds and the low end was from motor carrier information for rollover crashes in general.

2 (Woodrooffe 2009)

ESC rollover reduction was 0 (straight, wet roads) -75% (dry curved roads).

ESC LOC reduction was 7 (straight, dry roads) to 19% (curved, dry roads).

RSC rollover reduction was 0-72%

RSC LOC reduction was 0-7%

3(Wang)

The effectiveness ratings of (2) were modified with the probability of occurrence of each case examined in the computer simulation to give 47% reduction in ESC rollover crashes and a 44% reduction in RSC rollover crashes and the LOC figures in the table. 44% is the midpoint of the range from (1), and using the same uncertainty on 47%, the range 40-56% resulted.

Woodrooffe (2011) examined the efficacy of stability control systems in single unit non-articulated trucks without trailers by using 2003-2007 heavy vehicle crash data, track testing and engineering judgement. ESC was judged to mitigate 13.7% of all single unit truck fatal involvements. This study identified ESC as being effective in crashes beyond 'loss of control run-off road' and 'first-event rollover' types: for example, loss of control from a truck avoiding another vehicle approaching it head-on, where a head-on or side-swipe collision results. Woodrooffe identified ESC relevant involvements in 63% of LOC run off road, 61% of first event rollover, 27% of 'other single vehicle', 21% of 'other run-off road', 21% of 'opposite direction', 11% of 'turning/intersection', 6% of 'hit object on road', 6% of 'same direction' and 13% overall fatal crashes. 2.3-6.5% of non-fatal crashes were ESC relevant: 57-61% of roll-over, 56% LOC run-off road, 18% of 'other run-off road' non-fatal crashes were found to be ESC relevant.

In this study, an efficacy of 14% was used for loss of control crashes, and an efficacy of 40% was used for first event rollovers. The upper value of 56% (Table 1) applied to a more specific crash set (curved roads and excessive speed) and so could not be considered. Another issue with the use of these efficacies relates to differences in road alignment and weather conditions. The estimates were produced through application of weighted averages of efficacies determined by combinations of road surface (wet/dry) and curvature (straight / curved) given that ESC is most effective at preventing crashes on curved low friction roadways. The road surface and curvature distribution is likely to differ in the context of this study. For example, Western Australian roads are likely to be straighter and drier than US averages. However, given the series of other assumptions involving the identification of sensitive crashes and the accurate calibration of the ESC system and the unknown effect of road surface quality, adopting these efficacies is reasonable. 51% of the LOC ESC sensitive crashes were found in the most recent three years of crash data in Australia to be on straight (or unknown geometry) roads in fine (or unknown) conditions: 49% were either on curved roads or in wet weather.

Benefits of ESC also included providing a longer life for heavy vehicle tyres from the avoidance of flat spotting during hard stops and permitting a more aggressive steer input prior to loss of control (Woodrooffe 2011). ESC contributes an insignificant proportion of the vehicle weight so the increase in fuel use attributable to the extra weight of the ESC system over its lifetime is considered negligible.

The performance of both ESC and RSC were found (Brown 2009) to be highly dependent on the driver's speed. It is also dependent on how well the system has been calibrated to the vehicle on which it is fitted. Pearson (2011) showed concern over the fact that the ESC supplied in new vehicles is tuned to the prime mover without the trailer, which when attached will radically alter the centre of gravity, wheelbase and height, and thus mean that the ESC thresholds are improperly set.

Both RSC and ESC fitment in prime movers were found to have positive net benefits (Murray 2009, Woodrooffe 2011, National Highway Traffic Safety Administration 2012), however retrofitting of ESC and RSC to prime movers was considered too complex to be feasible and retrofitting of TRSC was considered not to be cost effective (National

Highway Traffic Safety Administration 2012). Park (2012) provides an ESC per truck (prime mover + trailer) benefit of US$635 per year. The benefits from this study were arrived from the simulation of LOC and rollover crashes.

The cost of an ESC system to a new heavy vehicle already fitted with ABS/EBS is estimated at AUS$2000 (Pearson 2011) or higher if it is purchased as part of a package. Pearson (2011) estimates that without ABS/EBS, the cost is likely to be AUS$6000 higher. Even greater costs are expected if the system is retrofitted.

A National Road Safety Strategy November 2012 progress report (2012) informed that mandating ESC in heavy vehicles in Australia is under consideration. However, Pearson (2011) found few manufacturers currently supplying Australia to offer ESC.

1.2.4 Other emerging vehicle safety technologies

Anderson(2011) evaluated the likely relative benefits of emerging vehicle safety technology using New South Wales (NSW) Police reported crash data from 1999-2008. The report also described the technology. Anderson (2011) estimated the fitment of emerging technologies to prevent 75% of narrowly sensitive crashes and 25% of broadly sensitive crashes. Anderson (2011) further assumed that injury and fatal crashes were equally reduced. In this study it was assumed that minor, serious and fatal injuries, as well as property damage only crashes were similarly reduced by the fitment of the technology. The expected injury or crash reduction over all crashes was calculated as the sum of the product of 0.75 and the proportion of crashes narrowly sensitive to the technology and the product of 0.25 and the proportion of crashes broadly sensitive to the technology.

A summary of Anderson's description of Fatigue Warning Systems follows.

Fatigue warning system

This technology targets crashes resulting from driver fatigue such as those that occur when the driver is not in control. Fatigue may be detected by using infrared cameras to detect changes in eyelid movements of the driver, by using sensors to detect erratic steering wheel movements or a combination of these. Once fatigue is detected the driver may be alerted with an audible signal. It commenced as standard to the Mercedes S Class and is available on Volvo trucks for $1500. It is also becoming cheaper and more widely available.

2.0 DATA SOURCES

2.1 Crash Data

Police reported crash data used in this project were originally provided for the Used Car Safety Ratings and included data from New Zealand and five Australian states: New South Wales (NSW), Victoria (VIC), Queensland (QLD), Western Australia (WA) and South Australia (SA). The Australian data were supplied respectively by *Roads and Traffic Authority* (RTA) in NSW, *VicRoads* in Victoria, *Queensland Transport*, Western Australian *Department of Main Roads* and *Road Crash Information Unit of the Department of Transport, Energy and Infrastructure* in SA. The New Zealand Data was provided by the *New Zealand Transport Authority*. This data covered the complete years, 2001-2010, except for Queensland who supplied no 2010 data and only partial data for 2005. Counts of *cases* for each jurisdiction and crash year are in Appendix B.

NSW, QLD, SA and WA crash data records were for crashes that resulted in death or injury or a vehicle being towed away. WA and SA data records also included crashes where property damage was greater than a defined sum (which was defined as $3000 after July 1 2003). Crashes are reported to the Police in Victoria if a person is killed or injured, if property is damaged but names and addresses are not exchanged, or if a possible breach of the Road Traffic Regulations has occurred. This means that uninjured records from the Victorian data are incomplete and only crashes involving injury are reliably reported in Victoria. New Zealand data also did not include non-injury crashes.

The distribution of crashed heavy vehicles by jurisdiction and crash types: killed and serious injury (KSI), minor injury (MI) and property damage only (PDO), is illustrated below. In the context of this report minor injury crashes do not include crashes where serious and fatal injuries occurred and PDO crashes do not include crashes where injuries occurred. Definitions of 'Crash Severities' are presented in Appendix A.

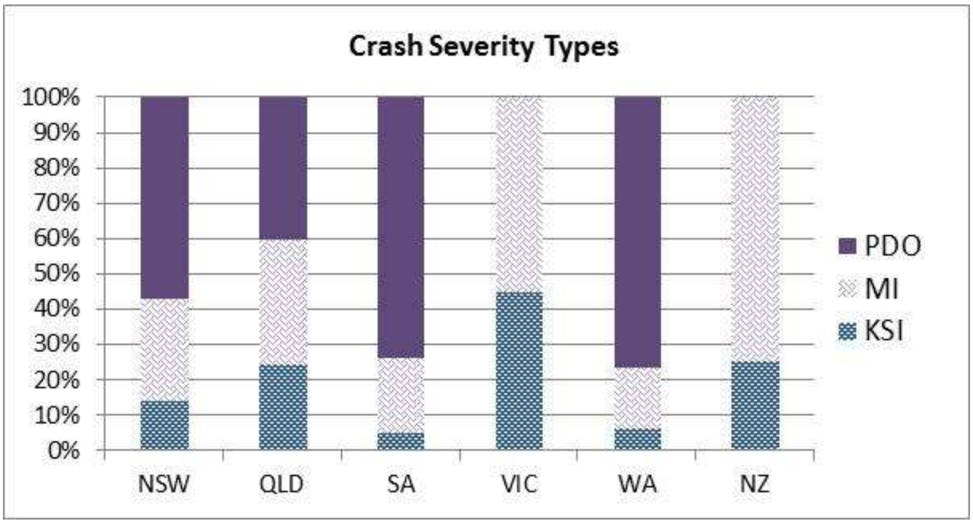


Figure 1

Distribution of crashed heavy vehicles by crash severity and jurisdiction: 2008-2010 (QLD 2007-2009)

Heavy vehicles were categorised into vehicle types; details on the methods used to identify heavy vehicles and heavy vehicle types are discussed in Appendix B. **Figure 2Figure 1** illustrates the distribution of vehicle types for each crash type and jurisdiction.

Figure 2

Distribution of crashed heavy vehicles by vehicle type, crash severity and jurisdiction: 2008-2010 (QLD 2007-2009)

Other Issues with Australian Crash Data

Data Management is presented in a more detailed form in the appendices. The following are dot points presenting some issues primarily with consistency between states that must be considered when examining the results section.

Crashes

- 2005 Queensland Crash Data is incomplete so period 2 contains an incomplete picture for Queensland.
- Crashes with a 'Minor Injury Crash Severity' do not include crashes with serious injuries or fatalities.
- Crash location as rural, remote or metropolitan was not available for Queensland.
- Property damage only crashes are not available for Victoria (or New Zealand).
- Queensland crash data does not include 2010, so each period grouping is bounded by crash years one year earlier than for the other states.

Injuries

- Injury summaries are based on the number of injuries (of each severity) for a *crash* and are presented by heavy vehicle type for the first heavy vehicle listed in the crash data. Only a small proportion of heavy vehicle crashes involved more than one heavy vehicle.
- Crash Injuries include injuries from riders/occupants on/in the other non-heavy vehicles and also injuries from pedestrians.
- NSW only provided two injury severity categories: injured and fatal.

Crashed Vehicles

- Crashed vehicle summaries are based on the number of crashed heavy vehicles of a crash type.
- Multi-vehicle fatal or serious injury crashes may include vehicles were no injuries were sustained, or vehicles where only minor injuries were sustained.
- Pedestrian involved fatal or serious injury crashes may include vehicles were no injuries were sustained, or vehicles where only minor injuries were sustained. It is likely that the serious injuries were sustained by pedestrians.
- The total number of occupants in a crashed vehicle is not known for Victoria.
- NSW only provided two crash severity categories: injury and fatal.
- Crashes with parked vehicles listed as cases in the crash data were considered to be multi-vehicle crashes.

Crashed Heavy Vehicles

- Heavy Vehicles are assumed to have a GVM >4.5 for Victoria, South Australia and New Zealand.
- Articulated vehicles and road trains may only be identified in Victorian data in the 2010 crash year.

Issues with identification of crashes sensitive to emerging vehicle technologies

- SA does not have a crash code variable similar to the 'DCA', 'ACCRUM' or RUMCD' of other states.

- Speeding, or inappropriate speed as a contributing factor as identified by the police was able to be identified only for NSW, SA and WA.
- Exceeded driver blood alcohol limits were identifiable only for NZ, QLD, SA, VIC and WA.
- Fatigue as a factor, as identified by police, was only present in the NZ and WA data.
- Heavy vehicle roll overs could only be identified in non-collision crashes in WA.
- Heavy vehicles as the rolled vehicle in multi-vehicle crashes could be determined in NSW, VIC and SA. In QLD it was not possible to identify which vehicle rolled in multi-vehicle crashes.
- The colliding vehicle in AEBS sensitive crashes could only be determined for WA.
- The colliding vehicle in LDWS sensitive sideswipe crashes could not be determined, even in WA.
- Identification of crashes at roads with edge line marking could be estimated with the use of various variables in all jurisdictions.
    - Highways and expressways could be identified:
        - for NSW & SA as divided roads and dual freeways;
        - for VIC & QLD as divided roads;
        - for WA as highways from the highway coding or highway road name; and
    - For NZ highways and expressways could not be identified, however sealed and bitumen roads could.

2.2 Australian Crash Costs

The Australian unit injury costs for fatal and serious crashes and their associated vehicle related costs have been taken from the Bureau of Transport Economics' report that described a methodology to estimate the costs due to road crashes in Australia (Bureau of Infrastructure Transport and Regional Economics [BITRE] 2009). These are not costs specific to truck crashes, but apply generally to road crashes by severity. This report took a hybrid human capital approach to estimating the magnitude of different components of the costs of injury from road crashes.

In their report (Blincoe 2002) of the cost of motor vehicle crashes in the USA, Blincoe, Seay, Zaloshnja, Miller, Romano, Luchter & Spicer described the human capital approach as a method of costing injury that considers individuals as functioning as "producers and consumers of economic output" (p.13). Costs associated with their decreased consumption and production as a result of their injuries as well as the resources society must contribute to their treatment that could otherwise have been used to increase "the societal wellbeing" (p.13) are counted in the cost of the injuries. The human capital approach does not consider costs associated with pain and suffering, reduced quality of life or loss of emotional wellbeing unless these consequences of crashes require medical attention or they result in loss of the ability to consume and produce. BITRE (2009) also note that the human capital approach can be used to value a loss in a road crash victim's ability to participate in non-paid work, such as caring for other family members or contributing to their community.

The alternative to the human capital approach is to include the cost of pain and suffering and reduced quality of life in the total costs associated with injury due to road trauma: the willingness to pay method, which involves estimating the maximum amount of money a person is willing to pay to reduce risks to their lives. This approach enables the quality of life and "joy of living" to be valued when estimating the cost of injury.

Both the willingness to pay and the human capital approaches have their deficiencies. The reader is referred to BITRE (2009) for a detailed description of the disadvantages and advantages of both approaches. BITRE (2009) recognised that as willingness to pay includes elements that the human capital approach does not include in its estimates of cost, the former approach usually gives higher values of the cost of injury than the human capital approach. The hybrid approach used by BITRE (2009) includes: a notational age dependant value for the quality of life that would be lost by the unknown individual in the event of their premature death; an allowance for pain, grief and suffering that the family and relatives of the deceased suffer; costs to employers for the disruption caused; the cost of a premature funeral and the costs of prosecuting culpable drivers. Despite all the quality of life inclusions in the hybrid approach BITRE (2009) estimates the full 'willingness to pay' costs at 52% higher than their hybrid approach.

In their report on the cost of road crashes in Australia, BITRE (2009) decided to use the hybrid human capital approach, so that estimates of crash costs could be compared with costs from previous Bureau of Transport Economics studies. Since their 2000 publication, the injury and crash costs estimated by BTE (2000), have been used widely in studies that have attempted to quantify the cost of injury in Australia: e.g. (Cameron 2000 , Bureau of Transport and Economics [BTE] 2001, Morris 2001, Green 2003, Connelly 2006). Therefore, the present study uses the updated 2006 values estimated by BITRE (2009), further updated to year 2010 prices.

The BITRE (2009) produced estimates of the average cost of crashes, disaggregated by jurisdiction and crash severity (fatal crash, serious injury crash, minor injury crash and property damage-only crash (Table 2).

Table 2 : Estimated social cost of road crashes jurisdiction, dollars, 2006 (BITRE, 2009)

	Fatal	Serious	Minor	Property damage Only
NSW	$2,667,484	$265,670	$14,723	$9,979
Victoria	$2,670,591	$265,430	$14,709	$10,075
Queensland	$2,664,622	$266,016	$14,740	$9,867
South Australia	$2,667,755	$265,619	$14,722	$9,988
Western Australia	$2,660,398	$266,815	$14,784	$9,632

To update 2006 costs to 2013 costs the Consumer Price Index (CPI) in 2006 was compared with the CPI in 2013. The Australian Bureau of Statistics (2006) reported that the weighted average CPI for Australian capital cities in the September quarter of 2006 was 155.7, while in the September quarter of 2011, it was 179.4. It was then reset to 100 in 2012 so the September 2011 CPI became 99.8 to the September 2013 of 104.0. Multiplying the estimated average costs by (179.4/155.7) x (104.0/99.8) gave the estimates of the average costs in year 2013 prices, which are shown in Table 3 .

Table 3 : Estimated social cost of road crashes by jurisdiction, AUS 2013 dollars

	Fatal	Serious	Minor	Property damage Only
NSW	$3,202,864	$318,992	$17,678	$11,982
Victoria	$3,206,594	$318,703	$17,661	$12,097
Queensland	$3,199,427	$319,407	$17,698	$11,847
South A	$3,203,189	$318,930	$17,677	$11,993
Western A	$3,194,355	$320,366	$17,751	$11,565

The unit costs associated with road crashes that are shown in Table 3 represent the costs associated with these events if they occurred in 2013.

2.3 New Zealand Crash Costs

Societal crash costs by crash severity for June 2012 were available from the New Zealand Ministry for Transport (Financial Economic and Statistical Analysis Team 2013). These costs were updated to 2013 values using the ratio of Statistics New Zealand CPIs for June 2013 and June 2012: 1176/1168 (Statistics New Zealand 2013).

Table 4 : Estimated social cost of road crashes, NZ dollars, 2013 and 2012

	Fatal	Serious	Minor
2013	$ 4,475,445	$ 777,288	$ 85,582
2012	$ 4,445,000	$772,000	$85,000

2.4 Crash Cost issues specific to heavy vehicles

The authors acknowledge that although generic crash cost by severity accurately address the (by far) major contributor to the crash costs, the human costs of injury; they most likely under-estimate costs related to traffic disruption, road furniture damage, property and environmental damage, and logistic company losses from failure to meet schedules and damages to vehicle loads. Heavy vehicle involved crashes represent only four percent (2008-2010) of all crashes, so the costs specific to heavy vehicles contribute to only a small proportion of the 'all crash'. As an example, the table below illustrates the differential in crash repair costs, with the repair to articulated vehicles estimated at more than ten times that of cars.

Table 5 : Estimated per crashed vehicle repair cost, $ AUS 2006 dollars, (BITRE 2009)

	Repair Cost
Cars	$2,989
Buses	$9,523
Rigid Trucks	$12,000
Articulated Trucks	$31,400

In addition, it is acknowledged that the operating costs also vary widely within heavy vehicle crashes depending upon the heavy vehicle type involved. Rigid and articulated trucks have very different operating characteristics. Rigid trucks tend to operate in a localized zone around their base, whereas articulated trucks are more often represented in interstate and long-distance operations. So although both truck types operate with greater crash risk exposure than for passenger vehicles, the greater distances travelled for articulated trucks would mean a greater crash risk exposure than for rigid trucks. And, because articulated trucks spend more time on high speed roads, they face a greater risk of severe injuries, when a crash does occur. Thus over the average operational life of a truck, crash costs for articulated vehicles are expected to be greater than those for rigid trucks. Table 6 illustrates the exposure difference between rigid and articulate trucks. In the fourth column, one can see that in 2006 an average articulated truck travelled four times further than an average rigid truck, which had in turn almost twice the exposure as an average passenger vehicle.

An attempt was made to include these additional costs to the average crash costs to make them more specific to heavy vehicles. Table 6 presents some of the steps in this process. Vehicle kilometres travelled (Bureau of Infrastructure Transport and Regional Economics [BITRE] 2011) (column 2) and registered vehicle counts (Australian Bureau of Statistics 2013) (column 3) were used to determine the average number of kilometres travelled for each vehicle type (column 4). The product of the estimated 2006 societal costs of road crashes by vehicle type in cents per vehicle kilometre travelled (Bureau of Infrastructure Transport and Regional Economics [BITRE] 2009) (column 5) and the average kilometres travelled per vehicle produces an estimated cost per vehicle type (column 6) in 2066 Australian dollars. 96% of the additional cost, updated using the CPI to 2013 dollars, is presented in column 7. In 4% of cases, the additional heavy vehicle costs would have been included in the average crash costs by severity.

Table 6 : Estimated social cost of road crashes, $ AUS 2006 dollars, (except last column)

	Vehicle Kilometres travelled (billion km)	Registered vehicles	Average kms travelled/vehicle	cost by vehicle type, cents per VKT	cost by vehicle type, $ per vehicle	Additional 2013 HV cost
Rigid Trucks	8.24	403,839*	20,404	4.8	$979	-$25
Articulated Trucks	6.46	71,680	90,123	4	$3,605	$3,001
Buses	1.96	75,375	26,003	6.1	$1,586	$674
Cars and LCV	160.99	13,344,733†	12,064	8.3	$1,001	

†includes campervans * includes non-freight carrying trucks

On the basis of these assumptions, crash expenses for passenger vehicles and rigid truck rate similarly. This is most likely due to the additional vehicle related expenses being compensated for by reductions in injury expenses likely from the lower occupancy rate and greater protection offered in rigid trucks. However, for buses and more particularly articulated trucks, it is clearly obvious that crash expenses are greater than for passenger vehicles.

An alternative Australian pricing strategy will be presented where $670 is added to the expenses for each bus crash and $3,000 to the expenses for each articulated truck crash. Only 6% of heavy vehicle crashes involved more than one heavy vehicle, and it is likely that most of the multi-heavy vehicle crashes involve rigid trucks, so there is very little under-estimation of additional expenses due to counting only one articulated truck or bus in each of the articulated truck and bus heavy vehicle crashes. Given the repair costs presented in Table 5 , there still appears to be under-estimation of heavy vehicle related costs.

3.0 METHODOLOGY

3.1 Non-fatal injuries for NSW

NSW data does not distinguish serious from minor injuries; however it was necessary to estimate the split of non-fatal injuries/crashes into serious and minor in order to present an Australian summary. Serious and minor injured persons of heavy vehicle crashes, and crashed heavy vehicles of serious and minor injury crashes were estimated for NSW using a ratio of 'serious to non-fatal' calculated from the combined states of WA, SA, QLD and VIC for each set of crashes, defined by severity, vehicle and crash type.

3.2 Identification of crashes sensitive to emerging technologies

Crashes sensitive to the emerging safety technology were identified to match those used to determine efficacy in the relevant literature cited in Section 1.2. AEBS, LDWS and FWS sensitive crashes were identified using the road user crash definition variables in a modified version of the manner described by Anderson (2011) in the CASR Road Safety Research Report, *Analysis of crash data to estimate the benefits of emerging vehicle technology.* Modifications to this methodology were applied to better match the methods used in the efficacy evaluations and are detailed below.

3.2.1 Lane Departure Warning Systems

Anderson (2011) discussed high speed limits, alcohol use and speeding as contributing factors to crashes caused by lane departure. Anderson suggested that crashes sensitive to lane departure warning systems be limited to those on highways and expressways, in speed zones greater than 80 km/h, and to those where there is no illegal speeding or no illegal alcohol use. The alcohol and speeding limitations remove sensitive crashes which may not be effective to the technology. The 'highway/expressway' limitation was imposed because lane departure systems need to identify reflective lane markings which may not be present on lesser road classifications. The '80 km/h' limitation was imposed because it is the speed zone in which lane departure crashes are expected, (and also serves to identify roads where lane marking may be present). In this study, lane departure sensitive crashes were limited to those where the driver was not identified as speeding, nor identified as over the blood alcohol limit, and to those where a crashed vehicle was travelling on a highway or freeway in a speed zone greater than or equal to 80 km/h.

Jurisdictional variation in the identification of speed zones, speeding, alcohol as a factor and edge line marked roads has been discussed in Section 2.1 and in Appendix B. It is not clear how Anderson (2011) identified "edge marked" roads in NSW.

Lane departure warnings are designed to prevent unintentional movement from lanes; crashes affected by these warnings are of the 'out of control' type. The contributing factors for heavy vehicle *loss of control* and rollover crashes were well presented by Elsasser, Barickman, Albrecht, Church, Xu and Heitz (2013). For convenience an extract of this part of their report is presented in Appendix F.

