Investigation of Key Crash Types: Rear-end Crashes in Urban and Rural Environments
Abstract
This report collates research into factors contributing to the incidence and severity of rear-end crashes in urban and rural environments in Australia and New Zealand. It also identifies a number of possible pertinent mitigation measures.

A crash data analysis (for a five year period 2006-2010) and inspection of key crash sites were conducted to supplement available research on this topic. Recommendations are made on practical ways to reduce the incidence and severity of rear-end crashes within the working environment of the Safe System approach.

The National Road Safety Strategy has identified intersection crashes as one of the most frequent crash types occurring on Australian roads. As rear-end crashes are a common collision type at intersections, they have been targeted as part of the strategy.

Keywords
Rear-end crash, contributory factors, engineering treatments countermeasures, road design, vehicle design, enforcement, signalised intersections, headway, yellow phase times.

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Summary

The National Road Safety Strategy has identified intersection crashes as one of the most frequent crash types occurring on Australian roads. As rear-end crashes are a common collision type at intersections, they have been targeted as part of the strategy.

Rear-end crashes feature significantly in jurisdictions’ road crash statistics. Whilst most rear-end crashes do not lead to fatalities, about one-quarter result in fatal or serious injuries. About two-fifths of CTP insurance claims are for rear-end crashes, amounting to a quarter of all CTP costs.

Austroads has commissioned this research project to explore the contributory factors for rear-end crashes, especially those leading to fatal and serious injuries. Both urban and rural locations have been considered. The project sought to identify appropriate solutions, discussing both engineering treatments currently used and new potential treatments.

To meet the research goals, a literature review was undertaken. The review identified previous investigations into factors associated with rear-end crashes in urban and rural environments, measures that may be used to prevent such crashes, and the effectiveness of these measures. Crash data over a five-year study period (2006–10) was analysed. A series of site investigations was also conducted at ‘high’ crash sites in New South Wales, Victoria and Queensland to identify factors that may have contributed to the occurrence or severity of rear-end crashes.

Throughout the project, road environment, vehicle and driver characteristics were considered as potential crash contributory factors. Factors found to be related to an increased incidence or severity of rear-end crashes include:

- driver characteristics: distracted, younger, and male drivers have all been identified as at greater risk of being the striking driver in a rear-end crash. Older and female drivers are at greater risk of sustaining more serious injuries
- vehicle factors: larger vehicles have an increased risk of both being struck and being the striking vehicle in a rear-end collision; collisions involving larger vehicles with passenger cars can be more severe due to vehicle incompatibility
- road environment: rear-end crash risk is highest on highly trafficked, high-speed roads and at intersections, particularly when signalised and/or featuring poor horizontal and vertical alignment.

The study identified a number of opportunities for future research. These include studying the rear-end crash risk associated with disruptions to traffic flow (such as caused by bus stops and driveways), and with short yellow phase times at traffic signals. Also, it is recommended that measures aimed at reducing tailgating be investigated.

Safety measures that could be affected were identified as either short-term measures that could be undertaken as part of a road maintenance program, or more substantial improvements to be undertaken as part of a capital works or road safety program.

Improvements to be undertaken as part of road maintenance included improved delineation and visibility at signalised intersections and treatment of the road surface. More substantial improvements to be undertaken include targeted treatment of at-risk intersections, replacement of red-light cameras with combined red-light speed cameras, and improved turning provisions at intersections.
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1. Introduction

1.1 Background

The National Road Safety Strategy has identified intersection crashes as one of the most frequent crash types occurring on Australian roads (Australian Transport Council (ATC) 2011). As rear-end crashes are a common collision type at intersections, they have been targeted as part of the strategy (ATC 2012).

It follows that rear-end crashes feature significantly in jurisdictions’ road crash statistics, consistent with the data that about two-fifths of CTP insurance claims are for rear-end crashes, amounting to a quarter of all CTP costs.

Austroads commissioned this research project to explore the causal and contributory factors for rear-end crashes, especially those leading to high severity outcomes. Both urban and rural locations have been considered, as were intersections and mid-block locations.

The project aims to identify appropriate solutions, discussing both engineering treatments currently used and new potential treatments.

1.2 Objective

The objectives of the study are:

- to identify factors that may cause or contribute to the occurrence and severity of rear-end crashes in urban and rural environments across Australasia
- to identify effective, fit for purpose remedial engineering treatments.

1.3 Method

The investigation initially involved conducting a literature review and internet search. The next step involved the collection and analysis of crash data across Australia and New Zealand. Detailed site investigations were then conducted at a sample of crash cluster locations across representative jurisdictions. The aim of each task was to identify factors that may have caused or contributed to crash causation or severity for rear-end crashes, as well as possible remedial measures.

Interim reports were published following each phase of the project, and informed future stages. All interim reports have been incorporated into this final report.