Narrow sensitivity crash types were defined by Anderson (2011) as all off path crashes except those from the vehicle being out of control on the carriageway (and thus no lane departure for the out of control vehicle) and those with deliberately turning. These are generally single vehicle crashes; however Anderson also considered sensitive crashes to include multivehicle crashes where an intentional lane change was not mad. Examples of these include head-on and 'not at intersection' crashes that did not involve overtaking. In addition to the crash types identified by Anderson (2011), this study included same direction lane side swipes. This was because the heavy vehicle literature evaluating LDWS efficacy always included sideswipe collisions. However a proportion of these side swipe crashed vehicles were excluded to recognise that it may not be the heavy vehicle that left the lane during a side-swipe collision. The fault could not be identified accurately for sideswipe collisions, however, crashed heavy vehicles in collisions sensitive to AEBS could be identified as the target rather than the collider when driverless, stopped or parked; or when the damage was only to the rear end of the heavy vehicle; or when the other vehicle was reversing. The correction factor was determined by the proportion of crashed heavy vehicles broadly sensitive to AEBS at speeds >80km/h that were found to collide into the other vehicle in Western Australia. This value was 97% for heavy vehicles in minor injury crashes and 98% for heavy vehicles in crashes of all other severities.

The LDWS efficacy used in this study was based on the work of Houser (2009) so crashes were not defined in the manner of Anderson (2011) as narrowly nor as broadly sensitive to LDWS. See Section 1.2.1 for discussion on LDWS efficacy.

3.2.2 Autonomous Emergency Braking Systems

The 'narrow' sensitivity crashes were defined by Anderson (2011) as crashes with vehicles travelling in the same direction which were hit in the rear, crashes whilst reversing in traffic and crashes with objects or vehicles parked/stopped on path. 'Broadly' sensitive crashes were crashes which involved a collision with something in the path which was either not a vehicle or not travelling in the same direction. This set included: crashes with trains, aeroplanes, pedestrians, animals and objects falling in their path, crashes at intersections, crashes with vehicles heading in the opposite direction, crashes whilst manoeuvring when entering or leaving parking or footways or U-turning into a fixed object and crashes whilst overtaking including only head on, pulling out, cutting in or turning.

Anderson(2011) found that removal of crashes where speeding was involved, only reduced the AEBS crash benefits slightly, so for this study, AEBS sensitive crashes where speeding was a factor were included.

Crashes in all speed zones were included because AEBS currently claims an effective working range of 10-180 km/h. However, a proportion, based on WA data, was used to exclude the collisions where the heavy vehicle was not doing the colliding, in a similar manner as was applied to LDWS sensitive sideswipe crashes (section above). This time, the proportions were calculated without speed zone limitations. These proportions disaggregated by crash severity and degree of sensitivity have been tabled below. Specifically, AEBS was assumed of no value in the sensitive crash if the involved heavy vehicle was parked or stopped; if the other involved vehicle was reversing; if it was a multivehicle accident involving a pedestrian, fallen load, hit object or hit animal and the heavy vehicle was driverless or not the colliding unit; or if it was a rear-end collision where the heavy vehicle was the target with a rear impact.

Table 7 : (WA) Proportion of colliding heavy vehicles in all speed zone, heavy vehicle involved crashes sensitive to AEBS.

	Fatal	Serious Injury	Minor Injury	PDO
Narrow	59%	59%	82%	79%
Broad	98%	99%	97%	93%

The application of crash efficacies to these crashes has been discussed in Section 1.2.2.

3.2.3 Electronic Stability Control Systems

Anderson (2011) identified loss of control (LOC) crashes for sensitivity to FWS. These included run-off road type crashes, but excluded LOC crashes where the vehicle stayed on the carriageway and LOC crashes during overtaking. In this study, all LOC crashes were considered ESC sensitive crashes, and in addition, first event roll-over crashes were identified as ESC sensitive. In multi-vehicle crashes, the crashed vehicle was excluded if it was found not to be the rolled vehicle in SA, VIC and NSW. In WA, rolled vehicles could only be identified in non-collision crashes. In Queensland no exclusions were made because it was not possible to identify the vehicle which rolled in multi-vehicle crashes.

These two crash types were not summed until after efficacies were applied because efficacies of ESC were defined in literature on these crash type divisions. The application of crash efficacies to these crashes has been discussed in Section 1.2.3. The crashes identified as sensitive in this study do not exactly match those of the efficacy studies. According to the sensitive crashes identified by of Woodrooffe (2011), a small proportion of other ESC relevant LOC crashes were not able to be identified in this study, however, in balance of this under-representation, first event rollover crashes were over represented because they included both tripped and untripped events.

3.2.4 Fatigue Warning Systems

Anderson (2011) discussed the two types of fatigue: sleep related and task related. Anderson defined fatigue crashes as those recoded in the crash data as such and used driver blood alcohol limits recorded in the crash database to separate out those that could be a sleep related fatigue crash. The logic being that sleep deprivation is more likely to be a factor at night and night time crashes are associated with alcohol. In an Australian feasibility study on the identification of fatigue related crashes in Police reported crash data (Diamantopoulou 2003) fatigue related crashes were identified as either those where the vehicle’s controller was described by Police as being sleepy drowsy or fatigued and/or the vehicle was involved in a “loss of control” type crash where no other relevant factor such as overtaking or speeding could be identified as a factor for the manoeuvre.

In this study, fatigue as a contributing factor could not be identified in the crash data for all jurisdictions and was not considered reliably reported in any jurisdiction. Thus, crashes sensitive to FWS were not selected on the basis of Police identified fatigue.

Exceeding the speed limit was added to the exclusion criteria of Anderson because Diamantopolou (2003) identified it as a separate contributing factor to the crash and as such if a choice was made to speed, fatigue warning systems would not prevent the crash from occurring. However, it is acknowledged that speeding could be a result of fatigue rather than choice. Speeding as a factor could not be identified in the data of New Zealand, Queensland and Victoria.

Amongst the FWS sensitive, loss of control crashes (described in the previous section), Anderson (2011) defined narrowly selected crashes as those where alcohol was not considered a factor (driver blood alcohol concentration [BAC] was below the 0.05% limit). Broadly selected crashes were those where the fatigue system would not be as effective due to the effects of alcohol (bac>0.05%). Drivers exceeding blood alcohol limits could not be identified in NSW.

In this study, all selected crashes were considered *broadly* sensitive due to the inability to consistently identify fatigue as a factor and because of the jurisdictional inconsistencies in identifying speeding and intoxicated drivers. As such, the *broadly sensitive* efficacy of 25% was applied, according to the methodology of Anderson (2011). Only "loss of control" crashes where speeding and alcohol were not recorded as outside the respective limits, were identified as broadly sensitive to fatigue technology.

3.2.5 Overlap of crash types

This report evaluates each safety technology independently. However, crash and injury savings attributed to each safety technology cannot actually be summed to produce the total savings possible if all the technologies were fitted within the vehicles. This is because crashes may be sensitive to more than one safety technology.

Police reported crashes identified as sensitive to ESC, LDWS and 'FWS' overlap considerably. All three system sensitivities include off path, loss of control crashes, on a straight or curved piece of road, which don't involve the making of turns, running off the end of a road, being out of control on the carriageway or mounting traffic islands. Essentially these three safety technologies prevent a lot of the same broadly defined kinds of crashes. However, the method employed in crash prevention by ESC is quite different from LDWS and FWS and this would mean that they act to prevent different sub-sets of the overlapping crash types. FWS will help prevent any kind of fatigue related crash, whereas LDWS and ESC respond only in specific circumstances, however when these are met, their targeted approach is likely to be more effective. ESC, as previously stated will help a driver retain control from an over- or under- steer event, which is often related to road curvature or low friction road surfaces (e.g. wet or gravel), whereas both LDWS and FWS are not designed to regain yaw stability. In fact, LDWS are less able to function in wet weather, due to the obstruction of the optical system, and do not work at all on unsealed roads (without edge lines), so by definition are the least functional on the surfaces on which ESC is the most functional. In addition LDWS work only at higher speeds, whereas both ESC and FWS will function at lower speeds.

Lastly, 'not-overtaking head-on' crashes are both LDWS and AEBS (broadly) sensitive crashes. These crashes represented only about 2% of heavy vehicle crashes, so this is not a significant issue.

3.2.6 Percentage of Sensitive crashes in SA

Crashes sensitive to emerging technologies could not be counted for South Australia using the methods used for other jurisdictions because SA crash data did not contain a road user movement or 'DCA' coding for the crashes. Attempting to identify sensitive crashes without this variable created inconsistencies that only could be remedied with the application of the Western Australian percentages of sensitive crashes to the South Australian heavy vehicle crash counts. Crashes sensitive to emerging technologies in South Australia were estimated in this way.

3.3 Cost of savings

The present value cost of fatal, serious injury, minor injury and property damage only crashes was calculated through multiplication of the 'per crash' values with the most recent three year period crash savings. The annual estimated benefit was averaged over the three years.

Property damage crash costs and crash reductions for Australia do not include content from Victoria.

3.4 Break even costs

Break even costs were calculated for heavy vehicles new in 2010. Annual crash savings expected from mandating these technologies were estimated just for new vehicles (with a year of manufacture equal to the crash year). A ratio of the crash savings associated with these new vehicles and the total registered heavy vehicles with a 2010 year of manufacture produced an estimated break even cost; the funds available per vehicle to spend on this technology before the costs of mandating outweighs the savings produced. When only the crashes in 2010 involving a heavy vehicle with a 2010 year of manufacture were considered, the savings in the first year were estimated. When savings from crashes of heavy vehicles of all year of manufacture were considered, the ratio was an estimate of expected lifetime savings.

The Federal Chamber of Automotive Industries (FCAI) quantifies 2012 Australian new heavy commercial vehicle sales at 31,050 units (Federal Chamber of Automotive Industries 2013, Federal Chamber of Automotive Industries 2013). This includes large coaches but not light buses (<20 and >=20 seat capacities) which were grouped with light commercial vehicles. As it is not expected that a great proportion of new heavy commercial vehicles were coaches, this value was used to estimate registrations of heavy trucks in Australia with a 2012 year of manufacture in the 2012 crash year.

Australian crash data only extends to 2010. FCAI (2013) considered the 2012 growth in new heavy commercial vehicles to be 9.9% or 2,789 units. This means that the 2011 new sales were 28,271. Using the same growth rate for the 2010-2011 period yields an estimate of 25,724 new heavy commercial sales in 2010 (Over estimations in growth will compensate somewhat for the over-estimation by inclusion of coaches). This estimate must then be further reduced due to the inclusion of 3.5-4.5 tonne GVM trucks, which are not included in this study. 19.1% of new vehicle truck registrations with at GVM over 3.5 had a GVM <=4.5 tonne in New Zealand in 2010. However, the percentage of crashed trucks with a known GVM was 11% in WA (2010) and 11% in QLD (2009), so the assumption that 11% of 2010 new truck registrations for 2010 in Australia seems plausible. This leaves an estimated 2010 new truck registrations (with a GVM>4.5 tonne) of 22,895.

Australian crash data does not include data from Tasmania, the Northern Territory or the Australian Capital Territory. Assuming that the percentage of 2010 registered vehicles that are from the five states (95%) applies equally to new trucks, yields an estimated 21,750 new 2010 truck registrations.

The New Zealand Transport Agency published new commercial vehicle registrations by GVM in its 2010 motor vehicle registrations report(New Zealand Transport Agency 2013). Narrowing the band to just 4.5 tonnes and above, and excluding buses, produced 1,853 units. However, it is likely that the New Zealand classifications of bus and truck include vehicles of a GVM of 3.5 to 4.5 tonnes. With this group included, the new vehicle registrations come to 2,290 units. There were 293 new buses with a GVM greater than 3.5 tonnes.

A further break down of new vehicle registrations by heavy vehicle type was not available.

In this study the average annual crash savings from the third period was used to estimate the 2010 total crash savings. Of the third period Australian crashed vehicles, 2.0% of trucks and 3.3% of buses with a known year of manufacture were found to be manufactured in the crash year. For New Zealand, the percentages were 2.0 and 1.6 respectively. About 10% of crashed trucks and 18% of crashed buses were present (from this period) in the Australian data bases without a year of manufacture. For New Zealand, only 2% of buses and 4% of trucks were without a known year of manufacture.

The ‘2.0% new’ ratio was found to generally apply, within ±0.5%, across the Australian truck crashes sensitive to various technologies within the small group of new heavy vehicles crashed in the third period. Given the likely variation possible from such small subsets, the figure of 2.0% was applied generally to the total truck related savings for each of the emerging technologies, to determine the portion attributable to only new vehicles. For New Zealand bus savings, ‘1.6%’ of crashed heavy vehicles were assumed to be new.

4.0 TRENDS

4.1 Registrations

The Australian Motor Vehicle Census (9309.0) reported average annual growth in registrations of buses, light rigid trucks and articulated trucks that surpassed growth for passenger vehicles over the period 2008-2013. The growth was 2% p.a. for passenger vehicles, 4.6% p.a. for light rigid trucks, 3.0% p.a. for buses, 2.9% p.a. for articulated trucks and 1.4% p.a. for heavy rigid trucks (Australian Bureau of Statistics 2013).

4.2 Vehicle kilometres travelled

BITRE has estimated a greater growth in Vehicle Kilometres travelled for heavy vehicles than for passenger vehicles over the period 2006 to 2010: forecasts are for 2008-2010. The percent increase from 2006, over the period, is 0.46 for petrol fuelled passenger vehicles, 5.0 for diesel fuelled rigid trucks, 10.7 for diesel fuelled articulated trucks, and 8.2 for buses of all fuel types (Bureau of Infrastructure Transport and Regional Economics [BITRE] 2011).

4.3 Crashed vehicle count and distribution trends

It is evident from **Figure 3**, that crash counts across all severities have decreased overall heavy vehicle types in Australia, because of reductions in rigid trucks and prime mover crashes. However, crashes of all severities have increased for Australian road train vehicles. The directions of these trends are consistent across metropolitan and rural regions (**Figure 5)**, but in remote regions (**Figure 6**), increases in crashes of all severities have been observed over the 9 year period: overall, across rigid trucks and road trains and over minor injury and PDO crashes for buses.

In New Zealand crash counts for buses and for trucks generally have remained stable. (**Figure 4**).

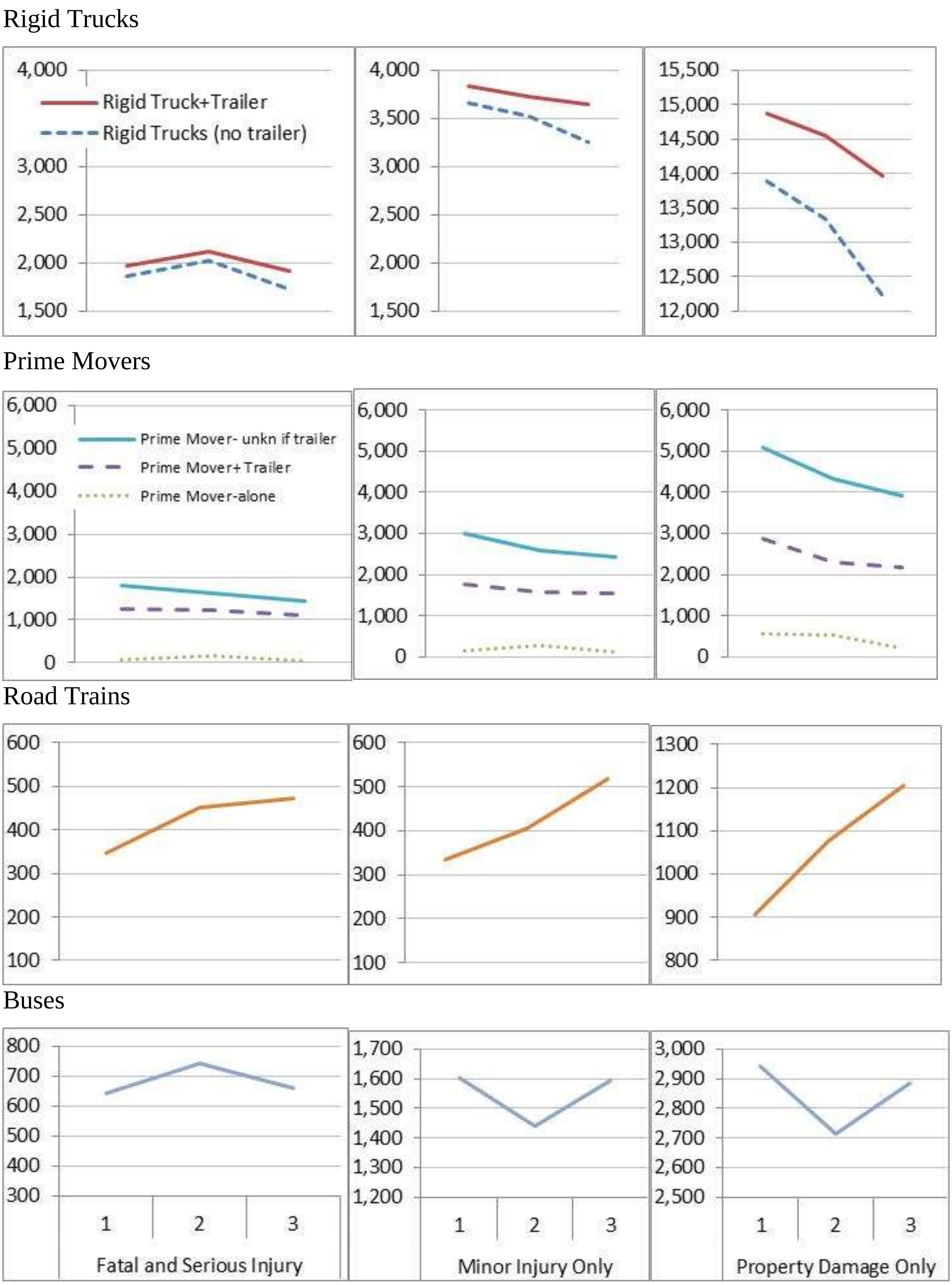
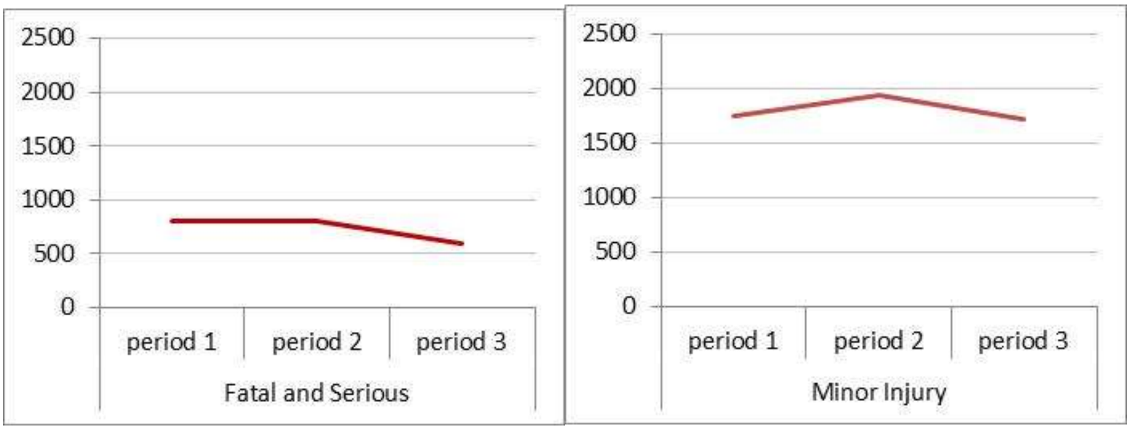


Figure 3

Australian crashed heavy vehicles by crash severity and vehicle type, over 3 three year periods spanning 2001-2010 (stacked)

Periods 1, 2 and 3 refer respectively to 2002-2004, 2005-2007 and 2008-2010 for NSW, VIC, SA and WA and to 2001-2003, 2001-2006 and 2007-2009 for QLD. PDO does not include Victoria

All Trucks



Buses

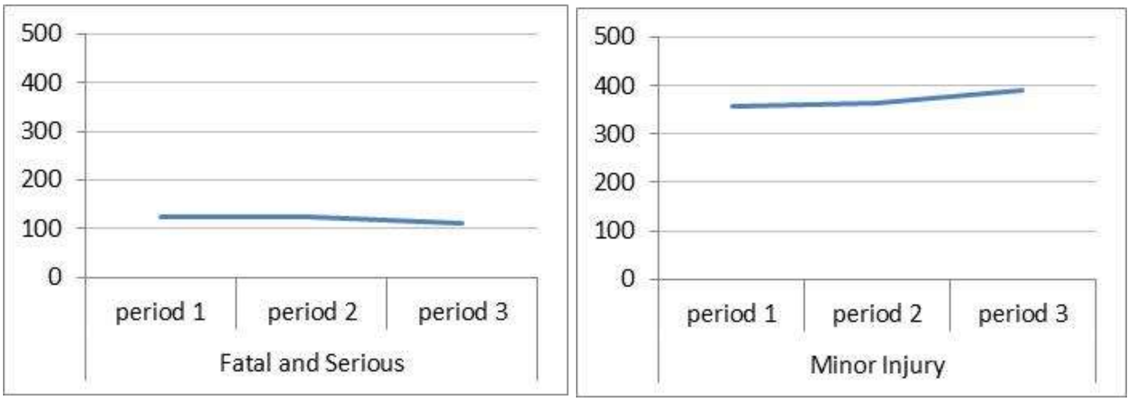


Figure 4

New Zealand crashed heavy vehicles by crash severity and vehicle type, over 3 three year periods spanning 2002-2010 (same scale as Australian vehicle types)

The distribution of Australian heavy vehicle types across crash severities and location was fairly stable over the three periods. However, the resulting trends in crash counts have not only caused the proportions of crashed heavy vehicles that are prime movers and rigid trucks to decrease and the proportion that are road trains to increase, but has also caused the proportion that are buses to increase as a consequence (**Figure 8** and **Figure 10**). In rural and remote areas proportions of rigid truck crashes were not observed to decrease.

The Australian crashed vehicle distribution was different for rural, metropolitan and remote regions (**Figure 9** to **Figure 10**). Buses and rigid trucks were more represented in metropolitan crashes and prime movers and road trains were more represented in rural and remote regions. Road trains were the most frequently involved crashed heavy vehicle in remote fatal and serious crashes, making up greater than 50% of all remote fatal and serious injury crash heavy vehicles in the period 2008-2010. In rural areas, the most frequent heavy vehicle type for the same crash severity was the prime mover group; representing about 40%. In metropolitan areas, rigid trucks were involved in about half of the fatal and severe heavy vehicle crashes of Australia in the period 2008-2010.

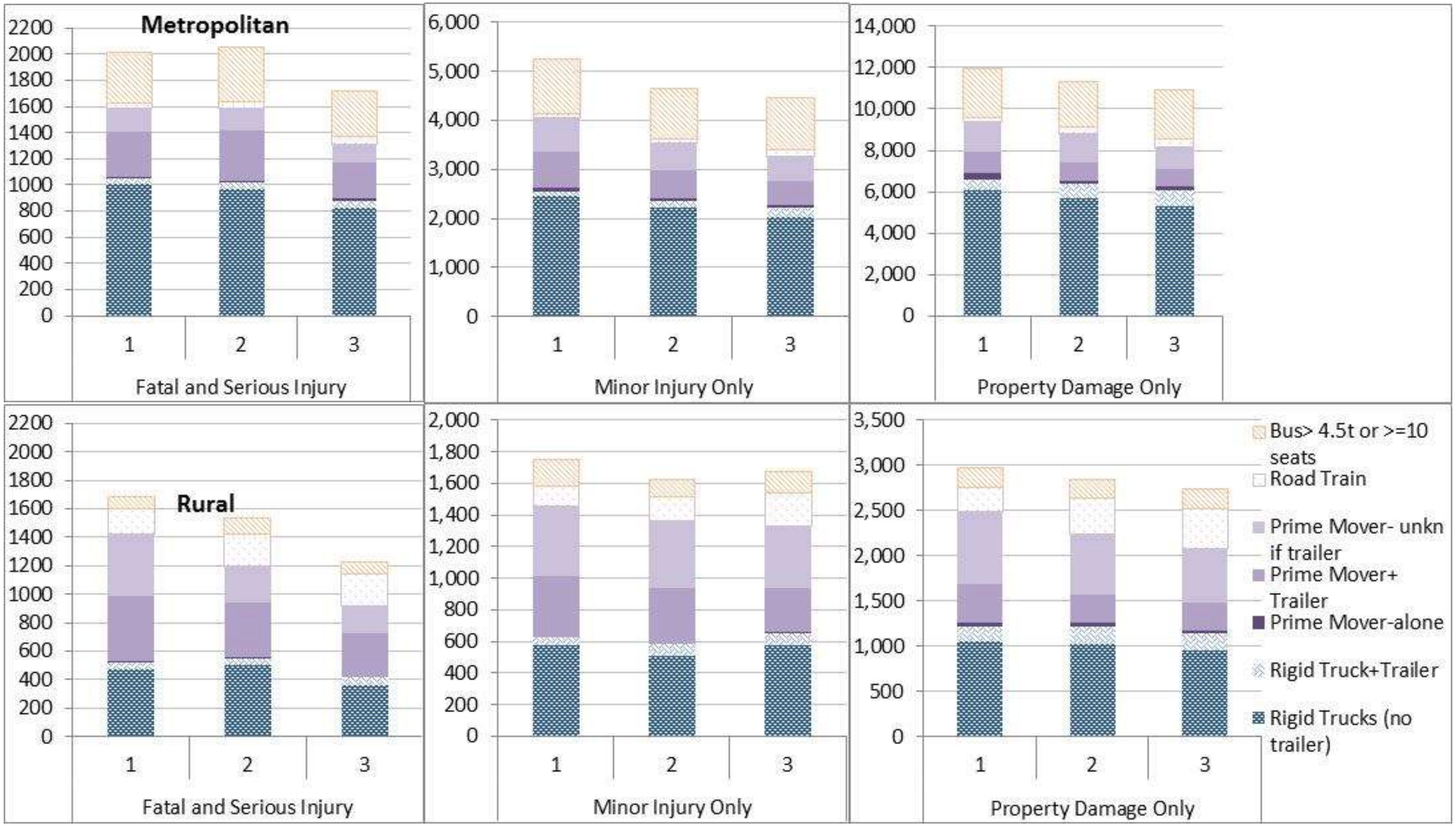


Figure 5

Australian crashed heavy vehicles by crash severity, type and location: Metropolitan and rural, over 3 three year periods spanning 2001-2010

(PDO does not include Victoria)

Figure 6

Australian crashed heavy vehicles by crash severity, type and location: Remote, over 3 three year periods spanning 2001-2010

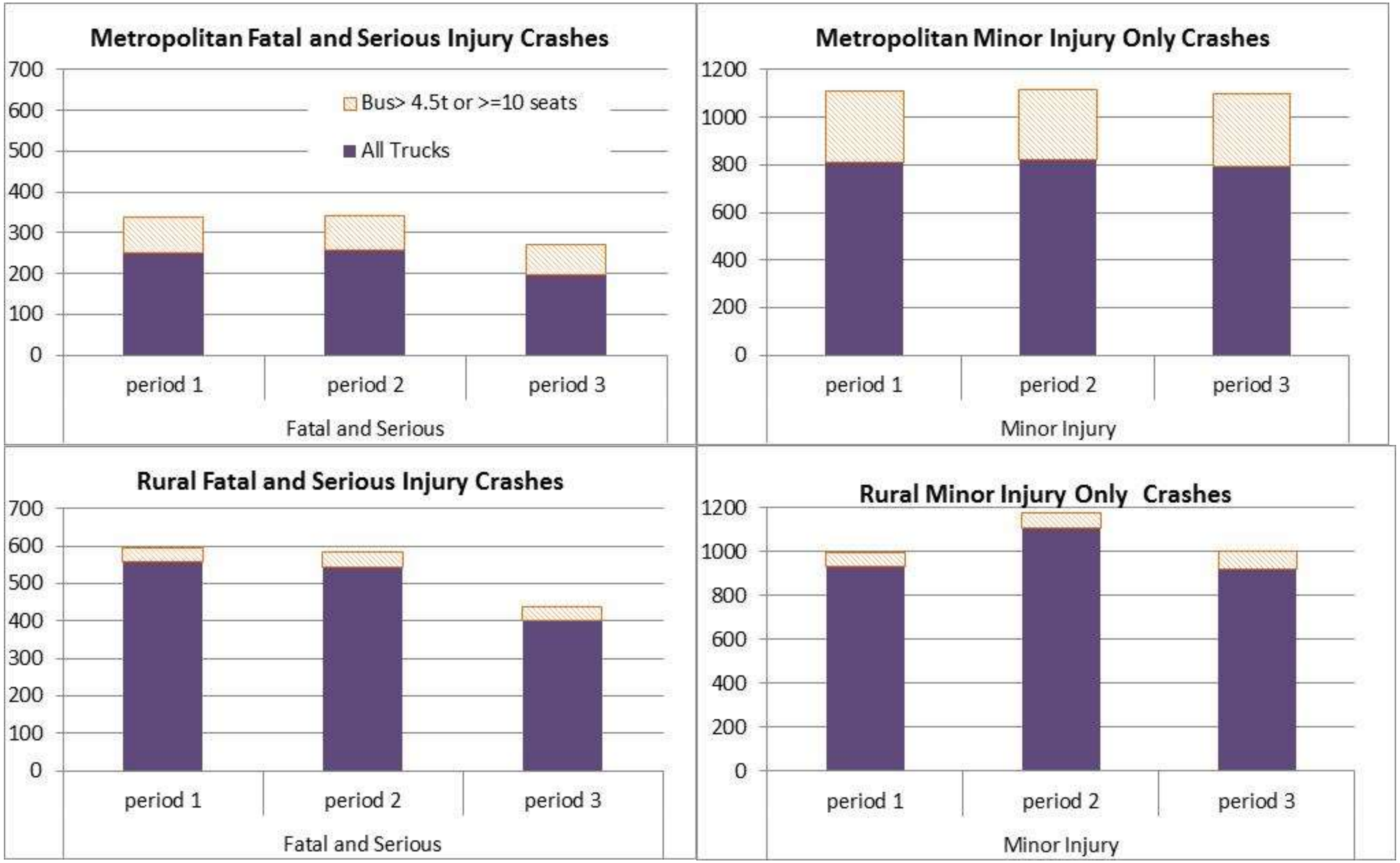


Figure 7

New Zealand crashed heavy vehicles by crash severity, type and location: over 3 three year periods spanning 2002-2010

For New Zealand, the distribution of crashed buses and trucks amongst metropolitan heavy vehicles was stable over the three periods, however, in rural areas (defined by speed zone), the proportion of bus crashes increased in both fatal and serious injury, and in minor injury crashes. Both metropolitan and rural fatal and serious crash counts fell over the three periods. Minor injury crash counts remained stable (**Figure 7**).

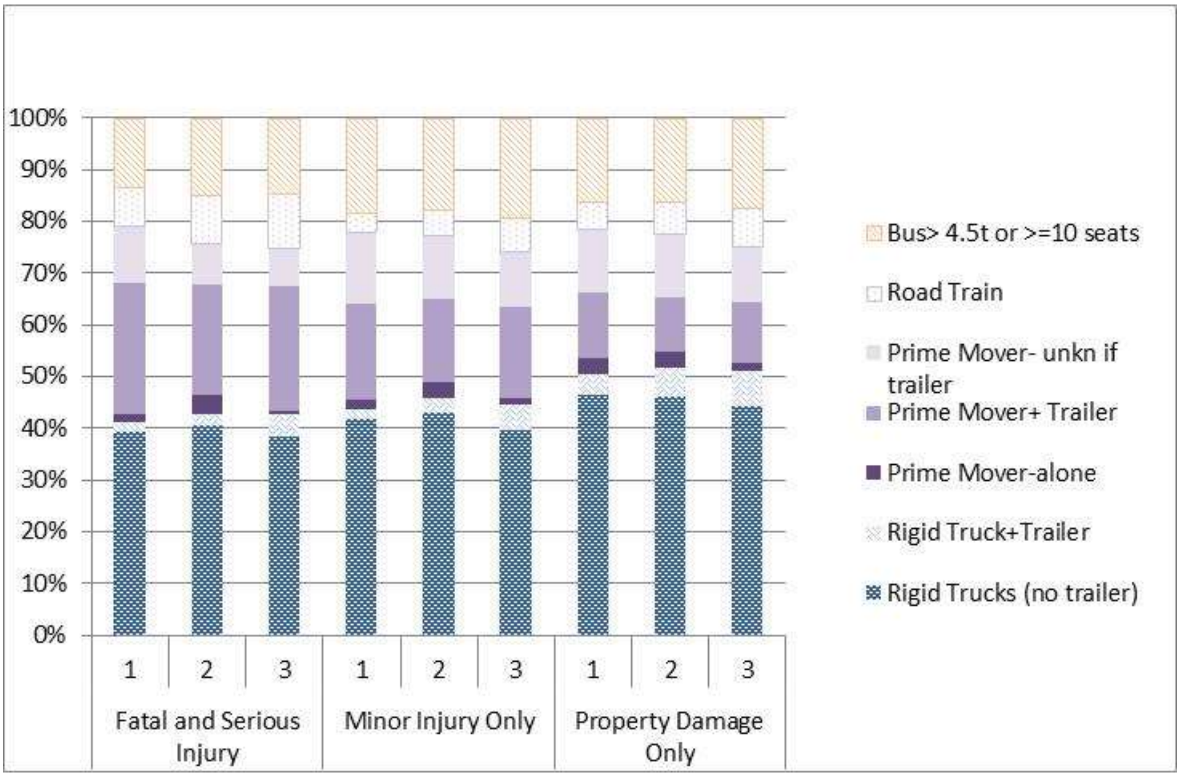


Figure 8
Distribution of Australian crashed heavy vehicle types by crash severity over 3 three year periods spanning 2001-2010

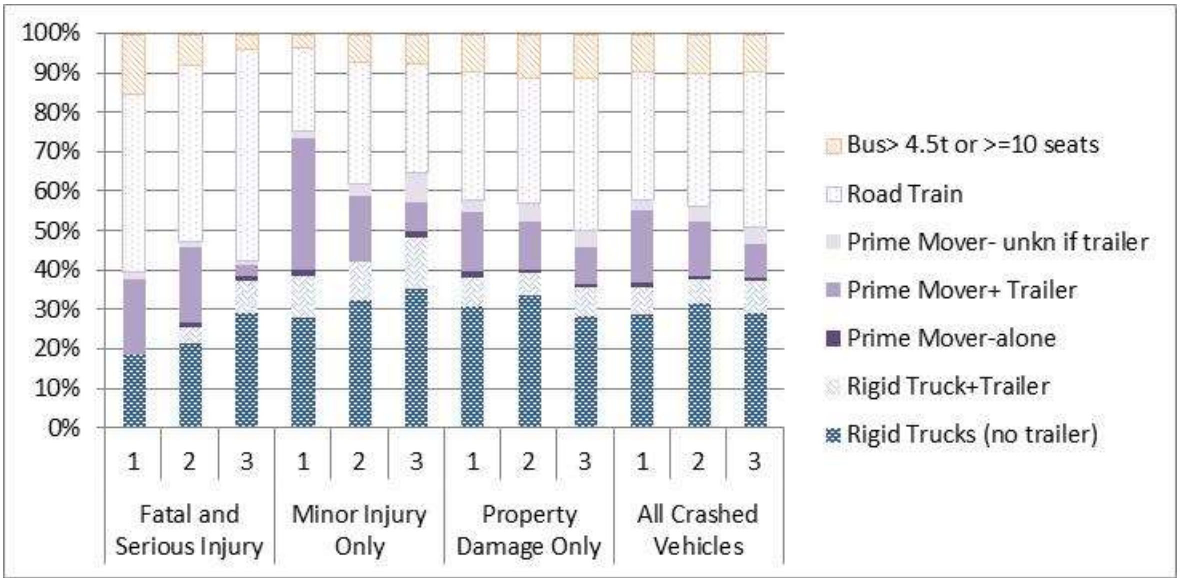


Figure 9
Distribution of Australian remote region crashed heavy vehicle types by crash severity over 3 three year periods spanning 2001-2010

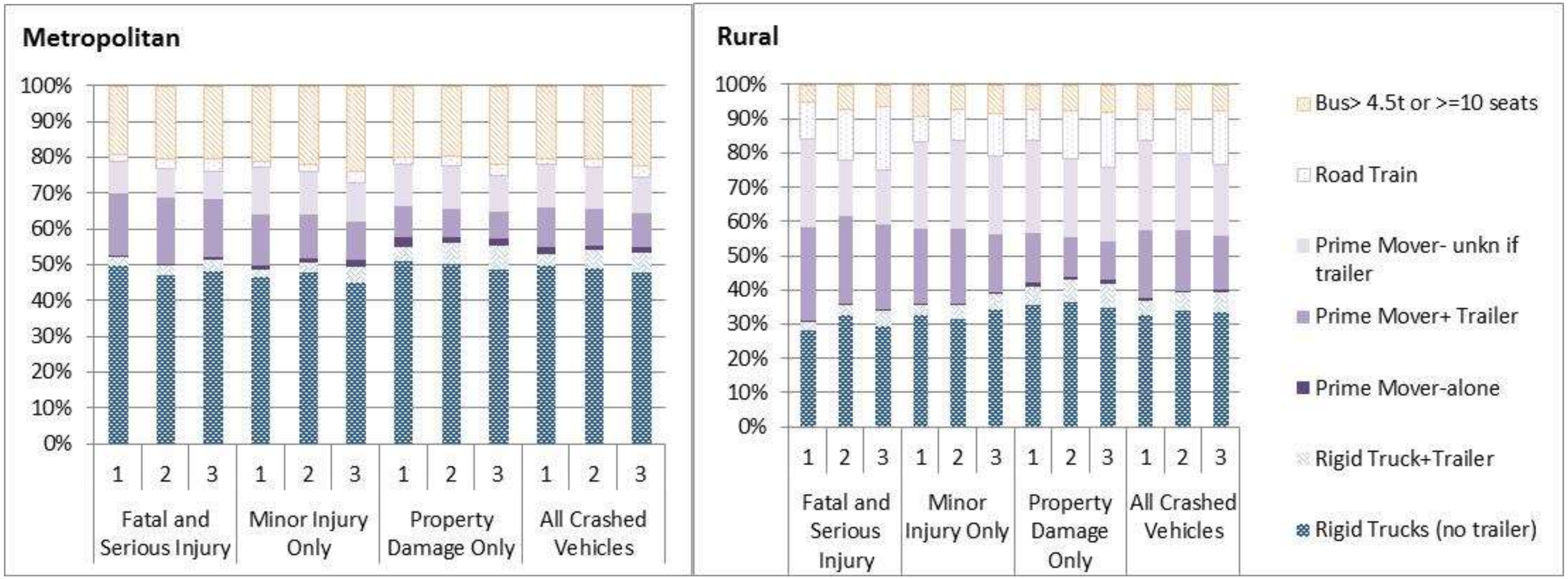


Figure 10

Distribution of crashed heavy vehicle types by crash severity and location over 3 three year periods spanning 2001-2010

4.4 Trends for specific crash types

Figure 11

Australian crashed heavy vehicle types by crash severity and specific crash types over 3 three year periods spanning 2001-2010 (Single vehicle)

(PDO does not include Victoria)

Single vehicle crashes decreased over the nine year period across property damage and fatal and serious injury crashes (**Figure 11** and **Figure 12**), but not across all heavy vehicle types; they have increased for road trains.

Run off road crashes and ESC sensitive loss of control crashes (which include loss of control crashes that both run off road and remain on the carriageway) are largely but not exclusively single vehicle crashes. Property damage only crashes of these types have remained fairly stable and Australian injury and New Zealand serious injury crashes have decreased. The changes by vehicle type (Australia) are summarised in **Table** 8 .

Table 8 : Percent increase for loss of control type crashes sensitive to ESC from period 1 to period 3

	KSI	Minor	PDO
Rigid Trucks	22	2	5
Prime Movers	-35	-18	-21
Road Train	23	55	27
Bus> 4.5t or >=10 seats	-2	9	10

First event roll-over crashes are generally run-off road single-vehicle crashes, however the roll-over may occur on the carriageway and there may be more than one vehicle involved. Fatal and serious injury first event roll-over crashes have increased for Australia and decreased for New Zealand over the 9 years. Australian minor injury and property damage only roll over crashes have decreased. The changes by vehicle type are summarised in **Table** 9 .

Table 9 : Percent increase for first event roll over type crashes sensitive to ESC from period 1 to period 3

	KSI	Minor	PDO
Rigid Trucks	17	41	-12
Prime Movers	17	-38	-35
Road Train	11	33	25
Bus> 4.5t or >=10 seats	-23	-26	-75

Lane Departure Warning System sensitive crashes are generally run-off road single-vehicle crashes, however the departure may be to the right into on-coming traffic, so the crash may involve more than one vehicle and not involve leaving the carriageway. Where the vehicle is a multi-vehicle crash, crashes were only considered sensitive to the technology if it may have possibly been avoided through fitment of the technology to the heavy vehicle, that is, if the heavy vehicle was thought to be the vehicle departing from the lane). Australian LDWS sensitive crashes have increased over the 9 years. The changes by vehicle type are summarised in **Table 10** . Fatal and serious injury LDWS sensitive crashes of New Zealand were observed to decrease over the period.

Table 10 : Percent increase for crashes sensitive to LDWS from period 1 to period 3

	KSI	Minor	PDO
Rigid Trucks	53	-1	46
Prime Movers	-22	-9	-18
Road Train	50		37
Bus> 4.5t or >=10 seats	-24	-1	99

Trending increases by crash severity and vehicle type have been highlighted in the three tables above. It is clear that with trending increases in Australian crashes sensitive to ESC and LDWS, technology for specific vehicle type and crash severity combinations, despite overall decreases in single vehicle crashes, the benefits of increased fitment of these technologies will only improve in time.

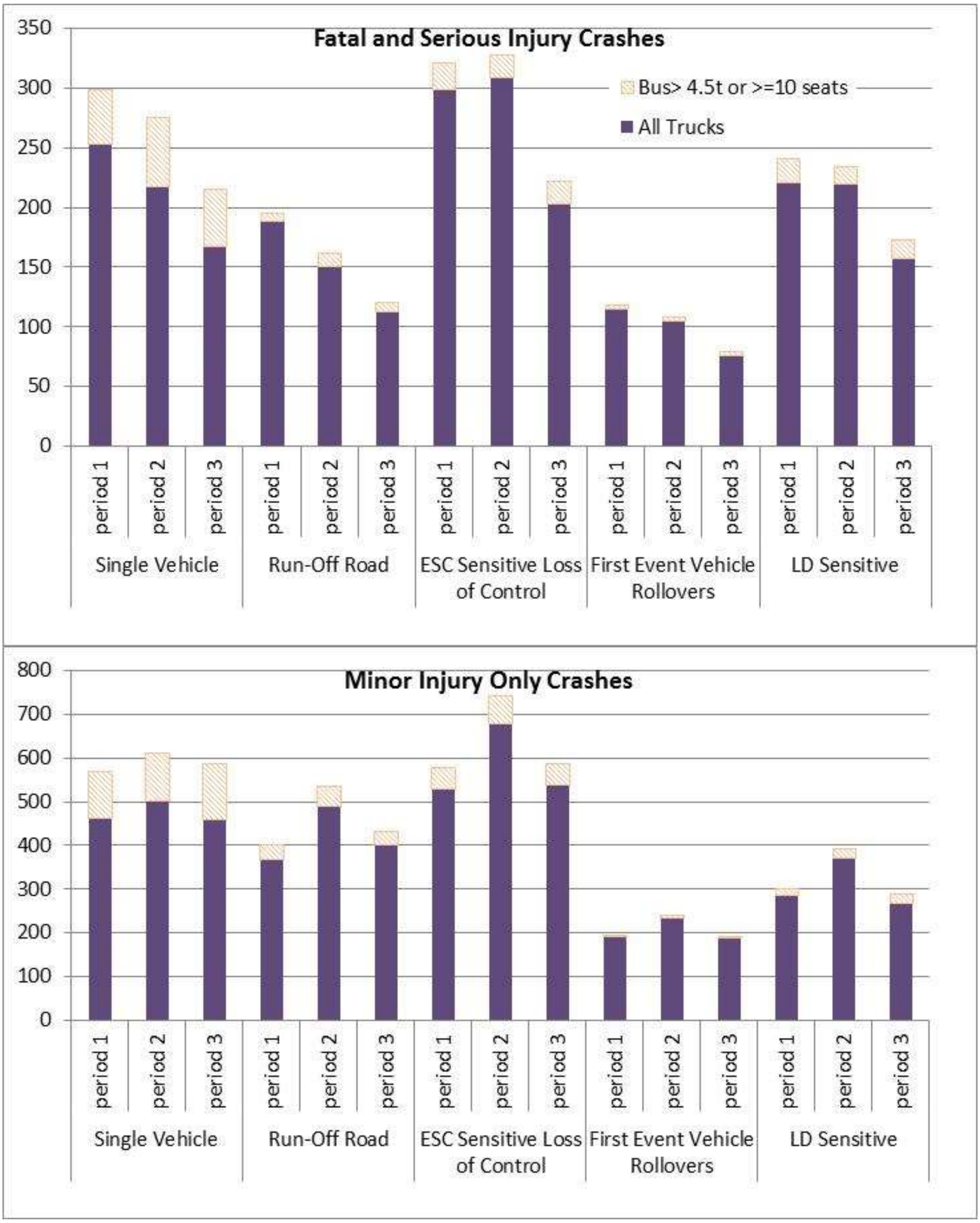


Figure 12

New Zealand crashed heavy vehicle types by crash severity and specific crash types over 3 three year periods spanning 2002-2010 (Single vehicle)

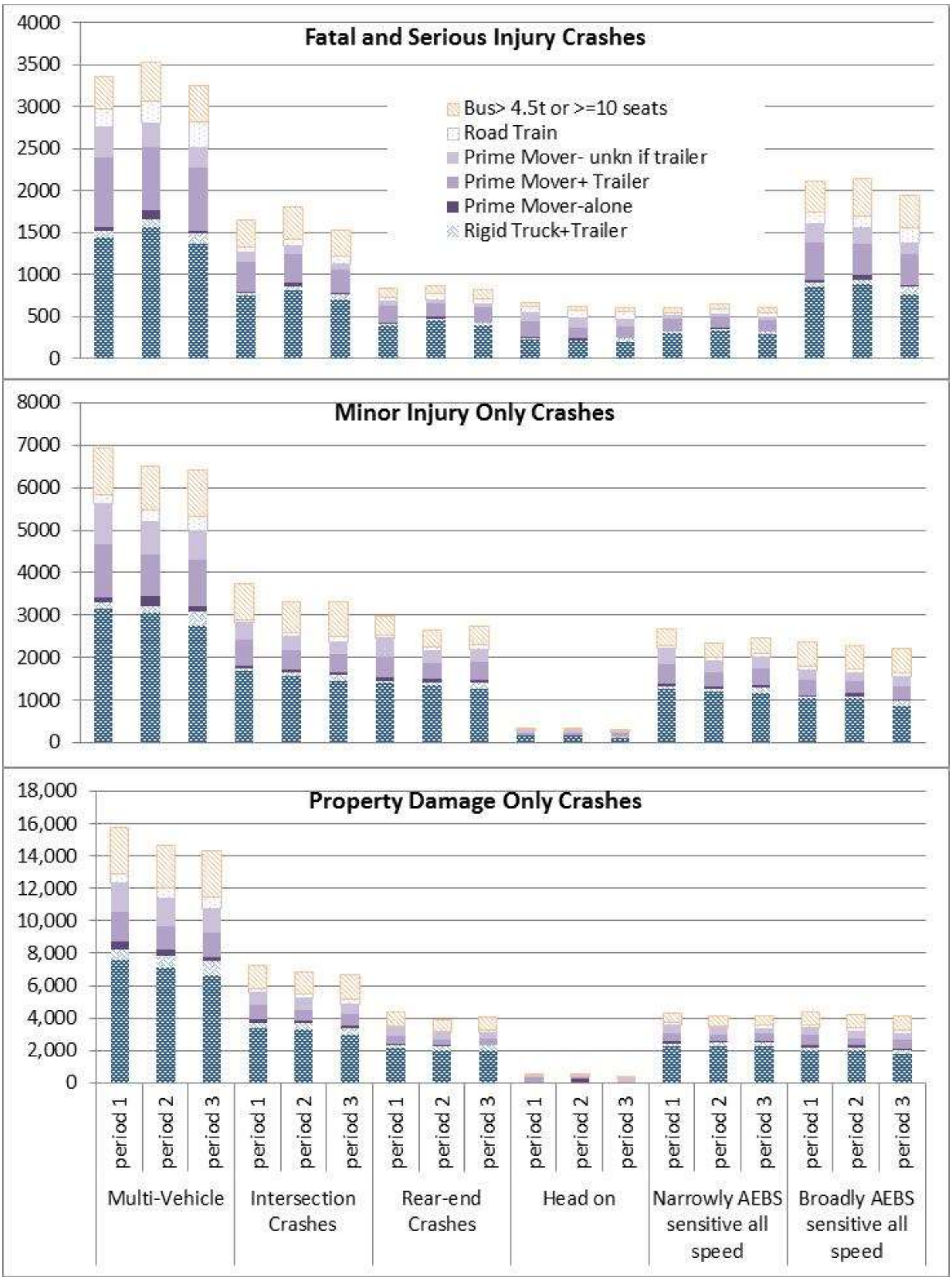


Figure 13

Australian crashed heavy vehicle types by crash severity and specific crash types over 3 three year periods spanning 2001-2010 (Multi-vehicle)

(PDO do not include Victoria)

Multi-vehicle crashes decreased over the nine year period across all severity crashes, but not across all heavy vehicle types; fatal and serious injury crashes increased for Australian buses and all severity crashes increased for road trains (**Figure 13**). Decreasing or stable crash numbers were also observed for intersection and rear-end crashes for prime movers and rigid trucks, and generally for heavy vehicle serious injury crashes of these two types in New Zealand. Bus crashes increased slightly for property damage only intersection and for fatal and serious injury rear-end crashes. Buses and road trains were also the exception to the observed head-on crash decreases. There was an increase in fatal and serious head-on bus crashes observed.