Task 1 – Literature review and internet search

A literature review and internet search were undertaken to:

- identify previous investigations into factors associated with rear-end crashes in urban and rural environments
- identify new or innovative measures that have been used to prevent crashes, and determine their effectiveness.

The literature search was conducted through the MG Lay Library at ARRB using the Australian Transport Index (ATRI) and Transport Online (TRIS & ITRD databases), while the internet search used the Google and Google Scholar search engines.
Task 2 – Collection and analysis of crash data

Mass crash data on rear-end crashes across Australia and New Zealand were analysed according to a variety of environmental, vehicular, and human factors. Data was collected over the five-year period 2006–2010. Trends in the data were identified and assessed to consider possible contributory factors, and to see how the incidence of these types of crashes were changing with time.

Task 3 – Site investigations

Site investigations have been undertaken at a representative sample of ‘high’ crash sites in New South Wales, Victoria and Queensland areas. The aim was to identify factors that may have contributed to the occurrence or severity of rear-end crashes.

A road safety survey was used to record road features that contributed to, or potentially contributed to crash occurrence or severity. The checklist was tailored to identify factors specific to rear-end crashes in urban environments.

1.4 Terms Used in the Report

1.4.1 Rear-end Crash

The term ‘rear-end crash’ is used to denote a scenario involving two vehicles, where the second vehicle strikes the rear of the first vehicle. Traditionally, this refers to situations in which both vehicles are being driven forwards at the time. A rear-end crash incident may involve multiple rear-end collisions, for example, when the struck vehicle is propelled forward and strikes a third vehicle in front.

For the purposes of this project, situations in which the lead vehicle is parked or stationary will also be considered.

A breakdown of the pertinent crash (e.g. RUM) codes considered for each jurisdiction will be provided in the reporting of the data analysis for this project.

1.4.2 Vehicle Involvement

In a two-vehicle rear-end collision, the first vehicle will be referred to as either the ‘lead’ or ‘struck’ vehicle, depending on the context.

The second vehicle will be referred to as either the ‘following’ or ‘striking’ vehicle, depending on the context.

In a multi-vehicle collision, the vehicles will be referred to as the first, second or third vehicle, based on the vehicle position relative to the head (front) of the group of vehicles.

1.4.3 Turn Manoeuvre

A number of references cited are sourced from countries where vehicles travel on the right side of the road. For the reader’s convenience and to maintain consistency in the report, all references to specific turning manoeuvres have been adjusted to reflect the Australian and New Zealand experience (travelling on the left side of the road).

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1 This was the latest five-year period for which crash data was consistently available across jurisdictions.
That is, where American references refer to left-turns in their original text, this report will refer to the manoeuvre as a right-turn or a ‘turn across the opposing flow’ depending on the context. When such references refer to right-turns in the original text, this report will refer to the manoeuvres as a left-turn or a ‘turn with the flow’, depending on the context.
2. Literature Review

2.1 Overview of the Rear-end Crash Issue

2.1.1 General Prevalence and Significance of Rear-end Crashes

Rear-end crashes are one of the most common crash types occurring on Australian roads. Whilst such crashes are generally less severe than other crash types, the sheer volume of rear-end crashes amounts to a highly significant cost when considering insurance claims. As rear-end crashes are the most likely of crashes to go unreported (Wang & Abdel-Aty 2006), it may also be that their prevalence is likely to be more widespread than suggested in the literature.

As significant safety gains are being made in minimising the severity and frequency of other crash types through the Safe System approach, there is an identified need to extend that to the impact of rear-end crashes.

Rear-end crashes amount to one-third of all crashes reported to police in South Australia (Anderson & Baldock 2008).

In South Australia between 2007 and 2011, the most common CTP claim was for rear-end crashes, amounting to 40% of all claims. In terms of cost, rear-end crashes accounted for 25% of the total costs of CTP claims, suggesting a high incidence, but relatively low severity of this crash type (Motor Accident Commission n.d.).

The situation in NSW is similar. Whiplash injuries, generally associated with rear-end crashes, account for 45% of all CTP claims, and about 27% of total CTP costs (Motor Accidents Authority 2009).

In the USA, rear-end crashes account for over 29% of crashes (National Highway Traffic Safety Administration (NHTSA) 2010). The proportion of fatal crashes in the USA that result from rear-end crashes has risen over the past decade from 5.3% in 2002 to 6.0% in 2011 (NHTSA 2013). This suggests that the safety gains being made in other crash types are not having the same impact on rear-end crashes.

2.1.2 Prevalence in Urban vs Rural Areas

The incidence of rear-end crashes is predominantly an urban issue - urban roads present a 20% higher risk of rear-end crashes than rural areas. This is because urban roads feature more of the characteristics that have been identified as present in rear-end crashes in general terms (as discussed in Section 2.2), e.g. higher traffic densities and more signalised intersections (Yan et al. 2005).