Crashes narrowly sensitive to AEBS are largely but not exclusively rear-end vehicle crashes. In addition to rear-end crashes, narrowly sensitive crashes include crashing into stationary vehicles or obstructions on the carriageway. Crashes broadly sensitive to AEBS include crashes with pedestrians and vehicles or objects which enter the path of the vehicle on the carriageway; this may include single vehicle hit–object collisions. Where the heavy vehicle is involved in a multi-vehicle crash, crashes were only considered sensitive to the technology if it may have possibly been avoided through fitment of the technology. For example if the heavy vehicle was the colliding vehicle and the other the target vehicle. Crashes of these types have decreased. The changes by vehicle type are summarised in **Table 11** and in **Table 12** .

Table 11 : Percent increase for Australian crashes narrowly sensitive to AEBS from period 1 to period 3

	KSI	Minor	PDO
Rigid Trucks	0	-2	3
Prime Movers	-10	-22	-26
Road Train	59	61	50
Bus> 4.5t or >=10 seats	16	-9	2

Table 12 : Percent increase for Australian crashes broadly sensitive to AEBS from period 1 to period 3

	KSI	Minor	PDO
Rigid Trucks	-5	-10	-7
Prime Movers	-26	-10	-21
Road Train	31	49	67
Bus> 4.5t or >=10 seats	5	-3	8

Trending increases by crash severity and vehicle type have been highlighted in the two tables above. It is clear that with trending increases in crashes sensitive to AEBS technology for road trains generally and for fatal and serious injury crashes involving buses, the benefits of increased fitment of these technologies will only improve in time for these two vehicle types.

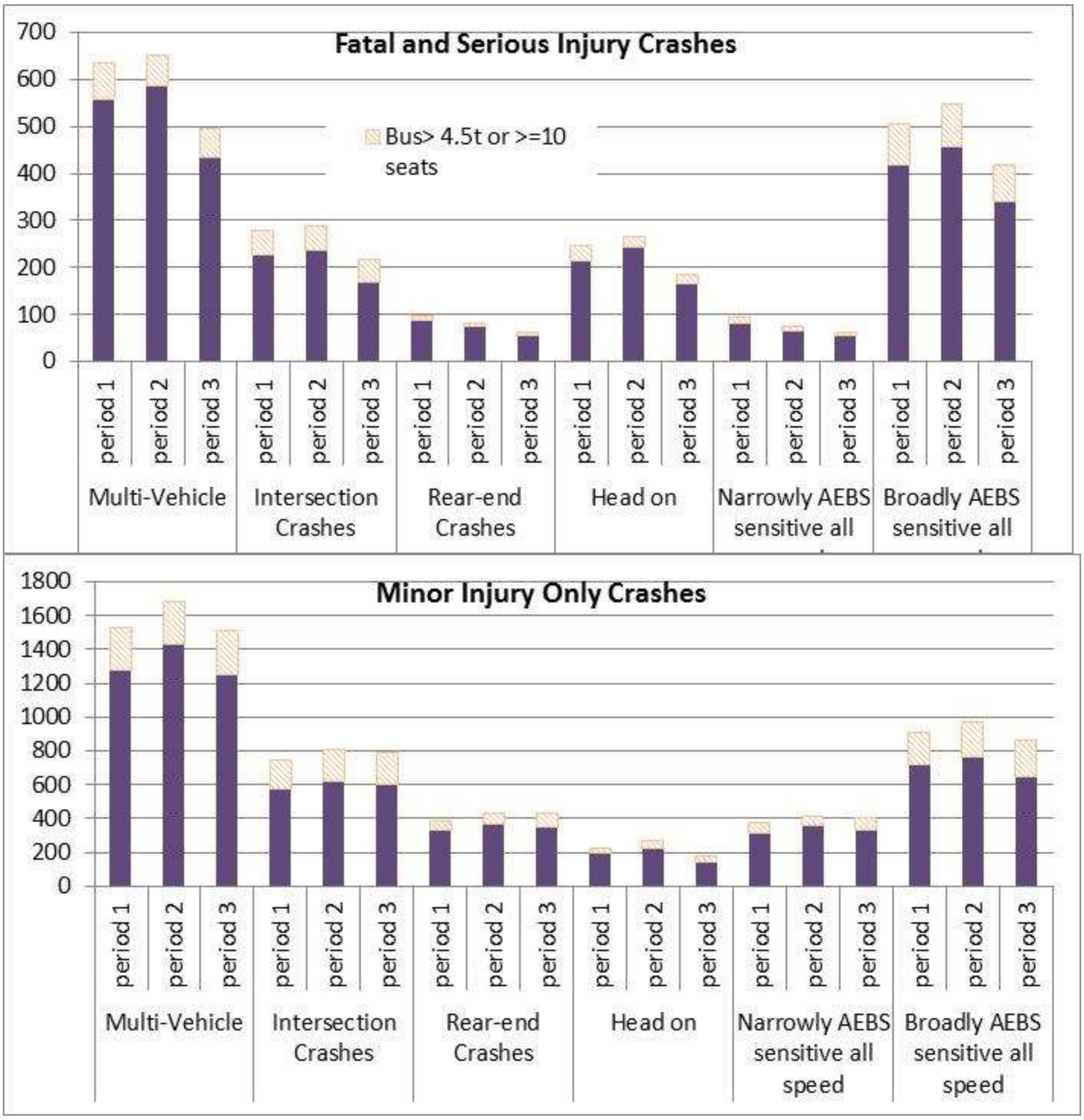


Figure 14
New Zealand crashed heavy vehicle types by crash severity and specific crash types over 3 three year periods spanning 2002-2010 (Multi-vehicle)

An increasing trend for collisions with unprotected vehicles (e.g. bicycles, small tractors, motorcycles) and decreasing trends for pedestrian collisions and for passenger vehicle collisions were observed across all severities (**Figure 15** and **Figure 16**).

In addition to further reducing rear-end passenger vehicle crashes, it is likely that mandated AEBS technology can improve crash outcome for heavy vehicle collisions with on-path, unprotected road users and possibly with those that cross the heavy vehicle path also.

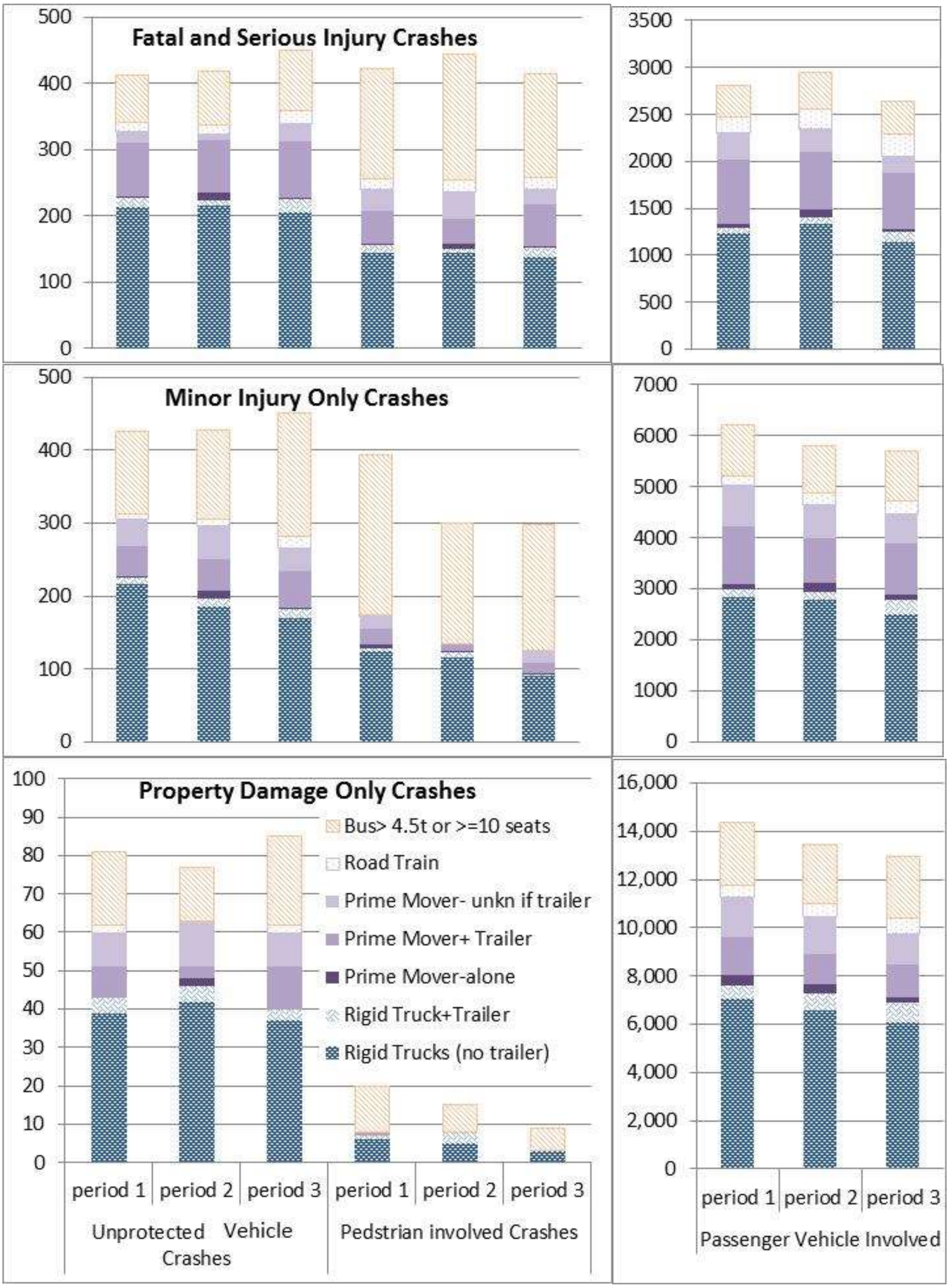


Figure 15

Australian crashed heavy vehicle types by crash severity and specific road user types over 3 three year periods spanning 2001-2010

(PDO crashes do not include Victoria)

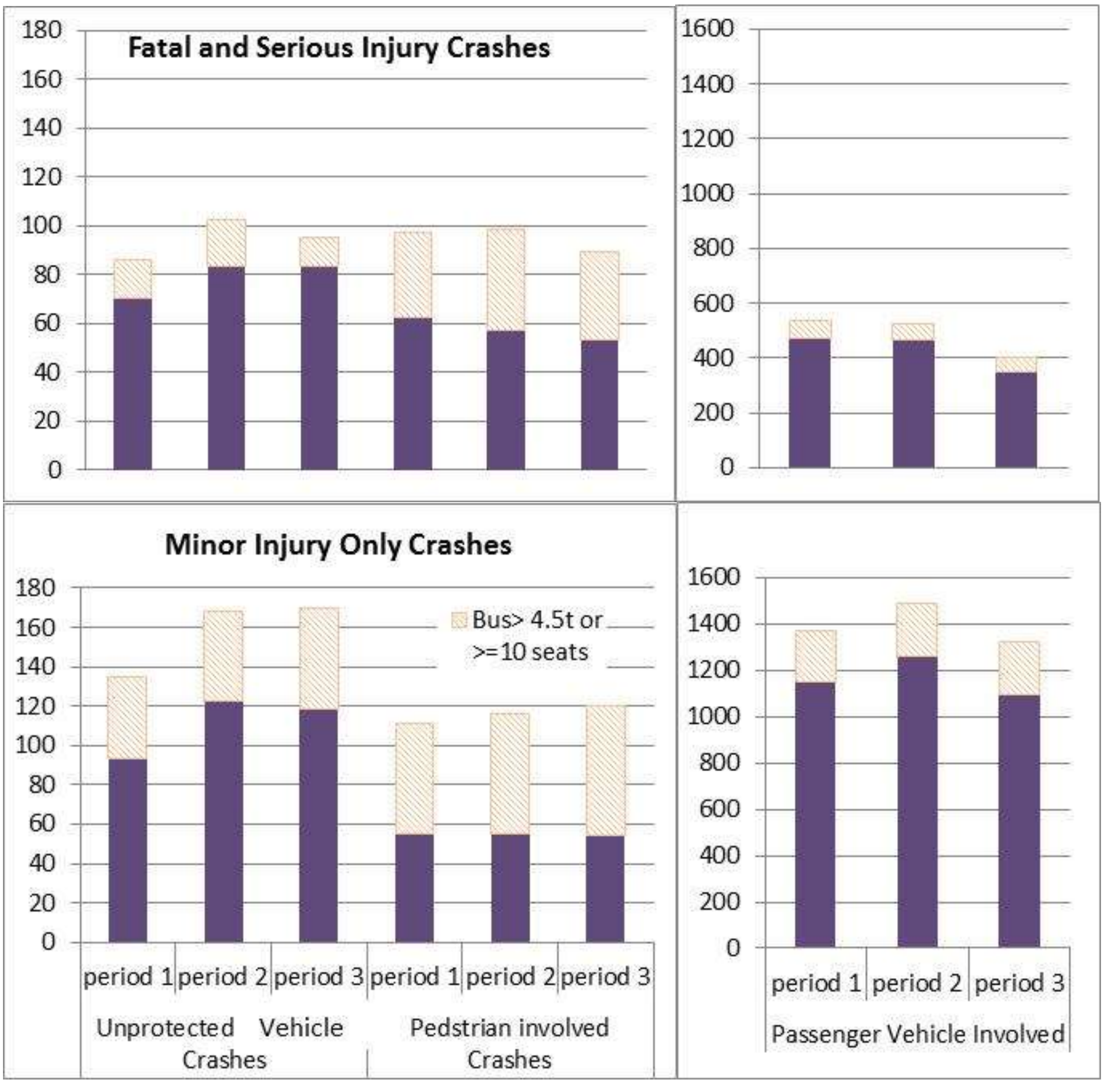


Figure 16

New Zealand crashed heavy vehicle types by crash severity and specific road user types over 3 three year periods spanning 2002-2010

4.5 Trends for road trains

Road train crashes of most types and severities were shown to increase across the three periods. **Table 13** summarises the observed increases from the first to the third period. Crash type-severity combinations with observed decreases are not shown.

The largest percent increase across all severities were observed in remote locations, however road trains involved in minor injury crashes in metropolitan regions observed a 73% increase over the periods. Increases greater than 100% were observed for minor injury head-on crashes and for minor injury crashes involving bicycles or motorcycles. The greatest increase in fatal and serious injury crashes was observed for crashes narrowly sensitive to AEBS (59%), crashes sensitive to LDWS, unprotected vehicle crashes and rear-end crashes (50%).

Table 13 : Percent increase for Australian crashes involving road trains AEBS from period 1 to period 3

	KSI	Minor	PDO	all
Lane Departure Sensitive	50		37	62
Narrowly AEBS sensitive all speed	59	61	50	54
Broadly AEBS sensitive all speed	31	49	67	50
ESC Sensitive Loss of Control	23	55	27	32
First Event Vehicle Rollovers	11	33	24	23
all	36	54	33	38
remote	67	58	67	66
Metropolitan	47	73	57	60
Rural	26	66	64	52
Multi-Vehicle	46	53	36	42
Unprotected Vehicle Crashes	50	135	0	73
Passenger Vehicle Involved	45	48	37	41
Rear-end Crashes	50	55	31	41
Intersection Crashes	46	58	37	43
Head on	22	123	42	41
Single Vehicle	21	56	28	32
Run-Off Road	16	80	18	30
Pedestrian involved Crashes	7			0

4.6 Trends in multi-heavy vehicle crashes

Despite the current decreasing trend in overall heavy vehicle crashes in Australia, the proportion of multi-heavy vehicle crashes have increased over the 9 years, which is indicative of the increasing presence of heavy vehicles on Australian roads (**Figure 17**).

Although presenting at a similar proportion of heavy vehicle crashes, there was no observable trend in multi-heavy vehicle crashes for New Zealand.

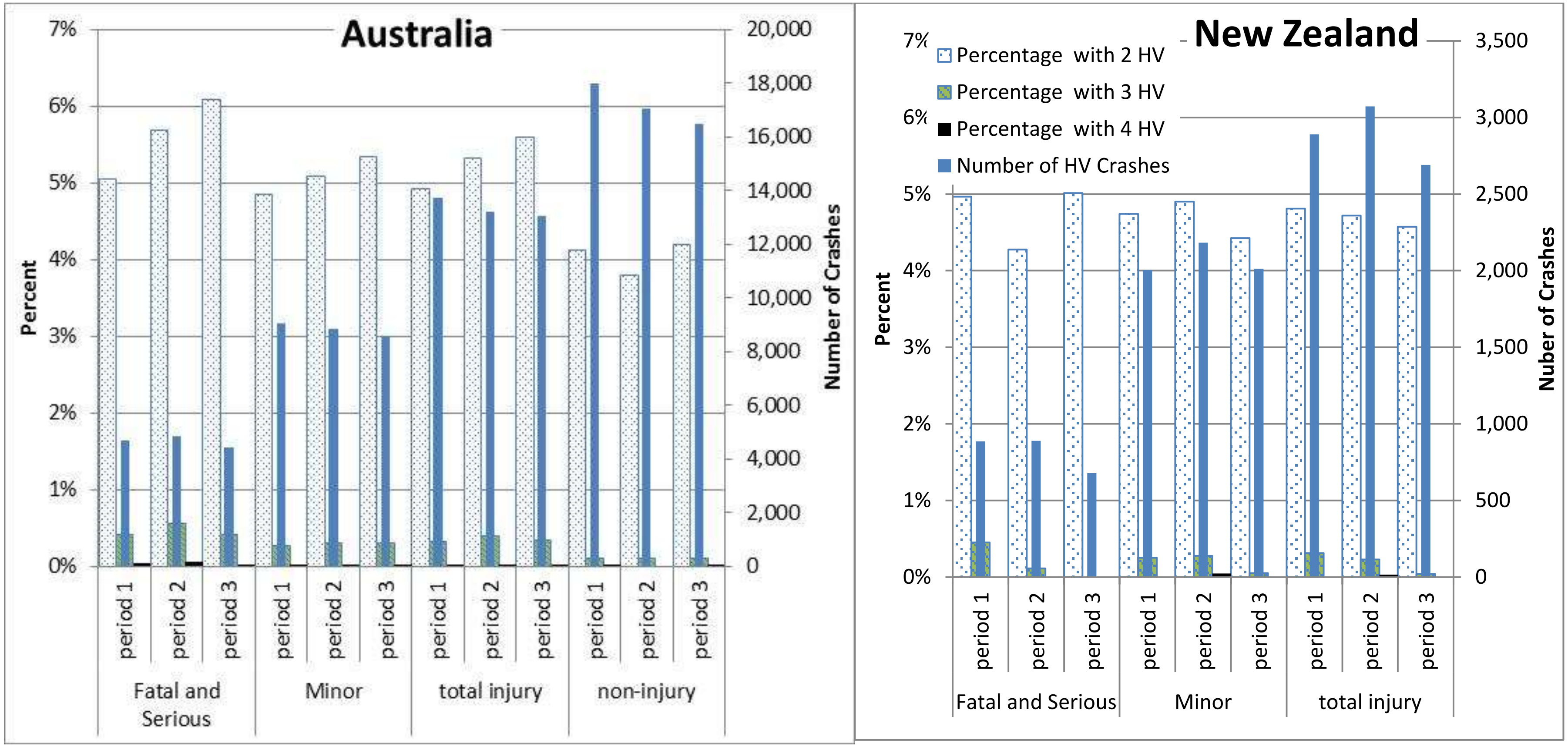


Figure 17

Frequency of heavy vehicle crashes and proportion of multi-heavy vehicle crashes by severity, over 3 three year periods spanning 2001-2010

(Australian PDO crashes do not include Victoria.)

5.0 PERIOD THREE HEAVY VEHICLE SUMMARY

The third period was defined as crashes from 2008, 2009 and 2010 for all states except for Queensland, where 2010 data was unavailable so the third period was for crashes from 2007, 2008 and 2009.

5.1 Vehicle occupancy

Over the entire 2000-2010 period, Australian crashed heavy vehicles, with the exception of buses, were occupied by only the driver in approximately 90% of cases. Truck occupancy rate was higher in New Zealand, with 62% having only a driver occupant. Australian crashed rigid trucks and road trains were more likely to have additional 1-3 passengers than were prime movers.

Half of the Australian crashed buses and 40% of the New Zealand crashed buses were occupied only by the driver. 37% of Australian crashed buses were occupied by 1-19 passengers and 12% by 20 or more passengers. 44% of New Zealand crashed buses were occupied by 1-19 passengers and 13 % by 20 or more passengers.

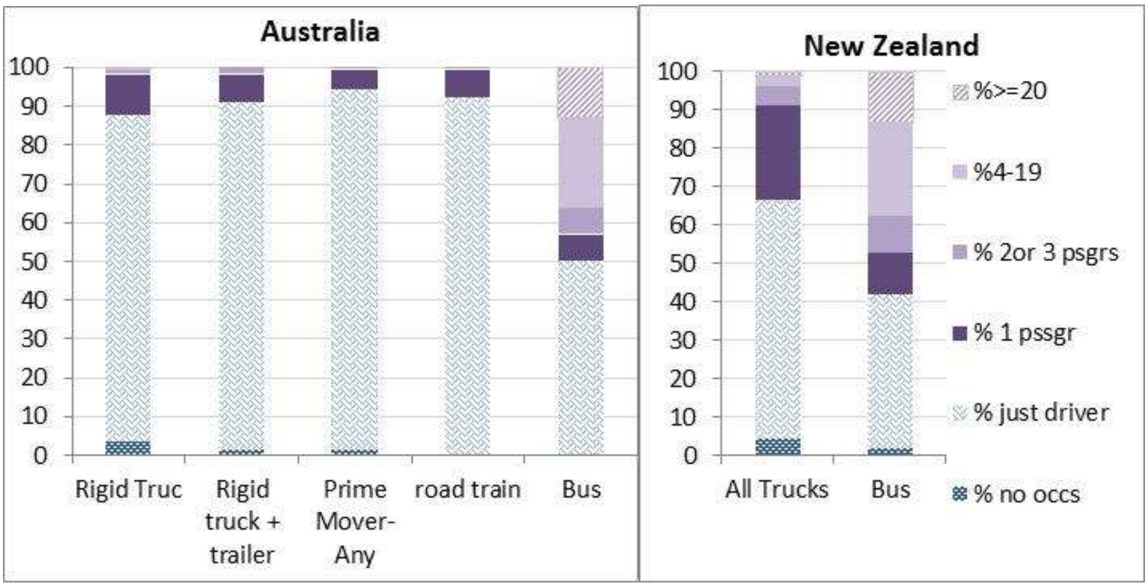


Figure 18

Distribution of occupancy categories for crashed heavy vehicles by type, (2000-2010)

5.2 Driver age

Over the entire period, 2000-2010, the most prevalent age range for drivers of crashed heavy vehicles is 35-54 years; more than half were controlled by drivers within this age group. The drivers of crashed rigid trucks were more likely to be younger than those of prime movers and road trains. Older drivers showed a greater representation in buses than in other crashed heavy vehicles.

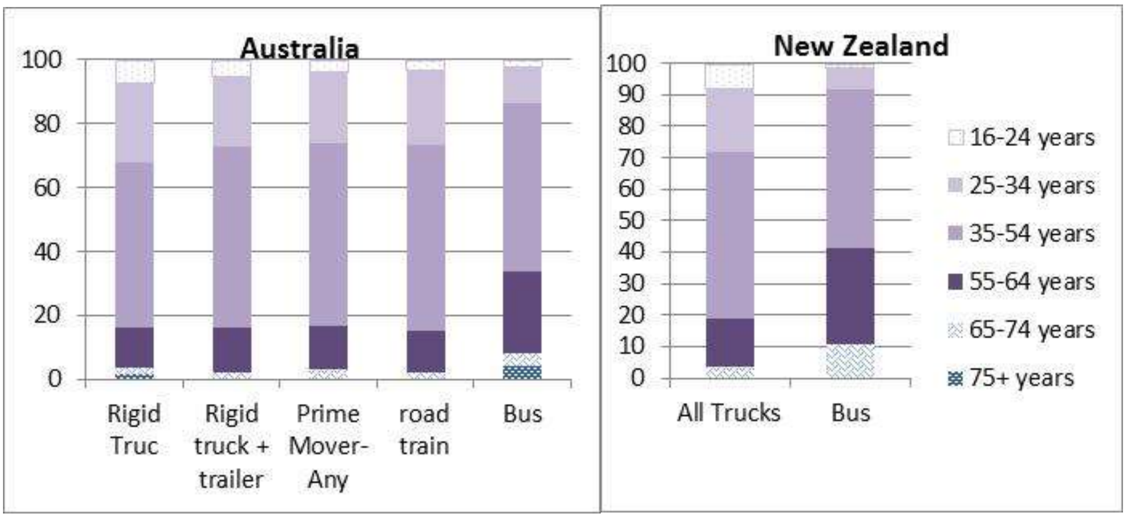


Figure 19

Distribution of driver age groups for crashed heavy vehicles by type,(2000-2010)

5.3 Crash injuries per crashed heavy vehicle by crash severity

Pedestrian, driver and other occupant injuries were counted for the heavy vehicle, and other vehicles involved in the crash. Crashed road train and prime movers produced the greatest number of fatalities and crashed buses produced the greatest number of serious or minor injuries per fatal and serious injury crash.

Rates of fatalities within New Zealand fatal and serious injury heavy vehicle crashes were higher, and the rates of serious injury lower, than for Australia.

Table 14 : Australian crash injuries per crashed heavy vehicle by crash severity, injury severity and vehicle type, in the third period (~2008-2010)

	Fatal injuries per fatal crash	Fatal injuries per fatal and serious crash	Serious injuries per fatal and serious crash	Minor injuries per fatal and serious crash	Minor injuries per minor crash
Australia					
Rigid Trucks (no trailer)	1.100	0.125	1.085	0.237	1.244
Prime Mover- +/- trailer	1.179	0.201	1.034	0.233	1.249
Rigid Truck+Trailer	1.125	0.181	1.034	0.242	1.254
Road Train	1.223	0.315	0.966	0.247	1.240
Bus> 4.5t or >=10 seats	1.101	0.086	1.262	0.607	1.436
Total HV Crashed vehicles	1.152	0.163	1.079	0.285	1.278
New Zealand					
Trucks	0.954	0.260	0.823	0.353	1.133
Bus> 4.5t or >=10 seats	1.123	0.188	0.992	0.835	1.306
Total HV Crashed vehicles	0.969	0.250	0.846	0.419	1.162

5.4 Location of Crashes

Table 15 : The percentage of heavy vehicle crashes by injury severity and location, in the third period (~2008-2010)

	Fatal Crashes	Serious	Minor	total injury	PDO	total
Australia						
Metropolitan	37	61	72	67	78	73
Intersection	25	36	41	38	41	40
Run-Off Road	14	17	11	13	9	11
New Zealand						
Metropolitan	27	42	52	49		
Intersection	21	34	38	36		
Run-Off Road	11	19	20	20		

Trends by vehicle type and location of crash were observed. Common sense leads us to deduce that road train crashes will predominantly be in rural areas and bus crashes will present with highest frequency in metropolitan regions and at intersections. The following paragraphs show the interaction of these common sense trends with crash severity.

73% of Australian heavy vehicle crashes occurred in metropolitan regions. The majority of non-fatal heavy vehicle crashes occurred in metropolitan regions, however as the severity of the crash increased, the proportion occurring in remote and rural regions increased, so that the majority of fatal crashes, (63% for Australia and 73% for New Zealand) occurred in remote or rural regions.

40% of Australian heavy vehicle crashes occurred at intersections. Intersection crashes had greater representation in less severe crashes: 41% of PDO heavy vehicle crashes were at intersections compared with only 25% and 21% (for Australia and New Zealand respectively) of fatal heavy vehicle crashes. Conversely, heavy vehicle crashes that involved a vehicle running off the road had a greater representation in more severe Australian crashes: for Australia this was 9% of PDO heavy vehicle crashes, compared with 17% of serious and 14% of fatal heavy vehicle crashes. For New Zealand we see run-off road crashes with a greater representation of minor injury crashes than of fatal crashes.

The trend for greater crash proportions in metropolitan areas was greatest for buses, but not evident for road trains, where 71% of injury and 62% of property damage only crashes occurred in rural or remote regions. Similarly, buses also had the highest, and road trains the lowest representation with intersection crashes. As would be expected, the reverse was true for run-off road crashes, where road trains and prime movers dominated.

Table 16 : The percentage of **Australian** heavy vehicle crashes at specific locations, by injury severity and vehicle type, in the third period (~2008-2010)

	Metropolitan	Intersection	Run Off Road

	total injury	PDO	total injury	PDO	total injury	PDO
Rigid Trucks (no trailer)	74	83	44	41	10	7
Prime Mover ± trailer	55	68	29	37	17	12
Rigid Truck+Trailer	63	76	36	39	12	9
Road Train	29	38	22	27	27	21
Bus> 4.5t or >=10 seats	86	90	49	52	4	3

Table 17 : The percentage of **New Zealand** heavy vehicle crashes at specific locations, by injury severity and vehicle type, in the third period (~2008-2010)

	Metropolitan	Intersection	Run Off Road
	total injury	total injury	total injury
Rigid truck	43	34	22
Bus> 4.5t or >=10 seats	77	48	8

The resultant concerns are: that although road trains represent only a small proportion overall of heavy vehicle crashes, they are representing highly in the more severe crashes; and although buses, rigid and articulated trucks, are more highly represented in less severe crashes, they are occurring in more populated areas and with much larger frequencies than road train crashes.

5.5 Other Road Users

With large proportions of heavy vehicle crashes in urban areas and at intersections, it is important to identify the other road users involved. In Australia, 83% of all heavy vehicle crashes (87% of PDO crashes and 76% of injury crashes) involve at least one other vehicle and for 89% of multi-vehicle crashes, at least one of the other vehicles is a passenger vehicle. In New Zealand, the Australian figure of 76% of injury crashes, is slightly lower at 72%, and 95% of these multi-vehicle injury crashes involve at least one passenger vehicle.

The interaction of the multi-vehicle crashes with injury severity was interesting, because the proportion multi-vehicle of each severity of injury crashes varied by only 5% units generally for heavy vehicle multi-vehicle injury crashes. However, for Australian passenger vehicle involved crashes, the range was wider, and trended toward decreasing proportions of greater severity injury crashes. Indicating the possibility that Australian injury outcomes in passenger to heavy vehicle crashes were better than those for New Zealand. For both Australia and New Zealand the proportion of crashes that involved unprotected road user increased with increasing crash severity.

Table 18 : The percentage of heavy vehicle crashes of a specific crash type, by injury severity, in the third period (~2008-2010)

	Fatal Crashes	Serious	Minor	total injury	PDO	total
Australia						
Multi Vehicle	73	73	78	76	87	83
Passenger Vehicle	52	60	70	66	79	73
Unprotected vehicles (incl. bicycles)	13	9	5	7	1	3
Pedestrian involved	15	8	4	6	0	2
Rear-end	7	20	34	28	25	26
Head-on	33	10	4	7	3	5
New Zealand						
Multi Vehicle	74	69	72	72		
Passenger Vehicle	60	55	63	61		
UPRU (vehicle, incl. bicycles)	14	13	8	9		
Pedestrian involved	14	12	6	7		
Rear-end	4	10	21	18		
Head-on	41	22	8	13		

Two specific types of multi-vehicle crashes are also presented in Table 18 **:** Rear-end and Head-on. These crash types were listed to demonstrate the effect of location and type of impact on multi-vehicle crash severity. In Australia, 26% of heavy vehicle crashes were rear-end crashes. This crash type primarily occurred in urban areas and as such showed the severity trend of metropolitan crashes; increasing in proportion with decreasing crash severity. However, the trend did not extend to 'no injury' crashes, which were proportionally lower than minor-injury crashes in Australia. This was probably because most heavy vehicle rear-end crashes involved a collision with a lighter vehicle, so that the possibility of under-running along with the transfer of momentum, made for a poorer 'other road-user' outcome, not likely to just involve property damage. Head-on crashes, of course were observed with a greater representation as crash severity increased. In Australia, head-on crashes are 11 times more highly represented in fatal heavy vehicle crashes than in no-injury heavy vehicle crashes.

Table 19 : The percentage of heavy vehicle crashes of a specific crash type, by injury severity and vehicle type, in the third period (~2008-2010)

	Multi-Vehicle		Passenger Vehicle		Unprotected vehicle (incl. bicycles)		Pedestrian involved		Rear-End		Head On	
	total injury	PDO	total injury	PDO	total injury	PDO	total injury	PDO	total injury	PDO	total injury	PDO
Australia												
Rigid Trucks (no trailer)	83	92	73	84	8	1	5	0	34	29	7	2
Prime Mover-±trailer	75	82	64	73	5	1	3	0	26	20	9	4
Rigid Truck+Trailer	80	83	71	74	5	0	3	0	30	23	9	3
Road Train	64	60	51	52	4	0	2	0	18	14	13	4
Bus> 4.5t or >=10 seats	68	97	59	90	11	1	15	0	24	27	4	2
New Zealand												
Trucks	73		62		9		5		18		14	
Buses	65		56		13		20		17		9	

Australian, multi-vehicle crashes of all the kinds in Table 18 (except head-on) make up a lesser proportion for road trains than for other heavy vehicle types (Table 19) which is most likely due to their activity primarily in less populated regions and greater probability of involvement in single vehicle crashes. However it is interesting to see that head on crashes make up 13% of road train crashes, but only 4-9% of other Australian heavy vehicle types. This adds to the growing evidence of high severity injury risk for road train vehicle crashes.

There were no property damage only (Australian) crashes involving pedestrians for articulated trucks and prime movers; for buses and rigid trucks the proportion was only 0.4 and 0.04% respectively. The proportion pedestrian involved injury crashes of heavy vehicle crashes was 3-8 times higher for buses than for other heavy vehicles. This is not surprising given that pedestrians are more likely to encounter a bus than a prime mover, however, it is notable that, at 90%, the highest proportion of property damage only crashes that were passenger involved (Australian) was also seen for buses, (with rigid trucks coming a close second, at 84%).

5.6 Crashes sensitive to emerging technology

Section 3.2 discussed the methods used to identify crashes sensitive to emerging technologies. The fatigue warning system crashes were a subset of the ESC loss of control crashes in which crashes identified with exceeded driver blood alcohol limits or exceeded speed limits were excluded. No speed restrictions were placed on AEBS sensitive crashes; and LDWS sensitive crashes included only those in speed zones at 80 km/h and above where edge line marking was likely.

Table 20 : The percentage of heavy vehicle crashes sensitive to emerging technologies, by injury severity, in the third period (~2008-2010)

	Fatal Crashes	Serious	Minor	total injury	non-injury	total
Australia						
AEBS -Narrow	8	15	30	24	26	25
AEBS- Broad	62	40	27	33	26	29
LDWS	11	7	3	5	3	4
ESC LOC	16	19	13	15	11	13
ESC Rollover	5	10	7	7	4	5
Fatigue	15	18	12	14	10	11
New Zealand						
AEBS -Narrow	6	10	20	17		
AEBS- Broad	71	55	41	46		
LDWS	35	21	14	16		
ESC LOC	31	31	28	29		
ESC Rollover	13	10	9	9		
Fatigue	25	23	22	22		

Crashes sensitive to AEBS represented the greatest proportion of crashes at each injury severity with more than half of all heavy vehicle crashes sensitive to this technology in some way. However many of these crashes were only broadly sensitive to AEBS, and as such did not offer as much in potential crash reductions, but given that 62% of Australian fatal heavy crashes and 40% of Australian serious heavy crashes were broadly sensitive to AEBS, even with the lower 'broadly sensitive' crash reduction rates, it is possible that AEBS will still extend sound protection against fatal and serious injury crashes. Sensitivity to injury crashes was similar for PDO crashes (57% cf 52% respectively). For New Zealand the proportions of heavy vehicle crashes broadly sensitive to AEBS technology were even greater, however, the narrowly sensitive crashes were lower in proportion than in Australia.

Although only 4% of Australian heavy vehicle crashed vehicles were identified as sensitive to LDWS, the protection offered was greater for higher severity crashes with 11% of fatal crashes sensitive to LDWS. Sensitivity to injury crashes was almost double that of PDO crashes. The same trends were seen in New Zealand crash data; however, given that in the Australian data, LDWS sensitive crashes were limited to those on highways and freeways, and in New Zealand they could not be, it is not surprising to see that greater proportions of heavy vehicle crashes sensitive to LDWS were identified in New Zealand data.

18% of Australian heavy vehicle crashes were found to be sensitive to ESC technology, with the greatest proportions seen in serious injury crashes where almost 30% of crashes were sensitive. Crashes sensitive to fatigue warning systems were also greatest in proportion for serious injury crashes (18%); over all severities, 11% of crashes were sensitive to FWS.

Greater proportions of the New Zealand ESC and FWS sensitive crashes were identified than were for Australia.

Heavy vehicles, not only were impressively sensitive to AEBS over all crash severities but also across heavy vehicle types (Table Table 21 **)**. It appeared that rigid trucks had most to benefit from AEBS with 63% of injury and 56% of PDO crashes sensitive to this technology. New Zealand truck injury crashes demonstrated 61% sensitivity to AEBS. Road trains displayed the poorest proportion of sensitive crashes with a still impressive 44% of injury and 38% of PDO crashes. For New Zealand, ESC sensitive crashes represented strongly at 43% of truck injury crashes.

ESC, LDWS and FWS technologies were more sensitive to the crashes of articulated trucks and road trains than to those of rigid trucks and buses. The proportion of bus crashes sensitive to these three technologies was no more than 4% for both injury and PDO crashes. For Australian buses, the greatest proportion of technology sensitive crashes, of the three technologies, was seen for fatigue warning systems. The proportion of rigid truck crashes sensitive to these three technologies was no more than 16% for injury and 9% for PDO crashes. For rigid trucks, the greatest proportion of technology sensitive crashes, of the three technologies, was seen for ESC systems

Table 21 : The percentage of heavy vehicle crashes sensitive to emerging technologies, by injury severity and vehicle type, in the third period (~2008-2010)

	AEBS				LDWS		ESC				Fatigue	
	Narrow		Broad				LOC		Roll-over			
	total injury	PDO	total injury	PDO	total injury	PDO	total injury	PDO	total injury	PDO	total injury	PDO
Australia												
Rigid Trucks (no trailer)	30	31	33	25	3	2	12	8	4	1	10	7
Prime Mover-±trailer	23	22	28	24	8	4	21	14	13	5	20	14
Rigid Truck +Trailer	25	25	32	25	6	4	16	12	8	6	14	11
Road Train	16	16	28	22	10	9	33	34	19	21	31	29
Bus> 4.5t or >=10 seats	18	21	43	31	1	1	4	3	1	0	4	3
New Zealand												
Truck	17		43		18		32		11		25	
Bus	16		60		17		13		1		10	

The vehicle type most sensitive to LDWS was road trains where 10% of injury and 9% or PDO crashes were sensitive.

Road trains and articulated trucks both demonstrated high sensitivity to ESC and fatigue warning systems. 52% and 34% respectively of injury crashes; and 54% and 19% respectively of PDO crashes were found to be sensitive to ESC; and 31% and 20% respectively of injury crashes and 29% and 14% respectively of PDO crashes were found to be sensitive to FWS.

6.0 INJURY AND COST SAVINGS ASSOCIATED WITH SAFETY TECHONOLOGY

6.1 Crashes saved over the Third three year period

Tables 22 to 29 display the crash reduction and percentage crash reduction estimates for fatal, serious injury, minor injury and non-fatal crashes for scenarios where each of the four emerging technologies were mandated with the assumption of no current fitment and the assumption that the technologies work at the stated efficacies (Section 1.2). The reductions tabled apply only to the third, most recent, three year period.

6.2 Annual Crash cost savings

Tables 30 to 37 display the societal crash cost savings for the average annual crash reductions from Section 6.2. The annual cost savings were calculated from the average annual crash reduction over the third three year period.

AEBS

At the maximum efficacy, one quarter of all heavy vehicle *fatal* crashes could be prevented from the mandating of AEBS systems. This translated to an annual saving of costs to Australian society of $187 million and to New Zealand society of $62 million (NZ).

It is also estimated that up to 17% of Australian and 14% of New Zealand heavy vehicle serious injury crashes and up to 3% of Australian property damage only crashes may be prevented by AEBS fitment. However, because of translation of serious injury to minor injury crashes, the AEBS fitment model estimates an increase of 1-5% of minor injury crashes. In total, societal savings across crashes of all severities were estimated at $AUS 82-254 million for Australia. Across injury crashes only, savings of $NZ 25-81 million were estimated for New Zealand.

Maximum AEBS related percent fatal and serious injury crash reductions were higher for rigid trucks than for articulated trucks in Australia. In New Zealand, fatal and serious crash reductions were greater for buses than for trucks. In Australia, these fatal and serious injury crash reductions translated to an estimated annual maximum of $AUS104 million in rigid trucks and $121 million in articulated trucks and road trains.

LDWS

At the maximum efficacy, 6% of all Australian heavy vehicle *fatal* crashes from the mandating of LDWS systems could be prevented. This translated to an annual saving of costs to Australian society of $45 million. Because edge-lined roads were not as easily identified in the NZ dataset, greater maximum crash reductions were obtained. Fatal crashes, at a maximum reduction of 17%, translated to the same societal cost in New Zealand (but in New Zealand dollars).

Table 22 : Crash reductions expected from mandatory fitment of AEBS by vehicle type and crash severity, in the third period (~2008-2010)

	AEBS Sum Reductions						
	Australia				New Zealand		
	Fatal Crash	SI Crash	MI Crash	Property Damage only	Fatal Crash	SI Crash	MI Crash
Rigid Trucks (no trailer)	18-53	102-319	-197 to -126	0-175			
Rigid Truck+Trailer	4-11	7-23	-13 to -11	0-23			
Prime Mover w/w- trailer	23-68	44-140	-115 to -74	0-49			
Road Train	10-29	10-31	-48 to -22	0-15			
All Trucks (NZ)					12-36	18-59	-30 to -29
Bus> 4.5t or >=10 seats	5-15	40-126	-65 to -47	0-53	2-6	5-16	-7 to -1
Total HV Crashes	58-175	204-643	-421 to -275	0-314	14-42	22-75	-37 to -31

Australian PDO crashes do not include Victoria.

Table 23 : 2010 Percentage Crash reductions expected from mandatory fitment of AEBS by vehicle type and crash severity

	AEBS % Reductions						
	Australia				New Zealand		
	Fatal Crash	SI Crash	MI Crash	Property Damage only	Fatal Crash	SI Crash	MI Crash
Rigid Trucks (no trailer)	9-27%	7-21%	-6 to -4%	0-2%			
Rigid Truck+Trailer	9-27%	5-15%	-3%	0-2%			
Prime Mover w/w- trailer	8-25%	4-12%	-5 to -3%	0-1%			
Road Train	8-23%	3-9%	-9 to -4%	0-1%			
All Trucks (NZ)					8-23%	4-13%	-2%
Bus> 4.5t or >=10 seats	9-26%	7-21%	-4 to -3%	0-2%	9-28%	5-18%	-2 to 0%
Total HV Crashes	8-25%	5-17%	-5 to -3%	0-2%	8-24%	4-14%	-2 to-1%

Table 24 : Crash reductions expected from mandatory fitment of LDWS by vehicle type and crash severity, in the third period (~2008-2010)

	Lane Departure Warning System Crash Reductions						
	Australia				New Zealand		
	Fatal Crash	SI Crash	MI Crash	Property Damage only	Fatal Crash	SI Crash	MI Crash
Rigid Trucks (no trailer)	5-10	19-42	16-34	40-88			
Rigid Truck+Trailer	1-3	3-6	6-13	15-32			
Prime Mover w/w- trailer	9-20	33-73	34-74	52-114			
Road Train	4-8	11-23	12-25	28-61			
					13-28	23-50	61-133
Bus> 4.5t or >=10 seats	1-2	1-3	3-6	5-12	1-2	3-5	5-10
Total HV Crashes	19-42	67-147	70-153	141-307	14-30	26-56	66-143

Australian PDO crashes do not include Victoria.

Table 25 : 2010 Percentage Crash reductions expected from mandatory fitment of LDWS by vehicle type and crash severity

	Lane Departure Warning System % Reductions						
	Australia				New Zealand		
	Fatal Crash	SI Crash	MI Crash	Property Damage only	Fatal Crash	SI Crash	MI Crash
Rigid Trucks (no trailer)	2-5%	1-3%	0-1%	1%			
Rigid Truck+Trailer	4-8%	2-4%	1-3%	1-3%			
Prime Mover w/w- trailer	3-7%	3-6%	1-3%	1-3%			
Road Train	3-7%	3-7%	2-5%	2-5%			
All Trucks (NZ)					8-18%	5-11%	4-8%
Bus> 4.5t or >=10 seats	1-3%	0-1%	0%	0%	6-12%	3-6%	1-3%
Total HV Crashes	3-6%	2-4%	1-2%	1-2%	8-17%	5-10	3-7%

Table 26 : Crash reductions expected from mandatory fitment of ESC by vehicle type and crash severity, in the third period (~2008-2010)

	ESC Sum Reductions						
	Australia				**New Zealand**		
	Fatal Crash	SI Crash	MI Crash	Property Damage only	Fatal Crash	SI Crash	MI Crash
Rigid Trucks (no trailer)	4	64	107	129			
Rigid Truck+Trailer	1	11	23	49			
Prime Mover w/w- trailer	16	128	165	173			
Road Train	6	47	70	169			
					15	44	149
Bus> 4.5t or >=10 seats	2	6	12	16	2	2	8
Total HV Crashes	29	256	376	536	16	46	157

Australian PDO crashes do not include Victoria.