Baldock et al. (2005) reported that 94% of rear-end crashes in South Australia occurred within the Adelaide metropolitan area, whilst only 6% occurred outside of Adelaide. In terms of total crashes reported, rear-end crashes accounted for 34% of all crashes in the Adelaide metropolitan area, and just 10% of rural crashes in South Australia. However, it is important to note that as only crashes reported to police are recorded, the low prevalence of this crash type in rural environments may be due to a combined effect of a lower crash rate and a lower rate of reporting.

In terms of deaths on South Australian roads, rear-end crashes accounted for 9% of fatalities in the Adelaide metropolitan area, against 3% in rural parts of the state (Hutchinson 2008).
2.1.3 Lead Vehicle Movements

In the USA, the struck vehicle was initially stationary in 70% of rear-end crashes. When the struck vehicle was moving, 33% of the vehicles were in the process of making a turn across the opposing flow and about 17% were in the process of making a turn with the flow (Knipling et al. 1993).

For those vehicles in which the struck vehicle was moving, approximately half of these were decelerating and the other half were travelling slower than the striking vehicle. Rear-end crashes in which the struck vehicle was originally moving are generally more severe than those in which the vehicle was stationary (Knipling et al. 1993). It is surprising that rear-end crashes would be more severe when the lead vehicle is moving, as the difference in speeds between the two vehicles, and therefore the striking speed, should be lower. Knipling et al. (1993) does not provide an explanation for this.

As discussed in Section 2.4.3, the position between an occupant’s head and their head restraint can affect the severity of injuries sustained in a rear-end crash; and head distance increases during several driving tasks, particularly turn manoeuvres. It appears likely that the higher crash severity for rear-end collisions into moving vehicles may be due to driver head position during various driving tasks, as compared to when the vehicle is stationary.

2.1.4 Rear-end Crash Injuries

Whiplash

Whiplash injuries are the most common injury arising from rear-end crashes. Whiplash refers to a range of neck injuries, including mild muscle strain, soft tissue tears, and nerve or disc damage. Whiplash symptoms include neck pain, headaches, a reduced range of motion in the neck, and tingling in the arms (Chapline et al. 2000).

When a lead vehicle is struck from behind, the collision propels that vehicle forwards. The seats in the vehicle push the vehicle occupants forward. The torso moves ahead of the seat back due to a combination of the vehicle acceleration and rebound against the seat (IIHS 2008, Shin et al. 2003).

As the head is unsupported, it lags behind the forward motion of the torso. The torso will be moving forward whilst the head is still moving backwards. This difference in motion between the head and torso causes the neck to hyperextend (bend and stretch), contributing to shear and tensile forces and extension moments in the neck (IIHS 2008, Shin et al. 2003).

Severity of injuries

Compared to other crash types, the injuries sustained in rear-end crashes are generally less severe (Baldock et al. 2005). Under 5% of rear-end crashes occurring in South Australia resulted in a fatality or hospitalisation. A large proportion of the less serious casualties are treated for whiplash (Anderson & Baldock 2008).

Of those treated for whiplash, only around 5% sustain permanent disability and only 2% are unable to return to work due to the severity of their injuries (Anderson & Baldock 2008).

2.2 Road Environment Crash Contributory Factors

Austroads (2009a) listed crash contributory factors for rear-end collisions, which can be found in Appendix A. The literature supports those factors mentioned by Austroads (2009a) and also introduces other factors to consider.
2.2.1 Intersections

Rear-end crashes are most common at intersections. This is because at intersections, there is a greater presence of slow-moving or stationary traffic than midblock, e.g. as turning traffic waits for an opportunity to commence their turn. The greater the differential in travel speeds between lead and following vehicles, the greater the risk of a rear-end crash. When the lead vehicle is stationary, the differential speed reaches a maximum, that being the following vehicle’s travel speed (Baldock et al. 2005).

Six per cent of fatalities at signalised intersections in the USA are rear-end crashes (Antonucci et al. 2004), compared against 1% at unsignalised intersections (Neuman et al. 2003). Baldock et al. (2005) suggested that the higher traffic density at signalised intersections may be a contributory factor to the higher rear-end crash rate at these sites. Other factors contributing to the incidence of rear-end crashes at signalised intersections can be seen in Section 2.2.2.

Though less prominent than at signalised intersections, there is still an elevated risk of rear-end crashes at unsignalised intersections, as opposed to mid-block sections. Additionally, the risk of a rear-end crash occurring at an unsignalised intersection increases the closer it is to a signalised intersection upstream (Haleem et al. 2010).

2.2.2 Factors Relevant to Signalised Intersections

Vehicle position during yellow phase

Huang et al. (2006) suggested that rear-end crashes occur at signalised intersections during the yellow phase, when the lead vehicle has decided to stop, and the trailing vehicle intends to proceed through.

The risk of such a collision is related to the level of clarity as to whether or not a lead vehicle can pass through the intersection during the yellow phase. A vehicle’s ability to clear an intersection is at its most uncertain at the point when it is about 2.5–3.0 s from the stop line when the yellow phase of the signal begins. The rear-end crash rate peaks at this point, as drivers with a shorter time to stop can proceed through the intersection comfortably, whilst drivers with a longer time to stop can brake safely (Huang et al. 2006).

Notwithstanding the above, it is likely that in many of these cases, the lead vehicle decided to abort late in the scenario, resulting in heavy braking. The following vehicle, expecting the lead vehicle to proceed and hence planning to follow, would therefore be required to brake even harder to avoid a collision, which may not necessarily be possible.

It is also possible that a following vehicle may deliberately keep a short headway, attempting to clear the intersection during the yellow phase, making it more difficult to avoid a collision with a lead vehicle that has decided to abort.

Number of phases

Poch and Mannering (1996) reported that there is an increase in rear-end crashes at signalised intersections that feature either a very large (i.e. eight) or very low (i.e. two) number of signal phases.

Two-phase signals do not provide an additional control for any right-turns, requiring these vehicles to give way to opposing traffic. The queuing of such traffic leads to a conflict between stationary turning and through traffic, so increasing the risk of rear-end crashes. Two-phase signals also generally do not feature exclusive turn lanes, further exacerbating the conflict (Poch & Mannering 1996).

Eight-phase signals provide protected right-turns for all approaches. The large number of phases can lead to driver frustration from the increased wait time and sensory overload. Further, such intersections are generally associated with higher traffic volumes and more congestion, which in turn can contribute to a higher rear-end crash rate (Poch & Mannering 1996).
Red light cameras

Studies indicate that red-light cameras can be a highly effective tool in reducing a number of potentially severe crash types. For example, right angle crashes can be reduced by 13% and injuries from such crashes by 33%. Whilst the introduction of red-light cameras increases total crashes by 6%, total injury crashes are reduced by 12% (Høye 2013).

However, there is a general increase in rear-end crashes once red-light cameras are introduced at signalised intersections. Høye (2013) conducted a meta-analysis of a large number of studies considering crash rates at red-light camera sites. The analysis found an overall 39% increase in the rear-end crash rate and a 19% increase in rear-end crashes resulting in injury.

Miller et al. (2006) suggested that red-light cameras increase rear-end crashes by between 32 and 85%. This increase is associated with drivers braking more suddenly in order to avoid risking running a red-light and being penalised.

In contrast, Huang et al. (2006) found that red-light cameras increased the rear-end crash rate at higher operating speeds only; at lower speeds the crash risk was found to be lower. As an example, at three seconds to the stop line, with a two second headway, the cut-off speed was found to be about 40 km/h, below which the red-light camera seems to lead to a decrease in rear-end crashes. At a speed above 40 km/h, an increase in rear-end crashes was identified.

The exact cut-off speed at which a red-light camera is likely to result in an increase in rear-end crashes will vary based on the vehicle headway and the time distance from the stop line at the beginning of the yellow phase. The cut-off speed will be lower when vehicles maintain a shorter headway or the lead vehicle is positioned closer to the stop line. This is intuitive; both variables are already associated with an increase in rear-end crashes, which can in turn be counteracted by lower travel speeds (Huang et al. 2006).

Other factors at signalised intersections

Wang and Abdel-Aty (2006) identified that there was a higher risk of rear-end crashes along routes that had closer spacing of signalised intersections. Whilst the authors of the research study do not suggest an optimum spacing of traffic signals, they propose that signals should be well co-ordinated to counteract this issue.

It is possible that the higher rate of rear-end crashes when traffic signals are closer spaced may be related to a ‘see through’ effect. Drivers approaching an intersection at the red phase may mistakenly view a green signal at a later intersection as indicating a green phase at the intersection.

Wang and Abdel-Aty (2006) also reported that three-legged intersections have a lower rate of rear-end crashes than four-legged ones but do not attempt to postulate why this may be the case.

2.2.3 Vehicle Headway

The risk of a rear-end crash at a signalised intersection increases exponentially as the headway time gap decreases (Huang et al. 2006).

The headway time gap is defined as the time taken for a following vehicle to reach the lead vehicle’s current position. This may be influenced by factors such as driver attitude, awareness and skill, traffic conditions, visibility and vehicle geometry.

Regulation 126 of the Australian Road Rules requires a driver to maintain a safe headway behind the vehicle ahead, such that the driver can stop safely in order to avoid a collision if necessary. The regulation does not prescribe a quantifiable safe distance.
On motorways, drivers typically keep a headway of 0.5–1.0 seconds. This presents an issue as drivers generally consume 2–3 seconds to perceive and react to an unexpected change in traffic ahead. This is known as a driver’s perception and reaction time (PRT). As the driver headway is below their PRT, there is a reliance on viewing traffic conditions ahead of the vehicle that they are following (Hutchinson 2008).