Table 27 : 2010 Percentage Crash reductions expected from mandatory fitment of ESC by vehicle type and crash severity

	ESC % Reductions						
	Australia				**New Zealand**		
	Fatal Crash	SI Crash	MI Crash	Property Damage only	Fatal Crash	SI Crash	MI Crash
Rigid Trucks (no trailer)	2%	4%	3%	2%			
Rigid Truck+Trailer	3%	8%	6%	4%			
Prime Mover w/w- trailer	6%	11%	7%	4%			
Road Train	5%	14%	13%	14%			
All Trucks (NZ)					9%	10%	9%
Bus> 4.5t or >=10 seats	3%	1%	1%	1%	8%	2%	2%
Total HV Crashes	4%	7%	5%	3%	9%	9%	7%

Table 28 : Crash reductions expected from mandatory fitment of FWS by vehicle type and crash severity, in the third period (~2008-2010)

	Fatigue Crash Reductions						
	Australia				New Zealand		
	Fatal Crash	SI Crash	MI Crash	Property Damage only	Fatal Crash	SI Crash	MI Crash
Rigid Trucks (no trailer)	4	52	74	145			
Rigid Truck+Trailer	2	8	14	37			
Prime Mover w/w- trailer	13	77	112	152			
Road Train	6	29	45	95			
All Trucks (NZ)					10	29	105
Bus> 4.5t or >=10 seats	2	7	13	24	1	2	9
Total HV Crashes	26	174	258	453	11	31	114

Australian PDO crashes do not include Victoria.

Table 29 : 2010 Percentage Crash reductions expected from mandatory fitment of FWS by vehicle type and crash severity

	Fatigue % Reductions						
	Australia				**New Zealand**		
	Fatal Crash	SI Crash	MI Crash	Property Damage only	Fatal Crash	SI Crash	MI Crash
Rigid Trucks (no trailer)	2%	3%	2%	2%			
Rigid Truck+Trailer	4%	5%	4%	3%			
Prime Mover w/w- trailer	5%	7%	5%	4%			
Road Train	5%	8%	9%	8%			
All Trucks (NZ)					6%	6%	6%
Bus> 4.5t or >=10 seats	4%	1%	1%	1%			
					6%	2%	2%
Total HV Crashes	4%	5%	3%	3%	6%	6%	5%

Table 30 : Annual **Australian** crash reduction savings expected from mandatory fitment of AEBS by vehicle type and crash severity, million 2013$AUS

	AEBS $ Reductions				
	Fatal Crash	SI Crash	MI Crash	PDO	All
Rigid Trucks (no trailer)	$18.8- 56.4	$10.9 - 33.9	-$1.2 to -0.7	$0.00 - 0.69	$28.9 - 89.8
Rigid Truck+Trailer	$3.9 -11.6	$0.7 - 2.4	-$0.1	$0.00 - 0.09	$4.5 - 14.0
Prime Mover w/w- trailer	$24.2- 72.6	$4.7 - 14.9	-$0.7 to -0.4	$0.00 to 0.19	$28.5 - 87.1
Road Train	$10.2 – 30.7	$1.1 - 3.3	-$0.3 to -0.1	$0.00 – 0.06	$11.2 - 33.8
Bus> 4.5t or >=10 seats	$5.4- 16.1	$4.2 - 13.4	-$0.4 to -0.3	$0.00 – 0.21	$9.3 - 29.3
Total HV Crashes	$62.4 – 187.3	$21.6 - 68.0	-$2.6 to -1.7	$$0.0 - 1.2	$82.4 - 254.0
Alternative pricing					
Prime Mover w/w- trailer	$24.2- 72.7	$4.7 - 15.1	-$0.8 to -0.5	$0.00 to 0.22	$28.5 - 87.2
Road Train	$10.2 – 30.7	$1.1 - 3.3	-$0.3 to -0.1	$0.00 – 0.07	$11.2 - 33.8
Bus> 4.5t or >=10 seats	$5.4- 16.1	$4.2 - 13.5	-$0.4 to -0.3	$0.00 – 0.22	$9.3 - 29.4
Total HV Crashes	$62.5 – 187.4	$21.6 - 68.2	-$2.7 to -1.7	$$0.0 - 1.3	$82.4 - 254.2

Table 31 : Annual **New Zealand** crash reduction savings expected from mandatory fitment of AEBS by vehicle type and crash severity, million 2013$NZ

	AEBS $ Reductions				
	Fatal Crash	SI Crash	MI Crash	PDO	All Injury
Trucks	$17.9- 53.7	$4.6 – 15.4	-$0.9 to -0.8		$21.6 - 68.3
Buses	$2.7 -8.2	$1.2 - 4.1	-$0.19 to -0.04		$3.7 - 12.3
Total HV Crashes	$20.6 – 61.9	$5.8 - 19.5	-$1.1 to -0.9		$25.4 - 80.6

Table 32 : Annual **Australian** crash reduction savings expected from mandatory fitment of LDWS by vehicle type and crash severity, million 2013$AUS

	Lane Departure Warning System $ Reduction				
	Fatal Crash	SI Crash	MI Crash	PDO	All
Rigid Trucks (no trailer)	$4.8 - 10.5	$2.0 - 4.4	$0.1 - 0.2	$0.2 - 0.3	$7.1 – 15.4
Rigid Truck+Trailer	$1.6 - 3.4	$0.3 - 0.6	$0.03 - 0.08	$0.06 – 0.13	$1.9 - 4.2
Prime Mover w/w- trailer	$9.6 - 20.9	$3.6 - 7.7	$0.2 - 0.4	$0.20 - 0.44	$13.6 – 29.5
Road Train	$3.9 - 8.5	$1.1 - 2.5	$0.1	$0.07 - 0.15	$5.2 – 11.4
Bus> 4.5t or >=10 seats	$0.7 - 1.6	$0.2 - 0.3	$0.02 - 0.04	$0.02 - 0.05	$0.9 – 2.0
Total HV Crashes	$20.6 - 44.8	$7.2 - 15.6	$0.4 - 0.9	$0.5 - 1.2	$28.8-62.6
Alternative Pricing					
Prime Mover w/w- trailer	$9.6 - 20.9	$3.6 - 7.8	$0.2 - 0.5	$0.2 - 0.5	$13.7 – 29.7
Road Train	$3.9 - 8.5	$1.2 - 2.5	$0.1 - 0.2	$0.1 - 0.3	$5.3 – 11.5
Bus> 4.5t or >=10 seats	$0.7 - 1.6	$0.2 - 0.3	$0.02 - 0.04	$0.02 - 0.05	$0.9 – 2.0
Total HV Crashes	$20.6 - 44.9	$7.2 - 15.7	$0.5 - 1.0	$0.6 - 1.4	$28.9-62.9

Table 33 : Annual **New Zealand** crash reduction savings expected from mandatory fitment of LDWS by vehicle type and crash severity, million 2013$NZ

	Lane Departure Warning System $ Reduction				
	Fatal Crash	SI Crash	MI Crash	PDO	All Injury
Trucks	$19.2- 41.7	$6.0 – 13.0	$1.7 – 3.8		$26.9 - 58.5
Buses	$1.7 -3.7	$0.6 - 1.4	$0.1 – 0.3		$2.5 - 5.4
Total HV Crashes	$20.9 – 45.4	$6.5 - 14.5	$1.9 – 4.1		$29.4 - 64.0

Table 34 : Annual crash **Australian** reduction savings expected from mandatory fitment of ESC by vehicle type and crash severity, million 2013$AUS

			ESC $ Reductions		
	Fatal Crash	SI Crash	MI Crash	PDO	All
Rigid Trucks (no trailer)	$4.3	$6.8	$0.6	$0.5	$12.2
Rigid Truck+Trailer	$1.4	$1.2	$0.1	$0.2	$2.9
Prime Mover w/w- trailer	$16.6	$13.6	$1.0	$0.7	$31.9
Road Train	$6.5	$5.0	$0.4	$0.7	$12.6
Bus> 4.5t or >=10 seats	$1.8	$0.6	$0.1	$0.1	$2.5
Total HV Crashes	$30.6	$27.3	$2.2	$2.1	$62.1
Alternative Pricing					
Prime Mover w/w- trailer	$16.7	$13.7	$1.1	$0.8	$32.3
Road Train	$6.5	$5.1	$0.5	$0.8	$12.8
Bus> 4.5t or >=10 seats	$1.8	$0.6	$0.1	$0.1	$2.6
Total HV Crashes	$30.6	$27.4	$2.4	$2.4	$62.9

Table 35 : Annual **New Zealand** crash reduction savings expected from mandatory fitment of ESC by vehicle type and crash severity, million 2013$NZ

	ESC $ Reduction				
	Fatal Crash	SI Crash	MI Crash	PDO	All Injury
Trucks	$22.0	$11.3	$4.3		$37.5
Buses	$2.4	$0.6	$0.2		$3.2
Total HV Crashes	$24.4	$11.9	$4.5		$40.7

Table 36 : Annual crash reduction savings expected from mandatory fitment of FWS by vehicle type and crash severity, million 2013$AUS

	Fatigue $ Crash Reductions				
	Fatal Crash	SI Crash	MI Crash	PDO	All
Rigid Trucks (no trailer)	$4.4	$5.6	$0.4	$0.6	$11.0
Rigid Truck+Trailer	$1.7	$0.9	$0.1	$0.1	$2.8
Prime Mover w/w- trailer	$13.9	$8.2	$0.7	$0.6	$23.4
Road Train	$5.9	$3.1	$0.3	$0.4	$9.7
Bus> 4.5t or >=10 seats	$2.1	$0.7	$0.1	$0.1	$3.0
Total HV Crashes	$28.0	$18.5	$1.5	$1.8	$49.8
Alternative Pricing					
Prime Mover w/w- trailer	$13.9	$8.3	$0.8	$0.7	$23.7
Road Train	$5.9	$3.2	$0.3	$0.5	$9.9
Bus> 4.5t or >=10 seats	$2.1	$0.7	$0.1	$0.1	$3.0
Total HV Crashes	$28.1	$18.6	$1.7	$2.0	$50.3

Table 37 : Annual **New Zealand** crash reduction savings expected from mandatory fitment of LDWS by vehicle type and crash severity, million 2013$NZ

Fatigue $ Reduction					
	Fatal Crash	SI Crash	MI Crash	PDO	All Injury
Trucks	$14.2	$7.4	$3.0		$24.6
Buses	$ 1.9	$0.5	$0.2		$2.6
Total HV Crashes	$16.0	$8.0	$3.2		$27.2

It is also estimated that up to 4% of Australian and 10% of New Zealand heavy vehicle serious injury crashes, up to 2% of Australian and 7% of New Zealand minor injury crashes and up to 2% of Australian property damage only crashes may be prevented by LDWS fitment. In total, societal savings across crashes of all severities were estimated at $AUS 29-63 million for Australia. Across New Zealand injury crashes only, savings of $NZ 29-64 million were estimated.

Maximum percentage fatal and serious injury crash reductions were higher for articulated trucks than for rigid trucks in Australia. In New Zealand, fatal and serious crash reductions were greater for trucks than for buses. In Australia, these fatal and serious injury crash reductions translated to an estimated annual maximum of $AUS20 million in rigid trucks and $41 million in articulated trucks and road trains.

ESC

It was estimated that four percent of all heavy vehicle *fatal* crashes could be prevented through the mandating of ESC system. This translated to an annual saving of costs to Australian society of $31 million and to New Zealand society of $24 million (NZ).

It was also estimated that 7% of Australian and 9% of New Zealand heavy vehicle serious injury crashes and 5% of Australian and 7% of New Zealand minor injury crashes and 3% of Australian property damage only crashes may be prevented by ESC fitment. Across all Australian crashes, savings to society of $62 million were expected. Across New Zealand injury crashes only, savings of $NZ 41 million were estimated.

ESC related crash reductions were up to three times higher for road trains and articulated trucks than for rigid trucks in Australia. In New Zealand, minor and serious percentage crash reductions were much greater for trucks than for buses. In Australia, fatal and serious injury crash reductions translated to an estimated annual maximum of $AUS15 million in rigid trucks and $45 million in articulated trucks and road trains.

FWS

Fatigue warning systems offered similar protection to ESC systems with respect to fatal and property damage only crashes, however, their efficacy on Australasian serious and minor injury crashes was found to be 2-3% units lower. Similarly, FWS related crash reductions for articulated trucks and road trains was greater than for rigid trucks, and trucks generally displayed greater crash reductions than for buses.

Savings to society from the mandating of FWS was estimated at $28 million for fatal and $19 for serious injury Australian crashes and $NZ16 million and $NZ8 million respectively for New Zealand.

6.3 Break even costs

Annual crash savings expected from mandating these technologies were estimated just for new vehicles (with a year of manufacture equal to the crash year). A ratio of the crash savings associated with these new vehicles and the total registered heavy vehicles with a 2010 year of manufacture produced an estimated break even cost; the funds available per vehicle to spend on this technology before the costs of mandating outweighs the savings produced.

The following tables present, for Australian and New Zealand crashed trucks and for New Zealand crashed buses, the total annual crash savings for all heavy vehicles, the estimated savings attributed to just the new vehicles, and the savings per registered vehicle, also known as the break-even cost. As explained in Section 3.4, Australian new truck (>4.5t) registrations in 2010 were estimated at 21,750 and 2010 New Zealand new truck (>3.5t) registrations were 2,290. New Zealand 2010 new bus registrations were listed as 293.

Table 38 : 2010 and lifetime crash savings per registered new vehicle expected from mandatory fitment of safety technology to Australian Trucks manufactured in 2010

	Annual savings			
	All Crashes $AUS million	2010 yom crashes $AUS million	2010 Per registered vehicle, $AUS	Lifetime Per registered vehicle, $AUS
Minimum AEBS	$73.1	$1.46	$67	$3,359
Maximum AEBS	$224.7	$4.49	$207	$10,329
Minimum Lane Keeping	$27.8	$0.56	$26	$1,280
Maximum Lane Keeping	$60.5	$1.21	$56	$2,783
ESC	$59.6	$1.19	$55	$2,740
Fatigue	$46.8	$0.94	$43	$2,153
Alternative Pricing				
Minimum AEBS	$73.1	$1.46	$67	$3,359
Maximum AEBS	$224.8	$4.50	$207	$10,336
Minimum Lane Keeping	$28.0	$0.56	$26	$1,288
Maximum Lane Keeping	$60.9	$1.22	$56	$2,799
ESC	$60.3	$1.21	$55	$2,773
Fatigue	$47.3	$0.95	$44	$2,175

Table 39 : 2010 crash savings per registered new vehicle expected from mandatory fitment of safety technology to New Zealand Trucks manufactured in 2010

	Annual savings			
	All Crashes $NZ million	2010 yom crashes $NZ	2010 yom Per registered vehicle, $NZ	Lifetime Per registered vehicle, $NZ
Minimum AEBS	$22	$194,460	$85	$9,435
Maximum AEBS	$68	$614,398	$268	$29,811
Minimum Lane Keeping	$27	$242,338	$106	$11,758
Maximum Lane Keeping	$59	$526,823	$230	$25,562
ESC	$37	$337,477	$147	$16,374
Fatigue	$25	$221,485	$97	$10,747

It may be seen from these tables, that in 2010, in Australia, the one-year break-even costs for trucks are too low to cover the purchase and fitment of these technologies. In New Zealand, where the base costs per crash are greater, and where LDWS crashes were over-estimated, and where larger proportions of ESC sensitive crashes were observed, higher one-year break-even costs were estimated, but even these are unlikely to cover the costs of purchase and fitment. The affordability of these technologies is dependent upon the lifetime of the vehicle: taken over the estimated lifetime, fitment of these technologies appears to be cost effective to society.

AEBS crash efficacy was applied to crash injuries, and then converted to crashes, in order to apply 'per crash' costs. This means that of all of the technologies, the savings calculated for AEBS is most sensitive to the number of injuries per vehicle. Thus the large maximum AEBS savings for bus crashes reflects the large per vehicle occupancy, and at its maximum estimation, may cover the costs of fitment and purchase.

However, given that all of the bus break-even costs are high in comparison with trucks, it may also be that the crash data definition of 'bus' does not match up exactly with that used by the statisticians tabling new vehicle registrations in New Zealand. If the registration definition was less inclusive, then the break-even costs would be over-estimated.

Table 40 : 2010 crash savings per registered new vehicle expected from mandatory fitment of safety technology to New Zealand Buses manufactured in 2010

	Annual savings			
	All Crashes $NZ million	2010 yom crashes $NZ	2010 yom Per registered vehicle, $NZ	Lifetime Per registered vehicle, $NZ
Minimum AEBS	$4	$71,154	$243	$1,635
Maximum AEBS	$12	$233,764	$798	$5,373
Minimum Lane Keeping	$2	$47,425	$162	$1,090
Maximum Lane Keeping	$5	$103,098	$352	$2,370
ESC	$3	$61,706	$211	$1,418
Fatigue	$3	$50,019	$171	$1,150

6.4 Under-estimation of break-even costs and crash savings

The crash savings and break-even costs presented by this study do not show the complete picture, because they were estimated only from average 'all vehicle' crash costs and were not related specifically to heavy vehicles. In the third period, heavy vehicles represented only 4% of crashed vehicles overall, so heavy vehicle contributions to the average crash costs were small. However, the inflation factor used to address additional heavy vehicle related costs in the 'Alternative Pricing' strategy proved to be insignificant.

Crash costs for this study are still likely to be an under-estimation. When crash costs specific to heavy vehicles were used in literature (Grover 2008, Houser 2009, Murray 2009, Woodrooffe 2011, Kessler 2012), cost benefits resulted for ESC, LDWS and AEBS fitment (Section 1.2). The cost of lost time to logistic companies appeared to be one possible source of costing difference. In fact, in Houser's 2009 USA analysis of the costs and benefits of LDWS for the trucking industry, operational costs of a crash of any severity were estimated at $US 13,650 for head-on and side-swipe collisions, at $US 28,625 for single vehicle roll overs and at $US 28,950 for single vehicle road departure collisions. Environmental costs were listed at $US 82,500 for roll-over crashes and $24,000 to $35,000 for the other crash types. Houser lists property damage expenses as $US 34,167 for single vehicle road departure collisions, $US 55,833 for single vehicle rollovers and $US 27,500 for sideswipes and head-on crashes. These are estimates for the USA so they do not directly apply here, but it is not rocket science to see that they greatly exceed the

Australian crash costs estimates of approximately $18,000 for minor injury crashes and $12,000 for property damage only crashes.

In addition, this study only evaluated the savings in terms of crash reductions; literature (Section 1.2) has shown other financial benefits. For example: the reduction in harsh braking possible from AEBS; the extended life of tyres and reduction in ‘flat spotting’ from ESC fitment (which will then enable better steering and perhaps prevent even more collisions); and the reduced fuel consumption from improved traffic flow enabled through AEBS fitment.

Lastly it must be acknowledged that the crash costs related to articulated truck operations and rigid truck operations are expected to be vastly different, not only in terms of crash risk and severity related to the higher speed and exposure on the interstate path of an articulated truck, but also in terms of difficulty in the recovery of schedules when the loads are larger and the distances longer.

It is clear that the crash savings and break-even costs presented in this report are significantly underestimated. And it is likely that technology fitment for articulated trucks is more affordable than for rigid trucks in terms of break-even costs.

7.0 SUMMARY AND RECOMMENDATIONS

In Australia, there has been greater growth in heavy vehicle registrations and exposure than for passenger vehicles. Recent rigid truck registration growth was more than double and recent articulated truck exposure growth was more than twenty times that of passenger vehicles. Despite this, proportion of crashes involving heavy vehicles has remained stable at 4% from 2000 to 2010. However, given the noted exposure and registration growth, it is expected that that the proportion of heavy vehicle crashes in the future will increase, particularly for articulated trucks. Supporting this has been observed growth in heavy vehicle crashes for road trains and in remote regions over recent years.

Across the years of data considered in this study, heavy vehicles made up 4% of all vehicles involved in police reported crashes. However, the distribution was not the same across crashes of different severities. Heavy vehicles made up 13% of vehicles involved in fatal crashes compared to 3 to 4% of the vehicles involved in the other crash severities (serious, minor and non-injury). The growth in heavy vehicle exposure and the trends for crash increases observed for specific heavy vehicle types, will likely lead to significantly larger increases for fatal crashes than for less severe crashes.

Heavy vehicle involved fatal crashes were more likely to occur in rural areas. Greater proportions of less serious crashes occurred in metropolitan areas. Most heavy vehicle crashes occurred in metropolitan areas (73%), however, most *fatal* heavy vehicle crashes were in rural areas (63%, Australia, 73% New Zealand).

In rural and remote areas, the vehicles of concern are articulated trucks and road trains. In rural areas articulated (prime mover) type heavy vehicles were most frequent involved in fatal and serious injury crashes, representing about 40% of all heavy vehicle crashes in the 2008-2010 period. Road trains were the most frequently involved crashed heavy vehicle type in remote fatal and serious crashes, making up greater than 50% of crashed heavy vehicles in the same period. 71% of injury and 61% of property damage only road train crashes were also located in rural and remote areas for this period. Articulated truck and road train fatal and serious injury crashes were also shown to yield greater numbers of fatalities per crash than did those for other heavy vehicle types.

Single vehicle, run-off road crashes are associated with rural locations, a primary crash type aimed to be prevented by ESC, LDWS or FWS. Single vehicle road train crashes have increased over the ten year period, and specifically road train crashes that are likely to be prevented by ESC have increased over the three 3 year periods. Increases crashes likely to be prevented by ESC were also seen for rigid trucks and for buses (loss of control only) over the same period. Road train and rigid truck fatal and serious injury and property damage only crashes potentially prevented by LDWS have also increased over the three periods.

With observed growth in road train crashes and in heavy vehicle exposure generally, and with greater proportions of fatal heavy vehicle crashes in rural areas, growth in crashes potentially prevented by ESC, LDWS and FWS suggests increased uptake of these technologies through consumer programs or by mandate has the potential to dramatically reduce the number of deaths and serious injuries from heavy vehicle involved crashes. This is a reflection of the large proportions of more serious crashes observed to be potentially prevented by these technologies, particularly for articulated trucks and road trains. More than double the crashes potentially prevented by LDWS were fatal crashes than were minor or no-injury crashes. About 30% of Australian and 40% of New Zealand serious injury crashes were potentially prevented by ESC technology. Crashes potentially prevented by fatigue warning systems were also greatest in proportion for serious injury crashes (18%). 52% and 34% respectively of injury road train and articulated truck involved crashes were found to potentially be prevented by ESC; and 31% and 20% respectively of injury road train and articulated truck involved crashes were potentially prevented by FWS.

Scenarios which mandated LDWS, ESC and FWS fitment to all heavy vehicles of all years of manufacture predicted up to 6%, 4% and 4% respectively of all heavy vehicle fatal crashes could be prevented, saving annually up to 16, 11 and 10 lives in Australia and 10, 5 and 4 lives in New Zealand respectively. Across crashes of all crash severities, universal mandates are expected to save crash costs of up to $63, $62 and $50 million respectively in Australia and $64, $41 and $27 million in New Zealand.

It should be noted that the crash savings attributable to these technologies are not mutually exclusive although there is some potential synergistic benefits from combinations of the technology. Although LDWS, ESC and FWS are targeted to essentially loss of control crashes, they have different mechanisms and limitations so will act on different crashes within this general loss of control crash type. ESC is the only system that responds to yaw instability and is most efficient in low friction situations. LDWS will be most effective in higher friction situations on edge marked roads in fine conditions and at higher speeds. FWS will address some instances of lane departure in addition to those detected by LDWS, but will add detection of other fatigue related crash types not involving lane departure or prevent lane departure crashes where the LDWS may be unable to get the driver’s attention in time. AEBS is effective on crashes that are generally not prevented by LDWS, ESC and FWS, and the AEBS relevant crashes are more frequently found in in areas (metropolitan) where the other technologies are less effective.

As stated above, the majority of non-fatal heavy vehicle crashes occurred in metropolitan areas and were frequently at intersections. Overall, around 40% of non-fatal heavy vehicle crashes occurred at intersections. Metropolitan heavy vehicle crashes more frequently involved rigid trucks and buses. Rigid trucks were involved in about half of the fatal and serious injury heavy vehicle crashes of metropolitan Australia during 2008-2010. About 90% of bus crashes were in metropolitan regions and about 50% were at intersections. It is of particular concern that a large majority of heavy vehicle collisions were occurring in population dense areas, where the collision partner is generally a smaller vehicle offering less protection with a commensurately greater severity of injury resulting than would be incurred in a light passenger vehicle to light passenger vehicle collision. Bus crashes in particular presented a 3-8 times greater risk of a pedestrian injury crash than did other heavy vehicle types compounded by an observed increase in Australian fatal and serious injury multi-vehicle bus (and road-train) crashes over the study period.

83% of all Australian heavy vehicle crashes involved another vehicle, and for 89% of these, the other vehicle was a light passenger vehicle. For New Zealand the proportions were lower, because only injury crashes were recorded. The proportion of light passenger vehicle involved crashes decreased over time with increasing crash severity. The reverse trend was true for crashes involving unprotected road users. Across all crash severities, heavy vehicle collisions with unprotected road users (bicycles, motorcycles) were observed to increase over the 9 year period. Increases greater than 100% were observed for minor injury road-train crashes with unprotected road users.

Multi-vehicle, heavy vehicle involved crashes have a close association with metropolitan locations. A proportion of these may be prevented with AEBS. Fatal and serious injury crashes and property damage only crashes potentially prevented by AEBS have increased over time for buses (and road trains). In addition, more than half of all heavy vehicle crashes were considered potentially prevented by this technology; 70% for Australian fatal, 77% for New Zealand fatal and 65% for serious injury crashes. Rigid trucks demonstrated the greatest potential crash reduction due to fitting this technology with more than 60% of injury crashes and 56% PDO crashes potentially prevented. Encouraging the fitment of AEBS through consumer programs or mandate has the potential to significantly reduce metropolitan heavy vehicle collisions. This is a reflection of the observed growth in heavy vehicle exposure generally, the greater proportion of heavy vehicle crashes in metropolitan areas and the growth in some of the already substantial proportions of crashes potentially prevented by AEBS.

A scenario with AEBS fitment to all current heavy vehicles of all years of manufacture predicted that up to one quarter of all heavy vehicle fatal crashes could be prevented, with annual saving of 67 and 14 lives in Australia and New Zealand respectively translating to Australian social cost savings of $187 million and New Zealand social cost savings of $62 million (NZ). Across crashes of all severities, universal AEBS fitment is expected to save up to $254 million in Australia and $81 million in New Zealand.

AEBS is effective on crashes that are generally not prevented by LDWS, ESC and FWS, and the AEBS effective crashes are more frequently found in in areas (metropolitan) where the other technologies are least effective. However, as discussed in Section 3.2.5, there is some overlap likely in crashes broadly sensitive to AEBS. This overlap is small, so benefits gained from AEBS are largely expected to be in addition to those of the other three technologies.

In addition to crash reductions, AEBS has been shown to be associated with reduced fuel consumption, reduced tyre wear, 46m longer following distances, 5% increased headway time and 36% reduction in kinematic related events. In addition to crash reductions, ESC has also been associated with tyre wear reduction.

The number of deaths and serious injuries associated with heavy vehicle involved crashes in rural and remote regions may also be dramatically reduced by the fitment of ESC, LDWS and FWS technology to heavy vehicles. This is because:

- heavy vehicle exposure generally is increasing in rural and remote regions, particularly for articulated trucks and road trains;
- heavy vehicle fatal crashes mostly occur in rural areas;

- there is a greater representation of heavy vehicles within fatal vehicle crashes than in other crash severities;
- articulated truck and road train fatal and serious crashes were observed to have higher rates of fatalities per crash than did other heavy vehicle types;
- a growing proportion of rural crashes are potentially prevented by these technologies;
- large proportions of injury crashes and the severity of injuries sustained were found to potentially be prevented by these technologies with a greater proportion of New Zealand crashes potentially prevented by ESC than Australian crashes;
- 16, 11 and 10 lives in Australia and 10, 5 and 4 lives in New Zealand per year are expected to be saved per year if LDWS, ESC and FWS respectively were fitted to all heavy vehicles; and
- these technologies work by different mechanisms with different limitations, so combinations of these three technologies will produce greater savings.

The injuries and property damage associated with heavy vehicles may be dramatically reduced in metropolitan regions by fitting AEBS technology to heavy vehicles. This is because:

- heavy vehicle exposure generally is increasing;
- 73% of all heavy vehicle crashes occur in metropolitan regions (Australia);
- the fastest growth in heavy vehicle registrations was observed for rigid trucks, which were involved in about half of the metropolitan fatal and serious injury heavy vehicle crashes and rigid truck crashes showed the greatest potential crash reductions from AEBS technology;
- the proportion of unprotected road user collisions with heavy vehicles increased with increasing crash severity, and heavy vehicle collisions with unprotected vehicles increased over the 9 years of the study;
- about 90% of bus crashes were in metropolitan areas and buses presented a greater pedestrian injury risk than did other heavy vehicle types and serious and fatal multi-vehicle bus crashes were observed to increase;
- more than half of all severity and more than 70% of fatal crashes were deemed to be potentially prevented by AEBS technology; and
- 67 lives in Australia and 14 lives in New Zealand would be saved and annually if AEBS were fitted to all heavy vehicles

Analysis did not find LDWS, ESC and FWS to be highly cost effective over the first year of vehicle ownership although these technologies are generally installed in the vehicle for their lifetime so the lifetime cost effectiveness estimates are most relevant. It is possible crash savings estimated were conservative since the crash costs used were an average across all vehicle types. Crashes involving trucks are potentially higher cost than average due to expenses incurred to freight carriers from damaged loads and timetable disruptions which are specific to this vehicle type. With the expected growth in heavy vehicle exposure on Australian and New Zealand roads, and expected decreases in the cost of the technology as the market responds to European mandates and uptake increases, these technologies may become more cost effective.

In addition to cost, fitment limitations include the fact that ESC systems were not found to be feasible as a retrofit, that AEBS are not compatible with fully pneumatic tractor braking systems, and that AEBS may not work in vehicles without rear-end suspension. AEBS fitment is considered to work best with EBS and AEBS may also be integrated with ESC. These limitations may change over time as heavy vehicle design and technology develops.

Each of AEBS, LDWS and ESC have been shown in previous heavy vehicle studies to reduce heavy vehicle crashes of all severities, to be cost effective and to be accepted by drivers, which has led to AEBS and LDWS fitment mandates in Europe in N2, N3, M2 and M3 vehicles. This background in combination with the potential crash reduction benefits estimated in fitting these technologies to heavy vehicles in Australia and New Zealand established in this study point to a need to promote the uptake and eventual mandate of these technologies in Australasia. Results also point to the need to continue to evaluate the effectiveness of these technologies in real world application in Australasia as they become more prevalent in the fleet.

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APPENDIX A – CRASH DEFINITIONS

- A ***fatal crash*** was a crash that resulted in a road user dying within 30 days of the crash occurring;

- A ***serious injury crash*** was a crash that did not result in the death of a road user within 30 days but that did result in a road user being transported to hospital or admitted to hospital;

- An ‘***other injury’ or ‘minor injury’ crash*** was a crash that resulted in a road user being injured but no road users being fatally injured or seriously injured.

From these definitions of crash severity, the following further categorisations of crash severity were made:

- A ***serious casualty crash*** was a crash in which the most seriously injured road user was killed within 30 days as a result of the crash or transported to hospital or admitted to hospital as a result of the crash (i.e. a fatal crash or a serious injury crash);

- A ***casualty crash*** was defined as a crash in which a road user received an injury of any severity (i.e. a fatal crash, serious injury crash or an ‘other injury’ crash).

Crash Data by jurisdiction

In every state, a *case* (data line) represented a driver of a vehicle, a passenger of a vehicle or a pedestrian. Vehicles included planes, trains, trams, motor vehicles, motor cycles, agricultural vehicles, plant equipment, horse drawn vehicles, horses and bicycles. In additional a case could be a towed device (QLD, NSW and WA), a driver of a motorised wheel-chair (NSW, SA, WA and NZ), an animal (QLD, SA and NZ), a rider of a manual scooter (WA) or even an object or obstruction such as a pole, bridge or tree (SA).

Initial crash data management

Consolidating data from each crash year

Data preparation first involved creating a single data set for each jurisdiction. Consistency was created in variable names and formatting to enable crash year merging.

Universal variables across all jurisdictions were created prior to merging the vehicle data for the five states into a single dataset. This included information specific to a vehicle, such as counts of injured occupants by severity, as well as information specific to a crash. Sometimes this information was not available for all states. For example, the total number of occupants (and passengers) in a vehicle could not be known for Victoria, where only the number of persons involved in the crash was provided.

Table B.1: Cases in police reported crash data, by crash year and jurisdiction (2000-2010)

Year of Crash	NSW	QLD	SA	VIC	WA	NZ
2001	103,319	58,271	87,696	45,160	76,745	19,645
2002	99,267	43,968	86,228	45,508	73,928	22,385
2003	97,167	44,194	66,289	45,094	73,202	23,058
2004	93,240	46,027	49,157	43,075	76,481	22,578
2005	89,735	45,011	46,324	42,426	78,968	23,522
2006	88,935	43,716	45,026	33,186	80,133	24,475
2007	88,991	44,976	47,244	33,828	83,912	25,788
2008	83,565	46,204	47,481	33,343	79,368	24,534
2009	83,777	44,818	47,064	35,264	75,423	23,660
2010	83,351	Not Available	48,492	33,613	90,975	22,671
Total	1,015,893	451,651	659,077		867,602	232,316

Whilst the data studied in this project consisted only of heavy vehicles, *crash* information on injuries to involved pedestrians and occupants or riders of other involved vehicles was maintained. The injured persons of the injury crash may have included cyclists, horse riders, motorcyclists, pedestrians and occupants of non-passenger vehicles such as tractors, trucks and prime movers. All cases were defined by the occupant as: ‘Controller’, ‘Passenger, ‘Pedestrian’, ‘vehicle with no occupants’ or ‘Non-vehicle unit such as tree, pole or trailer'. Pedestrians included people on skates, skateboards, manual scooters and riding motorised wheelchairs.

Total injuries, by severity for each crash were counted. NSW only provided two severity categories: injured and fatal. In addition crash information also included vehicles per crash and counts of various crash types, including those in which at least one vehicle was towed were identified. Crash location (except for QLD) as rural, remote or metropolitan was also identified. Crashes with parked vehicles (listed as cases in the crash data) were considered to be multi-vehicle crashes.

Identifying Heavy Vehicles

Obviously to reduce a state data set to only heavy vehicles, and to identify crashes with other vehicle types, it was essential to correctly identify vehicle type as passenger vehicles, motorcycles, heavy vehicles, other motor vehicle types (e.g. agricultural vehicles, fork lifts and plant vehicles), unknown motor vehicles and unknown case types. For the most part, make, model and body could be used to distinguish motor vehicles from non-motor vehicle cases, and passenger vehicles from heavy vehicles. However, when this was not possible, other methods to identify heavy vehicles were possible. Tare weight was a crash variable in WA and QLD data, and when present, vehicles with a tare weight greater than 3.5tonne were assigned as heavy vehicles. This was because light commercial vehicles (<=3.5t) were included in the passenger vehicle classifications. In NSW vehicles with a tare of >= 4.5t could identified as heavy vehicles. Unit type variables were also used to identify other heavy vehicle types, for example: 'Semi Trailer', 'Rigid Truck Large' 'BDouble', 'Road Train' , 'Arctic Tanker', 'Rigid tanker', 'Coach', and 'Omnibus'. If still it was still not clear whether a vehicle was a passenger vehicle or a heavy vehicle, body type was looked at for NSW, QLD and WA. The body variable enabled identification of some heavy vehicle types; for example in WA, tow truck classes could be identified by body shape then gazetted information could be used to find a tare weight range. Vehicles that could be identified as motor vehicles but not identified as motor-cycles, passenger, heavy vehicles or 'other motor vehicles' (agricultural and plant vehicles) were classed as *unknown motor vehicles*. Cases that could not even be identified as non-motor-vehicle or motor vehicle units were classified as *unknown units.*

Data for each state was reduced to just heavy vehicles. Motor vehicles of unknown type and unknown case types were not included because they were likely to a) be passenger vehicles and b) small in proportion.

Distinguishing Articulated and Rigid Types

The ability to distinguish articulated and rigid trucks varied from state to state: for example, in *Queensland* articulated trucks included all rigid trucks towing a trailer, unless that trailer was a 'dog trailer'; in such circumstances the vehicle was considered rigid rather than articulated. The road train definition also included both rigid and prime movers towing 2 or more trailers. In addition, Queensland provided a variable to indicate the number of units being towed by a vehicle, thus rigid trucks towing a unit could be identified. The consequence of this is that in the graphics, the Queensland prime-mover categories with known or unknown trailer are likely to include some rigid trucks with trailers. It is not likely to be many: of the 68% of identified articulated heavy vehicles in the 2000-2009 data with a non-missing body type, 92% were labelled as prime movers.

In *Victoria*, there was no available unit defined to identify trailers, nor was there a variable identifying whether a vehicle was towing, however, the vehicle type categories 60-73, only available in our data from 2010 onwards, did indicate whether a prime mover was towing one or multiple trailers. Thus, it was not possible to separate road trains from other articulated vehicles (except in 2010) and also not possible to identify towing rigid trucks. The data dictionary did indicate that vehicles classified as semi-trailers were 'prime movers + trailer' combinations. It was likely that vehicles, of appropriate make, with articulated truck insurance and 'Truck' or 'Other Vehicle' classification were prime-movers (possibly without a trailer), since the data support information stated that they should not be coded as 'Semi-trailers' if they were an unattached prime mover.

Within the crash data of *New South Wales*, *South Australia and Western Australia*, unit descriptors distinguished rigid, articulated and road train trucks. The *Western Australian* data also used unit descriptors to indicate whether a truck was towing a trailer. Trailers were also identified as separate units and there were variables to indicate which of the crash vehicles (using the crash unit id) were towing the trailer. For *New South Wales*, data indicated that trucks were towing; this was more reliable for rigid than articulated trucks. It could not be determined in the *South Australian* data whether the road train was pulled by an articulated or by a rigid truck. A variable labelled "unittow" indicated that a unit was towing another by providing the type of unit being pulled: trailer, caravan, boat, horse float, agricultural implement, motor vehicle or other. The variable was also used to indicate a vehicle that was not towing.

In NSW and QLD, where the data showed trailers as 'cases', they were only included as a case if they were detached from the towing vehicle.

In New Zealand data, a body type variable, which was merged from registration data, identified 15% of trucks as articulated and some as heavy (3%) or light vans. Light vans were identified as light commercial vehicles and excluded from the analysis.

Distinguishing a >4.5 tare cut point or bus seat capacity

The ability to distinguish the 4.5 tonne cut point for rigid vehicles and buses was also not easily practised. With Western Australian and Queensland data, the process was simple since GVM or tare weight was mostly provided. Additionally, in Queensland, a rigid truck was by definition greater than 4.5 tonne gross weight. In NSW, an indicator variable was used to inform of tare weights greater or less than 4.5 tonnes. However, in the Victorian dataset, there was no available vehicle weight, nor data dictionary weight definitions of the vehicle categories for the Victorian crash data. Definitions were found in

"The Victorian Bus and Truck Drivers' Handbook" published by VicRoads[4] that describe a light rigid truck as having a gross vehicle mass (GVM) greater than 4.5 tonnes and a medium or heavy rigid truck as having a GVM greater than 8 tonnes, so given these VicRoads definitions, the Victorian Police reported crash database vehicle type of "Truck (excluding semi)" was taken as a rigid truck with a GVM greater than 4.5 tonnes if its insurance classification showed it as goods carrying; and as a rigid truck with an unknown tare weight, likely to be >4.5 tonnes if no goods carrying was evidenced. A South Australian GVM of >4.5 t could only be assumed for vehicles labelled as 'large rigid trucks'. When the make and model indicated a heavy vehicle likely to have >4.5 tonne GVM, but the vehicle was not grouped in the SA 'large rigid trucks' classification, a rigid truck (of unknown tare) was assumed. Percentages of rigid trucks, with tare weight unspecified, included in the analysis of the third period (2007-2009 for QLD and 2008-2010 for the remaining states) because of their vehicle category or make and model making them likely to be >4.5 tonne GVM are tabled below. All NSW rigid trucks were classified as greater than or less than 4.5t GVM.

Bus seat capacity was not provided in New Zealand, New South Wales, Western Australia nor in Queensland data, however, by definition, in Queensland a bus was determined to have at least 10 seats. No similar definition was available for New South Wales and Western Australian 'Bus' vehicles, however, there were vehicle categories for 'passenger vans' into which buses with less than 10 seats fell. In the Victorian data, seat capacity was mostly available to distinguish buses with 10 or more seats from their 9-13 seat bus category. Their other category ,'Bus/Coach', was assumed to have a more than tonne 4.5 GVM. Generally, without any other information, if the number of injured passengers listed in the data exceeded 9, the bus was considered to have at least 10 seats. A South Australian GVM for buses of >4.5 t could only be assumed. Light commercial vehicles (by make and model) and minibuses (by body type) were excluded from the analysis where possible in the New Zealand data.

Table B.2: Percent unknown tare weight vehicles of Australian rigid trucks in third period (2008-2010, QLD 2007-2009)

	Crash Type			
	Fatal	**Serious Injury**	**Minor Injury**	**No Injury**
Australia	19	13	22	20
NSW	0	0	0	0
QLD	48	21	22	20
SA	30	10	12	12
VIC	6	10	10	
WA	25	37	42	42

[4](http://www.vicroads.vic.gov.au/NR/rdonlyres/1F94436A-ED03-476F-BB60-637404F533BE/0/Bus_and_Truck_Handbook_0713_WEB.pdf)

Identifying Crashes sensitive to emerging technologies

Crashes sensitive to the presented emerging technologies were identified in all states, however, those from SA were estimated in a different manner because SA data did not include a similar road user movement crash coding variable.

Speed zones >=80 km/h were identified for lane keeping technology sensitivity.

Illegal speeding, driver fatigue, drivers over the alcohol limit and crashes on roads with edge line marking needed to be identified so that crashes sensitive to emerging technologies could be identified. Illegal speeding was able to be identified only for NSW, SA and WA. Exceeded driver *blood alcohol limits* were identifiable only for NZ, QLD, SA, VIC and WA. *Fatigue as a factor* was only present in the NZ and WA data. Identification of crashes at roads with *edge line marking* could be estimated with the use of various variables in all jurisdictions. Highways and expressways could be identified: for NSW & SA as divided roads and dual freeways; for VIC & QLD as divided roads and for WA as highways from the highway coding or highway road name. In addition Victorian roads with edge lines were also identified by a road type variable : *BYPASS, FREEWAY, FREEWAY CN, FREEWAY EAST, FREEWAY WEST, HIGHWAY, HIGHWAY EAST, HIGHWAY WEST* and *TOLLWAY*; and by a variable called *mel_hier*: *AH, F, FW*. In WA, roads with edge lines were identified by strings within the *Road Number*, *Intersection Road Names*, *Cross Road Name* and *Road Name* variables. If the first four characters of the *Road Number* were '000H' or the first character was ‘H’, or the letters ‘HWY’ or ‘FWY’ appeared in the road names, then the crash was selected. In NZ, the only information additional to the speed zone available to identify the possibility of edge lines was information on whether or not a road was sealed.

Identification of heavy vehicles by jurisdiction

New Zealand

The data provided by NZ contained information on vehicle type, VIN, make and model and body type which could be used to identify heavy vehicles. Tankers, tow truck and emergency vehicles could not be identified, however plant equipment could be excluded using a combination of the ‘Other’ crash vehicle type, ‘special purpose’ registration vehicle type, body description (e.g. mobile machine) and makes and models.

Table B.3: NZ: Possible heavy vehicle types

Crash code	Vehicle Type (crash)	Vehicle Type (registration)	Body type (registration)
B	Bus	BUS	ARTICULATED TRUCK
L	School Bus	GOODS VAN/TRUCK/U	CAB AND CHASSIS ONLY
T	Truck	MOTOR CARAVAN	FLAT-DECK TRUCK
		SPECIAL PUROPOSE	HATCHBACK
			HEAVY BUS
			HEAVY VAN
			LIGHT VAN
			OTHER TRUCK
			SELF PROPELLED CARAVAN
			SERVICE COACH

Heavy vehicle data was excluded when a market group had successfully been assigned to a vehicle of the crashed vehicle types B, L and T (see table B2) during the data preparation for the *Used Car Safety Ratings*. This amounts to 2% of 'B', 5% of 'S' and 3% of 'T' vehicles. In other instances of where the registration type, make and model did not match those of the merged crash data, the crash report data, if consistent within itself, was assumed correct.

New South Wales

The data provided by NSW contained information on vehicle weight, type, load, VIN, make and model and body type which could be used to identify heavy vehicles.

Possible Heavy Vehicles would fall within the data base vehicle types tabled below.

Table B.4: NSW: Possible heavy vehicle types

Group code	Group Name	Vehicle type code	Vehicle Type Name	Comment
2	Light Trucks			Excluded (100% tare <4.5 t)
		10	Light truck	
		11	Mobile vending	
3	Heavy Rigid Trucks			Included (100% tare >4.5 t)
		12	Large rigid	
		13	Rigid tanker	
4	Articulated Trucks			Included (100% tare >4.5 t)
		8	Road train	
		9	B-double	
		14	Arctic tanker	
		15	Semi-trailer	
5	Bus			Included (72% tare >4.5 t, 3% unknown tare)
		17	STA bus	
		18	Coach	
		19	Other bus	98% of unknown tare weight
6	Emergency Vehicle			(25% tare >4.5 t, 2% unknown tare)
		21	Ambulance	Excluded
		22	Fire brigade	Excluded
		23	Police	Included
		24	Tow truck	Included
		25	Other emergency vehicles	Included
7	Other Motor Vehicle			
		20	Self prop plant	Excluded
		27	Tractor	Excluded
		29	Other mot. veh.	Included if >4.5 t

Vehicles between 3.5 and 4.5 tonne were identified only as <4.5t tare weight. Vehicles greater than 4.5 tonne in tare weight were identified. It appeared that vehicles exactly at 4.5 tonne tare fall into no category. The following is a list of issues arising from unknown actual tare weight.

- When a passenger vehicle make and model for “light trucks” and “buses” was unavailable, it was assumed that these vehicles were over 3.5 tonnes in tare, otherwise they would have fallen in a passenger vehicle category; however such an assumption could not be made for emergency vehicles.
- It was not known whether emergency vehicles, light trucks and buses were over 3.5 tonnes tare when they were listed as under 4.5t.
- 90% of the “other Motor vehicles have an unknown tare weight,
- 25% of tractors and plant vehicles have an unknown tare weight,

It was also not possible to identify as articulated, buses, emergency or other vehicles. Emergency vehicles and buses over 4.5t were assumed to be “rigid”.

Queensland

The data provided by QLD contained information on full vehicle tare and GVM (gross vehicle mass), type, VIN, make and model and *body* which could be used to identify heavy vehicles.

The full tare weight was used to distinguish vehicles between 3.5 and 4.5 tonne GVM to enable light commercial vehicles to be successfully identified. The makes, models, body styles and VINs of these vehicles were used to help identify vehicles in this weight range in other states.

The body type was used to distinguish emergency vehicles and other modified trucks from self-propelled plant and farm equipment within the ‘special purpose’ category. The modified trucks, for example tankers and tow trucks were included in truck categories in other states. Ambulances were identified but fire trucks and police cars could not be identified. All ambulances were identified as passenger vehicle types. Coaches were not able to be distinguished from other buses.