Motorists find it difficult to maintain a sufficient headway in denser traffic, given that lane changes occur frequently. A vehicle entering into the headway created by a following driver causes the latter to decelerate until they have again provided themselves with an appropriate headway (Hutchinson 2008).

Exacerbating the issue is that most motorists are unaware of what constitutes a safe headway, or how to determine it (Song & Wang 2010).

Taieb-Maimon and Shinar (2001) reported on a field study, where drivers were asked to maintain a safe distance, or to maintain a comfortable distance behind the vehicle ahead, at speeds ranging from 50 to 100 km/h. It was found that driver headway times remained relatively constant across varying speeds. When asked to keep a ‘safe’ headway, the average headway time was 0.66 s, compared with 0.98 s for a ‘comfortable’ headway. Both of these headway times are still well below the 2–3 s recommended headway time.

Headway can be further eroded if a following driver deliberately tailgates a driver ahead, either as an expression of anger, or to signal to the driver ahead a desire that they drive faster or give way (Hutchinson et al. 2008).

Drivers may also travel closer to the vehicle ahead as they are able to view beyond and ahead of this lead vehicle and feel that they are able to anticipate any changes in traffic. However, this does not permit the driver to anticipate sudden braking by the vehicle immediately ahead. Centred, high mounted, brake lights assist drivers to anticipate traffic changes ahead as they are visible to drivers further down a platoon (Hutchinson et al. 2008).

Headway distances can be influenced by the characteristics of the lead and following vehicle. This is discussed further in Section 2.4.

2.2.4 Traffic Conditions

Traffic congestion

The proportion of rear-end crashes occurring on a roadway has been found to increase with increasing traffic density. Such increases may be due to time of day, such as peak hour traffic, or the road type, such that arterial roads are likely to experience more rear-end crashes than collector streets (Baldock et al. 2005).

Yan et al. (2005) indicated that for every 10 000 vehicle increase in average annual daily traffic, the risk of rear-end crashes on that road increases by 12%.

The relationship between headway distance and traffic density supports this finding. As traffic density increases, the percentage of vehicles maintaining a short or very short headway increases linearly. As headway distance is related to rear-end crash propensity (see Section 2.2.3), this would lead to an increase in the rate of rear-end crashes (Aron et al. 1997).

Rear-end crashes have been found to occur more frequently in areas with higher population densities (Wang & Abdel-Aty 2006), most likely due to the correlation between population and traffic densities.
Speed environment

An increase in the risk of rear-end collisions can also be associated with higher operating speeds. Drivers travelling at higher speeds take longer to determine the relative velocity of a vehicle ahead. Therefore, drivers travelling at higher speeds have less time available to brake before reaching a stationary vehicle. As vehicles travelling at higher speeds require more time to brake, there is increased risk of rear-end crashes and of high severity outcomes (Kuge et al. 1995).

Yan et al. (2005) reported that roads with a posted speed limit of 55 mph (~90 km/h) feature a 4.6 times greater risk of rear-end crashes than roads with a 25 mph (~40 km/h) posted speed limit.

It is postulated that at signalised intersections, drivers at the higher speed behave more erratically, as they tend to be more hesitant in deciding whether to stop or proceed when faced with a yellow phase. Further, a trailing vehicle at lower speeds is able to brake or change lanes more easily to avoid collision (Yan et al. 2005).

Considering high-speed highways (including state, national and interstate highways) only, Lao et al. (2014) report that rear-end crash rates decreases as the speed limit increases. Such highways are generally designed to allow for smooth traffic flow, which should minimise the rear-end crash risk.

Traffic movements

As introduced in Section 2.2.2, the presence of right-turning vehicles is related to an increase in rear-end crashes. A higher presence of right-turning vehicles results in more decelerating, slow-moving and stationary vehicles on a roadway. This leads to an increase in rear-end crashes due to greater variations in travelling speeds on the roadway (Baldock et al. 2005).

Wang & Abdel-Aty (2006) identified that the incidence of rear-end crashes at a signalised intersection increases with the number of left- and right-turn lanes on the major road. The report notes that the number of turning-lanes at an intersection is directly related to the number of phases at a signalised intersection, and this may be the reason for the relationship.

Vehicle composition

Lao et al. (2014) found that rear-end crash risk increases as the truck composition increases, until reaching a peak at about 3%. It is proposed that the risk increases with increasing truck presence due to the higher rear-end risk involvement of trucks (outlined in Section 2.4). Once truck composition reaches 3%, the saturation is high enough that drivers begin to drive more cautiously, reducing the crash risk.

2.2.5 Work Zones

The incidence of rear-end crashes is higher in work zones. Between 40 and 59% of the crashes occurring in work zones are rear-end crashes (Dewar & Hanscom 2007). Moreover, rear-end crash fatalities are 2.7 times more prevalent at work zones and are 25 times more common than all other fatal crashes that occur at such sites (Antonucci et al. 2005).

The higher prevalence of rear-end crashes at work zones may be attributed to the higher presence of heavy vehicles and higher traffic density at such sites (see Sections 2.2.4 and 2.4). As traffic density or concentration of heavy vehicles increases, the risk of rear-end crashes also increases (Meng & Weng 2011).

It may be that there is a higher rate of driver distraction in work zones due to the changes to the surrounding environment, higher than usual number of signs and driver interest in work progress. Driver gazing at roadworks and crash sites, or ‘rubbernecking’ is known to slow traffic and lead to congestion (Masinick & Teng 2004), which in turn is associated with an increase in rear-end crashes.

The risk of rear-end crashes is highest in the lane closest to the work activity, with this lane having a rear-end crash risk three times higher than the adjacent lane (Meng & Weng 2011).
Investigation of Key Crash Types: Rear-end Crashes in Urban and Rural Environments

Work zones on high-flow roads such as motorways were found to be at greater risk of rear-end crashes than those on arterial roads (Meng & Weng 2011). This is understandable, as with continuous free travel and higher operating speeds in the normal operating environment, any change in traffic conditions due to works would be far more significant.

The most common cause of rear-end crashes near a work zone was due to driver merging decisions, particularly during peak periods (Meng & Weng 2011).

2.2.6 Road Geometry

Baldock et al. (2005) found that most rear-end crashes in South Australia occurred on straight, level roads and in clear conditions. On curves, 13.5% of collisions were rear-end, compared to 31.6% on straights. Similarly, 31.2% of collisions on level roads were rear-end crashes, compared to 20.9% at slopes, crests, or sags.

Baldock et al. (2005) also identified two possible reasons for the overrepresentation of rear-end crashes on straight and level roads:

1. It is general practice to place intersections, where rear-end crashes are most common, at such sites.
2. Drivers may be more alert on roads with longitudinal gradients or curves, and may therefore respond faster to avoid a rear-end crash.

Yan et al. (2005) looked particularly at rear-end crash occurrence at signalised intersections only, considering the influence of road geometry at the one location type. In contrast to Baldock et al. (2005), the study found that:

1. The rear-end crash risk for curves was about 79% higher than for the straight sections of road. This was attributed to decreased visibility, reducing the available time drivers have to adapt to changed traffic conditions.
2. The rear-end crash risk was about 28% higher for gradients (slopes) than on flat roads.
3. For downhill gradients, this was attributed to vehicle mass and momentum acting against vehicle braking, making it more difficult for drivers to respond to changes in traffic conditions. The report did not discuss factors in rear-end crashes on uphill gradients.
4. The crash risk on curve/gradient combinations appeared to be about twice that of flat, straight roads (Yan et al. 2005).

Wang et al. (2000) also pointed out that visibility is impaired on uphill gradients, limiting a driver’s ability to anticipate changes in traffic ahead.

Lao et al. (2014) identified that rear-end crash risk on highways peaked at gradients of 4.4% for downhill grades and 4% for uphill grades.

2.2.7 Visibility

Weather

Hassan and Abdel-Aty (2013) reported that, in Florida in the USA, the most common (about 48%) freeway crash type due to weather-related visibility issues was rear-end crashes. The study found that 96% of visibility obstructions were attributable to heavy rain, with the remainder associated with fog.

Yan et al. (2005) reported that the risk of rear-end crashes on wet surfaces was 1.8 times that on dry surfaces; and that on what the study referred to as ‘slippery surfaces’, the risk could increase to be 3.3 times higher. These findings are consistent with skid resistance theory and practical experience.
However, somewhat paradoxically, Baldock et al. (2005) found that wet roads and rain did not lead to an increase in the likelihood of rear-end crashes when compared against other crash types.

**Time-of-day**

Rear-end crashes appear to occur more frequently during the daytime than at night. Yan et al. (2005) reported that the risk of rear-end crashes is 50% lower at night. This is attributed to differences in traffic conditions at night time. During the night time, traffic density is generally lower. Further, peak hour traffic, when aggressiveness may be higher, is generally during the daytime.

However, Sullivan and Flannagan (2003) reported that given a scenario of similar traffic conditions, the rear-end crash rate is higher during night time. This finding was based on a study of rear-end crashes occurring at the same time of day, but both before and after daylight savings changes, in order to consider the effects of lighting under similar traffic conditions.

Sullivan and Flannagan (2003) reported that the rear-end crash rate during the times of darkness was more than twice that during daylight. Heavy vehicles (trucks) were eight times more likely to be struck from behind during darkness.