Table B.5: QLD: Possible heavy vehicle types

Category	Vehicle description
3	Rigid Truck- has >4.5t GVM and includes tippers
4	Articulated Vehicle: Prime mover plus trailer, Rigid Tuck + trailer (excl. dog)
5	Omnibus : includes: minibus, bus, coach, articulated bus, >10 seats
7	Special purpose vehicles including tractors, plant and farm machinery, road rollers and sweepers, emergency vehicles, tow trucks, tippers and campers
20	4wd 2000-2005
40	Road Train: including B-doubles and B triples, and prime mover or rigid truck + 2 or more trailers

South Australia

The data provided by SA contained information on vehicle type, VIN, make and model which could be used to identify heavy vehicles. Body type and vehicle weight were not available. However there were in addition 76 make categories. Categories 31-76 were only used for motorcycle and wheelchair units. The other categories were used for both light passenger and heavy vehicle units.

Make and model information were used to identify rigid trucks within the 'Light Truck' category.

Unattached trailers did not have their own unit type classification. Unattached trailers fell in the "other" category which referred to other non-motor vehicle units. 'Other' units have not been described further in the data set so it is impossible to know whether the 'other' units are unattached trailers.

Articulated Buses could be identified. Emergency vehicles could not be identified. Vehicle GVM (greater or less than 4.5) was unknown.

Table B.6: SA: Possible heavy vehicle types

Vehicle Category	Vehicle description
7	Rigid Truck Large
8	Semi-Trailer
9	Omnibus
10	Other Defined Motor Vehicle
33	B double - Road Train
36	Light Truck

In addition, SA matched registration vehicle information using ambiguous digit registration, which may be the reason that the following heavy vehicle unit types were listed with (non-utility, non-van or non-SUV) passenger vehicle makes and models. These vehicles were excluded from analysis:

Table B.7: SA: Heavy vehicles types matched with passenger vehicle registration models

Vehicle Category	Frequency
Rigid Truck Large	108
Semi-Trailer	84
Omnibus	10
B double - Road Train	15

Heavy Vehicle types with passenger vehicle makes/models of the van, utility, SUV, mini-bus or people-mover types are not included in the above count; but were excluded and considered passenger vehicles.

Victoria

The data provided by Victoria contained information on vehicle type, VIN, make and model which could be used to identify heavy vehicles. Except for 2005 data, body type was unavailable. Vehicle weight was not available. However there was, in addition, some information contained on seat capacity which when over 9 could indicate a heavy vehicle (bus); and some information on TAC insurance class which was useful for heavy vehicle classification and identification of emergency vehicles.

Road trains using rigid trucks could be identified. Articulated Buses could not be identified

Ambulances could not be identified except in 2005. Vehicle GVM (greater or less than 4.5) was unknown except for 2010, where categories indicated GVM.

Table B.8: VIC: Possible heavy vehicle types

Vehicle Category	Vehicle description
6	SEMI-TRAILER up to 2010
7	TRUCK(EXCLUDING SEMI) up to 2010
8	BUS/COACH
60	Prime mover only (2010 on)
61	Prime Mover + single Trailer (2010 on)
62	Prime Mover B Double (2010 on)
63	Prime Mover B Triple (2010 on)
71	Light Commercial Vehicle Rigid <=4.5 t GVM (2010 on)
72	Heavy Vehicle (Rigid) >4.5 t GVM (2010 on)

Table B.9: VIC: TAC insurance classes

Code	Description	Possible Heavy Vehicle
00	No insurance applicable	
10	Private vehicle, sedan, wagon, ambulance	
11	Other passenger vehicle (seats less than 10 persons)	
12	Other passenger vehicle (seats more than 9 persons)	
13	Taxi cab	
14	Bus	
20	Goods-carrying (< 2001 kg capacity, including utility)	Yes, if type 7 or 72
22	Goods-carrying (> 2000 kg capacity, not articulated)	Yes
24	Goods-carrying (> 2000 kg capacity, articulated)	Yes
26	Goods-carrying (> 2000 kg, farming)	Yes
29	Motorcycle (< 61 ccs)	
31	Motorcycle (61 to 125 ccs)	
33	Motorcycle (126 to 500 ccs)	
35	Motorcycle (> 500 ccs)	
41	Miscellaneous (Road rollers, graders, etc.)	
43	Miscellaneous (Veteran, vintage, farm machinery)	
45	Recreation vehicle (More than 3 wheels)	
50	Fire brigade (Metropolitan Fire Brigade)	
52	Fire brigade (CFA used to combat fires)	
55	Police (Motor car)	
56	Police (Motorcycle)	
57	Motor trades (Identification plate rate)	
58	Tow truck	Yes if type 7 or 72
59	Hire and drive yourself vehicle	

Western Australia

The data provided by Western Australia contained information on vehicle type, VIN, make model and body which could be used to identify heavy vehicles. In addition, there is information on tare, aggregate and GVM weights, cylinders, axles, HV class, power and fuel which aid heavy vehicle classification.

Table B.10: WA: Possible heavy vehicle types

Vehicle Category	Vehicle description
5	Truck
6	Prime Mover
7	Bus
23	Multi - Seated Van
24	Truck & 1 Trailer
25	Prime Mover & 1 Trailer
26	Road Train
27	Four Wheel Drive (Not Car Design)

And also within vehicle with an HV Configuration of 4-12 with appropriate non-passenger vehicle model and 3 or more axles (not a very reliable variable) with appropriate body type.

Articulated Buses could not be identified. Police Vehicles could not be identified.

Heavy vehicle body type was a reliable variable when present. The following lists the body types considered to include heavy vehicles. Highlighted types indicate that no light commercial vehicles fell in this category.

Table B.11: WA: Possible heavy body types

Ambulance	AMBULC	Panel Van	PVAN
Armoured Truck	ARMDTK	Road Sweeper	RDSWPR
Bin Carrier	BINCAR	Refrigerated Van	REFVAN
Bus Type	BUSTYP	R/R Table Top	RRTTOP
Car Carrier	CARCRR	School Bus	SCHBUS
Cement Agitator	CMTAGT	Stock Truck	STOKTK
Double Cab	DBLCAB	Truck Tanker	TANKTK
Fire Engine	FIRENG	Tip Truck	TIPTK
Fire Tender	FIRETD	Tour Coach	TOURCH
Garbage Wagon	GARBWG	Table Top	TTOP
Mobile Caravan	MOBCVN	Tow Truck Class 1	TTRKC1
Chassis Mounted Bin	MTDBIN	Tow Truck Class 2	TTRKC2
Motor Wagon	MTRWGN	Tow Truck Class 3	TTRKC3
Multi-Body Type	MULTI	Utility	UTE
Omnibus	OMNBUS	Van Truck	VANTRK
Prime Mover	PMOVER	Water Tank Truck	WTRTNK

Table B.11: Australian Rigid Truck classification Summary

	NSW	QLD	SA	VIC	WA
Emergency Vehicles	Fire Trucks and Ambulances identified by vehicle type and tare>4.5t	Ambulances identified by body type	None identified	Ambulances identified in 2005 by body type, Fire trucks identified by insurance class	Fire Trucks and Ambulances identified by body type
Tankers	Identified by vehicle type (as rigid or articulated) and tare>4.5t,	identified by body type	None identified	No	identified by body type
Tip Trucks and Tow Trucks	Tow trucks identified by vehicle type, tippers by body type. Tare>4.5t used to ID as rigid HV	Body type used to include Tippers and Tow Trucks from special purpose category	Not able to be known whether they are included in with trucks or in with ‘other defined motor vehicles’	Tow trucks and Goods carrying >2000kg‘other vehicles’ were identified from insurance class	Included in truck categories, identified by body type
Tare>4.5 identified	Yes	Yes	Assumed for 25% of light and all large rigid trucks	Assumed for truck category, expected if goods carrying	Yes
Other			75% of Light trucks were not considered Heavy Vehicles	Truck category may include isolated Prime Mover units	

Table B.12: Australian Articulated Truck classification Summary

	NSW	QLD	SA	VIC	WA
Articulated Trucks Identification					
	Yes but emergency and tow HV assumed rigid	Category includes rigid truck types	Yes, semi-trailers	Yes, semi-trailers	Yes
Identification of Rigid Trucks carrying trailers					
	Yes	Yes, but also inseparably included in articulated category	Yes	No category but insurance class may indicate articulation	Yes
Identification of prime mover without trailer					
	Not reliably	Yes but only as prime mover body type with 0 towed units.	Yes	No category, but insurance class may indicate articulation for a truck	Yes
Road Train Identification					
	Yes, road train category may include rigid truck types.	Yes, Category includes rigid truck types	Yes, Category may include rigid truck types	No, only possible in 2010 data	Yes

Table B.13: Australian Bus classification Summary

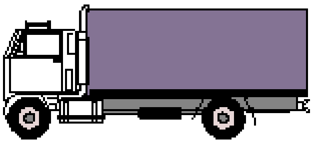
	NSW	QLD	SA	VIC	WA
Buses					
Small bus categorised separately	Multi-seated Van	No	No		Multi-seated Van
Ten seat minimum	No	Yes	No, Nothing defined	9 -13 seat category, most with seat capacity or occupant number	No
Tare >4.5 identified	Yes	Yes	Assume for Bus	Assume for Bus/Coach category	Yes

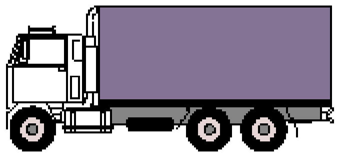
APPENDIX C – RIGID TRUCK ILLUSTRATIONS

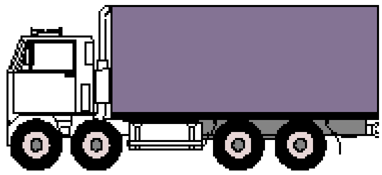
Grey: (Transport and Main Roads 2012)
Purple: (National Transport Commission, 2010)

A. RIGID TRUCKS: Single Unit

1. Two Axle **2. Three Axle** **3. Four Axle Twin-Steer**

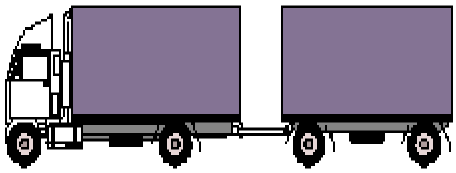


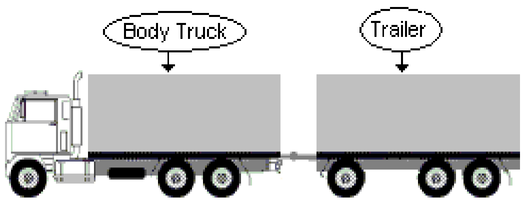




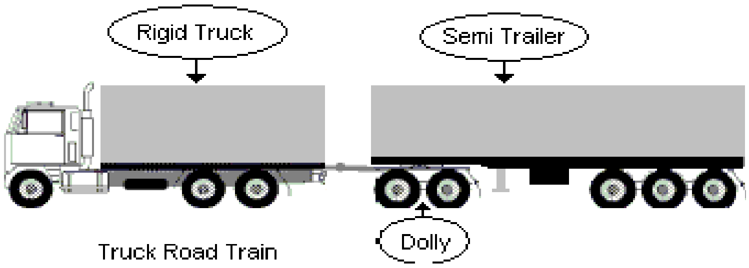
B. RIGID TRUCKS: Body Truck Tractor

1. Two Axle with Two Axle Dog Trailer **2. Three Axle with Three Axle Dog Trailer**



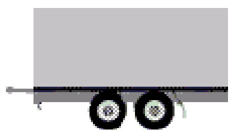


C. Rigid Truck Road Train

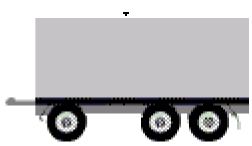


D. Trailers

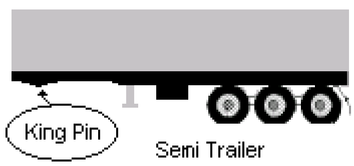
A dolly is used to convert a semitrailer to a dog trailer.

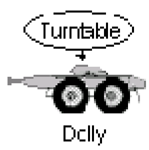


Pig trailer



Dog Trailer

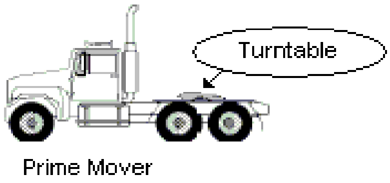




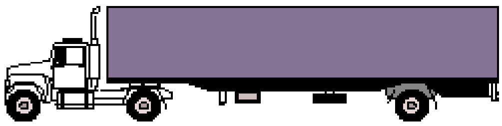
APPENDIX D – ARTICULATED TRUCK ILLUSTRATIONS

Grey: (Transport and Main Roads 2012)
Purple: (National Transport Commission, 2010)

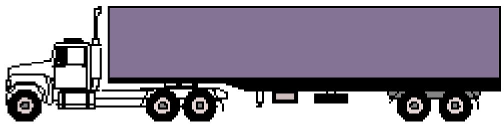
A. Prime Mover



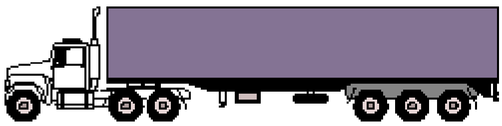
1. THREE AXLE SEMI-TRAILER



2. FIVE AXLE SEMI-TRAILER

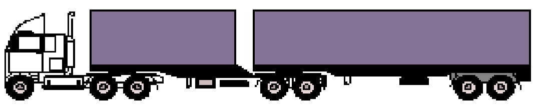


3. SIX AXLE SEMI-TRAILER

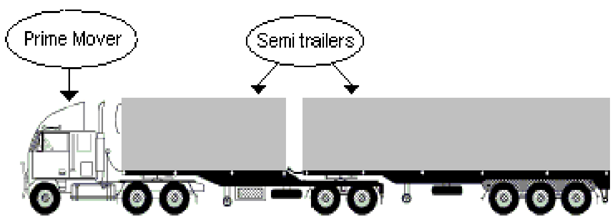


B. B-Double

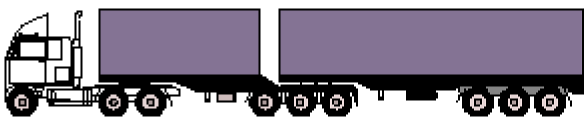
1. SEVEN AXLE B-DOUBLE



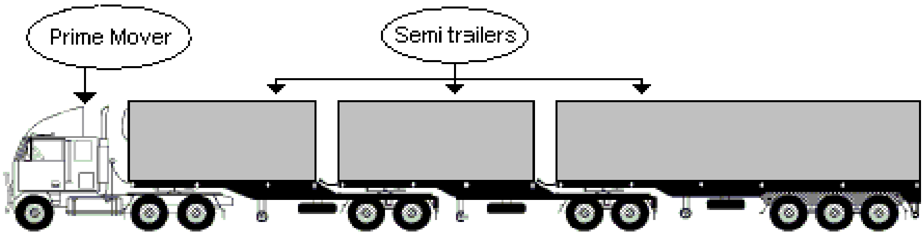
2. EIGHT AXLE B-DOUBLE



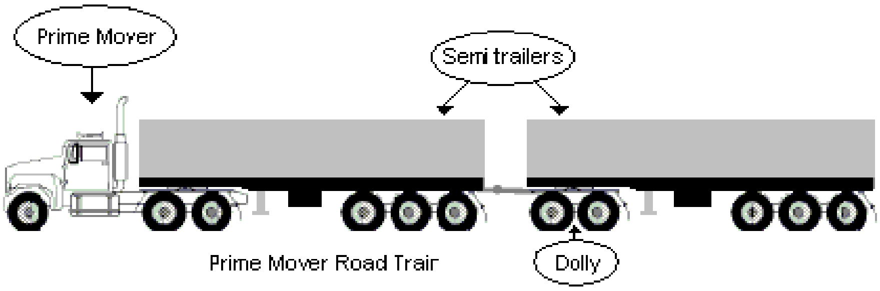
3. NINE AXLE B-DOUBLE



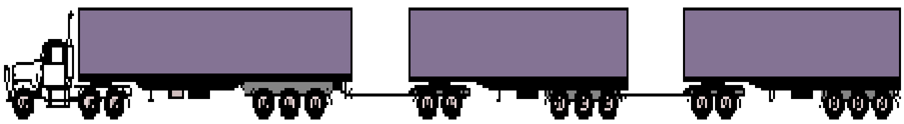
C. B-Triple



D. Double road train: Prime Mover Road Train towing 2 semitrailers

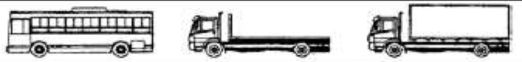
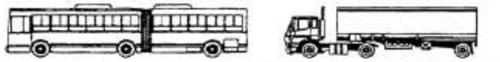
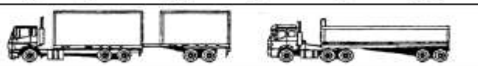
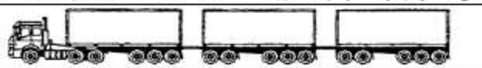


E. Triple road train: Prime Mover Road Train towing 3 semitrailers



APPENDIX E – AUSTROADS VEHICLE CLASSIFICATION SYSTEM

AUSTROADS Vehicle Classification System

Level 1 Length (indicative)	Level 2 Axles and Axle Groups		Level 3 Vehicle Type	AUSTROADS Classification		
Type	**Axles**	**Groups**	**Typical Description**	**Class**	**Parameters**	**Typical Configuration**
					LIGHT VEHICLES	
Short up to 5.5m		1 or 2	**Short** Sedan, Wagon, 4WD, Utility, Light Van, Bicycle, Motorcycle, etc	1	d(1) ≤ 3.2m and axles = 2	
Medium 5.5m to 14.5m	3, 4 or 5	3	**Short - Towing** Trailer, Caravan, Boat, etc	2	groups = 3 d(1) ≥ 2.1m, d(1) ≤ 3.2m, d(2) ≥ 2.1m and axles = 3, 4 or 5	
					HEAVY VEHICLES	
	2	2	**Two Axle Truck or Bus**	3	d(1) > 3.2m and axles = 2	
	3	2	**Three Axle Truck or Bus**	4	axles = 3 and groups = 2	
	> 3	2	**Four Axle Truck**	5	axles > 3 and groups = 2	
Long 11.5m to 19.0m	3	3	**Three Axle Articulated** Three axle articulated vehicle, or Rigid vehicle and trailer	6	d(1) > 3.2m, axles = 3 and groups = 3	
	4	> 2	**Four Axle Articulated** Four axle articulated vehicle, or Rigid vehicle and trailer	7	d(2) < 2.1m or d(1) < 2.1m or d(1) > 3.2m axles = 4 and groups > 2	
	5	> 2	**Five Axle Articulated** Five axle articulated vehicle, or Rigid vehicle and trailer	8	d(2) < 2.1m or d(1) < 2.1m or d(1) > 3.2m axles = 5 and groups > 2	
	≥ 6	> 2	**Six Axle Articulated** Six axle articulated vehicle, or Rigid vehicle and trailer	9	axles = 6 and groups > 2 or axles > 6 and groups = 3	
Medium Combination 17.5m to 36.5m	> 6	4	**B Double** B Double, or Heavy truck and trailer	10	groups = 4 and axles > 6	
	> 6	5 or 6	**Double Road Train** Double road train, or Medium articulated vehicle and one dog trailer (M.A.D.)	11	groups = 5 or 6 and axles > 6	
Large Combination Over 33.0m	> 6	> 6	**Triple Road Train** Triple road train, or Heavy truck and three trailers	12	groups > 6 and axles > 6	

Definitions:
Group: Axle group, where adjacent axles are less than 2.1m apart
Groups: Number of axle groups
Axles: Number of axles (maximum axle spacing of 10.0m)

d(1): Distance between first and second axle
d(2): Distance between second and third axle

APPENDIX F – CONTRIBUTING FACTORS IN ROLLOVER AND LOSS-OF-CONTROL CRASHES

(Elsasser 2013)

Contributing Factors in Rollover and Loss-of-Control Crashes

Many factors related to heavy-vehicle operation, as well as factors related to roadway design and road surface properties, can cause heavy vehicles to become yaw unstable or to experience a rollover. Described below are several real-world situations where roll or yaw instabilities might occur and stability control systems may prevent or lessen the severity of crashes]:

- **Speed too high to negotiate a curve** - Entry speed of vehicle is too high to safely negotiate a curve. When the lateral acceleration of a vehicle during a steering manoeuvre exceeds the vehicle's roll or yaw stability threshold rollover or loss of control is initiated. Curves can present both roll and yaw stability issues to these types of vehicles due to varying heights of loads (low versus high, empty versus full), and surface friction levels(ice versus snow versus wet versus dry)
- **Sudden steering manoeuvres to avoid a crash** – Driver makes an abrupt steering manoeuvre, such as a single or double lane change manoeuvre, or attempts to perform an off-road recovery manoeuvre, generating a lateral acceleration that is sufficiently high to cause a rollover or causing the vehicle to become yaw unstable. Manoeuvring a vehicle on off-road, unpaved surfaces such as grass, gravel, or dirt may require a larger steering input (larger wheel slip angle) to achieve a given vehicle response, and this can lead to a large increase in lateral acceleration once the vehicle returns to the paved surface.
- **Loading conditions** – Vehicle yaw due to over-steer is more likely to occur when a vehicle is in a lightly loaded condition and has a low centre of gravity height. Heavy-vehicle rollovers are much more likely to occur when the vehicle is in a fully loaded condition as a result of a high centre of gravity height. Cargo that is placed off-centre in the trailer will result in the vehicle being less stable in one direction than the other. It is also possible that improperly secured cargo can shift while the vehicle is negotiating a curve, thereby reducing roll or yaw stability. Sloshing can occur in tankers transporting liquid bulk cargoes. This condition is of particular concern when the tank is partially full because the vehicle may experience significantly reduced roll stability during certain manoeuvres.
- **Road surface conditions** – The road surface condition can also play a role in the LOC a vehicle experiences. On a dry, high-friction asphalt or concrete surface, a tractor-trailer combination vehicle executing a severe turning manoeuvre is likely to experience a high lateral acceleration, which may lead to a rollover or LOC. A similar manoeuvre performed on a wet or slippery road surface may result in LOC.
- **Road design configuration** – Some drivers may misjudge the curvature of ramps and not brake sufficiently to negotiate the curve safely. This includes ramps with decreasing radius curves as well as curves and ramps with improper signage. A decrease in super-elevation (banking) at the end of a ramp where it merges with the roadway causes an increase in vehicle lateral acceleration (and may be accompanied by the driver accelerating in preparation to merge).
- **Braking manoeuvres** – Most common heavy-vehicle LOC (jack-knife) events occur due to rear wheel lockup during braking. If the rear wheels are locked, they cannot generate any lateral force and only a very small side force (roadway crown or slight trailer angle) is needed to cause the tractor to lose directional control. Also, loss of steering control or “plow-out” can occur due to front wheel lockup, although this is most likely to happen on a heavy vehicle under light loading conditions and slippery road surfaces. Since most jack-knife crashes are caused by lockup of the tractor’s rear wheels during braking, the requirement for antilock brake systems on truck tractors, effective since 1997, has addressed a portion of the loss-of-control crashes due to wheel lockup during hard braking. SC systems are expected to further reduce crashes while braking in a manoeuvre.
- **Vehicle factors** – Severely worn tires (tread depth below 2/32 inch) are more likely to contribute to vehicle spinout or plow out under wet slippery conditions. The condition of the vehicle’s brakes, including brake adjustment, is critical in enabling the driver to reduce speed for upcoming curves, and also to prevent brake fade from occurring on long downhill grades. Replacing tires that have insufficient tread depth and maintaining the ABS in proper operating condition are critical in preventing jack-knife events and trailer swing during panic braking. Both RSC and ESC are enhancements to the ABS platform and for all of these systems to work properly, foundation brake systems and tires must be maintained in proper operating condition.