**2.2.8 Road Surface**

Hutchinson (2008) suggested that road surface should not play a significant role in rear-end crash risk when both vehicles are braking heavily under the same reduced skid resistance. However, as previously reported, not all rear-end collisions are a result of sudden heavy braking from the lead vehicle. Also, Hutchinson (2008) seems to assume that roads have a homogenous texture, whereas surface texture of the one section of road may vary due to textural wear and line markings.

**2.2.9 Parked Vehicles**

Vehicles parked on the side of a roadway can lead to an increase in rear-end crashes as they introduce uncertainty, and in many cases partially obscure visibility of the roadway ahead, making it difficult for trailing vehicles to anticipate changes in traffic conditions (Baldock et al. 2005).

Further, parked vehicles may themselves become obstacles, or may prevent drivers from changing lanes to avoid obstacles, such as vehicles waiting to turn. This may cause drivers to brake heavily, and lead to rear-end crashes with vehicles following (Baldock et al. 2005).

**2.3 Driver-based Crash Contributory Factors**

**2.3.1 Driver Inattention**

Driver inattention has been identified as the most common driving error associated with rear-end crashes, and is considered a greater factor than tailgating (Baldock et al. 2005, Hutchinson 2008).

**Driver distraction**

Stutts et al. (2005) reported that drivers are most commonly distracted in the moments prior to a rear-end crash.

Rakha et al. (2010) reported that 11% of rear-end crashes in which a heavy vehicle was the striking vehicle were attributable to internal distraction of the heavy vehicle driver, such as use of the radio or a mobile phone. A further 6% of such crashes were attributable to an external distraction of the heavy vehicle driver, such as roadside advertising or driver interest in a previous incident which may have occurred and still be in situ.
For teenage drivers, distractions from other passengers or from use of mobile phones were the most common in-vehicle distractions related to rear-end crashes (Neyens & Boyle 2007).

The relationship between rear-end crashes and distractions from passengers or mobile phones was studied by Consiglio et al. (2003), through a simulator based study of drivers. Participants in a driving simulator were required to drive behind a lead vehicle under different forms of distraction. During the simulated drive, participants were required to release the accelerator and begin braking as soon as they could after the lead vehicle ahead activated their red brake lamp.

Drivers having a conversation through either a hand-held or hands-free phone responded in 464 or 465 ms respectively, indicating negligible difference between these two modes of phone use. This is 18% higher than the delay experienced by undistracted drivers and 14% higher than the delay experienced by drivers distracted by the radio only (Consiglio et al. 2003). This finding supports the findings of Lamble et al. (1999) that cognitive distraction is the main factor in driver distraction-related rear-end crashes (see below).

Drivers distracted by a conversation with a passenger fared marginally better, with a 453 ms delay (16% higher than undistracted drivers). The authors of the research highlight that this may not be an accurate representation of the delay resulting from a real-world passenger conversation. The conversation in the study was scripted and did not reflect a real-world situation. Generally, passenger conversations would vary based on changes in the road environment and passenger appreciation of driver workload (Consiglio et al. 2003).

The first iPhone and Android smartphones were released in Australia in 2008. Smartphones provide a range of applications that may offer a source of further distraction for drivers (Turner 2011). As of May 2013, 65% of Australians used smartphones, up from 37% in 2011 (Google 2013). As this is an evolving issue, the distraction caused by smartphones and the relationship to rear-end crash risk will need to be monitored.

Cognitive inattention

A common cause of driver inattention related to rear-end crashes is cognitive inattention, where a driver is pre-occupied with their own thoughts to such an extent that they were not focussed on the driving task. This is often described as the driver having ‘looked but failed to see’. Causes of cognitive inattention may include emotional distress or daydreaming (Baldock et al. 2005).

Lamble et al. (1999) confirmed poor reaction times to deceleration of a lead vehicle when drivers are cognitively distracted. Drivers in a simulator were asked to perform memory and addition tasks whilst driving, and their response time to a simulated lead vehicle decelerating was measured. Drivers had a 0.5 s increase in delay before responding to the vehicle ahead. This amounts to a delay three times more than that experienced by drivers driving with a blood alcohol content (BAC) of 0.034–0.046.

The delay was found to be similar to the delay experienced by drivers trying to dial a telephone number at the same time, indicating that cognitive impairment is the prime factor in driver distraction-related rear-end crashes (Lamble et al. 1999).

Neyens and Boyle (2007) found that teenage drivers that were cognitively distracted were more likely to be involved in a rear-end crash than other crash types. Rear-end crashes amongst cognitively distracted teenage drivers were 2.8 times more likely than fixed object collisions, and 1.8 times more likely than angular collisions.

Poor division amongst driving tasks

Rear-end crashes can occur when the following driver fails to divide their attention between multiple driving tasks appropriately. For instance, a driver looking through their rear vision mirror may not notice in sufficient time that traffic ahead has stopped (Baldock et al. 2005).
Poor attention to road and traffic when changing lanes

Related to the issue of poor division amongst driving tasks is poor attention to the road during lane changing manoeuvres. In this case, a driver may be aware of traffic conditions in their lane ahead, and of traffic behind them, in their intended new lane. However, drivers may not notice that traffic in the lane they are changing into is stationary or slow, resulting in rear-end crashes once they have begun the lane change (Baldock et al. 2005).

2.3.2 Medical Conditions

As well as driver distraction, cognitive impairment leading to rear-end crashes can be a result of medical conditions. Uc et al. (2006) highlighted Alzheimer’s disease as having a particular relationship with rear-end crashes.

The research involved a simulator study of drivers with mild Alzheimer’s disease against a control group of elderly drivers. Drivers were exposed to an unexpected stopped vehicle. Alzheimer’s affected drivers responded slower to the vehicle ahead. Eighty-five per cent of such drivers either collided into the vehicle or performed an unsafe evasive manoeuvre such as swerving or abrupt braking, compared against 65% of the control group (Uc et al. 2006).

There was a marginally higher rate of rear-end crashes amongst Alzheimer’s affected drivers (5% compared against 3%) (Uc et al. 2006).

Alzheimer’s affected drivers were found to be at greater risk of being struck from behind in their vehicles. Seventy per cent of such drivers braked abruptly, compared with 37% of the control group. Such braking increases the risk of being struck (Uc et al. 2006).

2.3.3 Influence of Alcohol

Drivers under the influence of alcohol are at significantly greater risk of striking another vehicle from behind than other drivers.

Even drivers with a legal alcohol use level (for Florida, USA, which is 0.08 units) were found to have a 9.6 times higher rear-end crash risk than those that had not been drinking. Such drivers were also found to be overrepresented as struck drivers in rear-end crashes, suggesting that their driving behaviour may contribute to the collision (Yan et al. 2005).

Rear-end crashes involving drivers under the influence of alcohol have a higher severity than other rear-end crashes, with a greater likelihood of injury to the driver of either vehicle. This includes drivers within the legal limit (Yan & Radwan 2006).

2.3.4 Age

Crash risk

Elderly (over the age of 75) and young drivers (under 26 years of age) are most likely to be the operator of a striking vehicle in a rear-end crash. The risk of being the striking driver is somewhat parabolic in nature, decreasing from the age of 26 until reaching a trough at the age of 56–65 years, and then increasing again (see Figure 2.1) (Yan et al. 2005).
In urban environments in the USA, rear-end crashes are one of the most common crash types for young drivers to be involved in. Young drivers are 2.4 times more likely to be involved in a rear-end crash than a collision with a fixed object (Neyens & Boyle 2007).

Younger drivers tend to keep a shorter headway than older drivers, resulting in a greater risk of striking another vehicle in the rear (see Section 2.2.3) (Taieb-Maimon & Shinar 2001). There are two hypotheses for this behaviour:

- Yan et al. (2005) suggested that young drivers may be more prone to high risk-taking behaviour and aggressiveness.
- Mitsopoulos-Rubens et al. (2007) found that poor gap selection in novice drivers may be more likely due to poorer spatial understanding of the road environment. This is based on a study of appropriate gap selection amongst novice drivers compared to more experienced drivers. The study found that novice drivers were more likely to keep a short headway, and also found it more difficult to maintain the gap during fluctuations in traffic.
- Whilst the findings of Mitsopoulos-Rubens et al. (2007) were focused on driver experience rather than age, young drivers are generally less experienced than older drivers, and the findings should be just as applicable to this group.

Elderly drivers are considered to be at greater risk of being the striking driver in rear-end crashes due to physical and cognitive impairments that delay their response times (Yan et al. 2005).

Middle-aged drivers are considered to be at least risk, as this age group is associated with lower following speeds and lower aggressiveness (Yan et al. 2005).

**Crash severity**

As may be expected, elderly drivers are more at risk of sustaining spinal cord injuries in rear-end crashes that may lead to paralysis. Such injuries can occur even in low-speed impacts that would not result in injury in younger occupants (Viano 2008).
2.3.5 Gender

Males have a 19% higher risk of being the striking driver in a rear-end crash than females (Yan et al. 2005).

Chapline et al. (2000) reports that females suffer more severe neck injuries after rear-end crashes than males.

2.3.6 Restraint Usage

The wearing of a seatbelt helps minimise the severity of a rear-end collision by preventing occupant ejection and contact with unyielding parts of the vehicle interior that could otherwise result in a higher severity outcome. Seatbelts have been found to reduce the risk of fatalities for occupants of cars struck from behind by 56%, and by 81% for occupants of light trucks struck from behind (Kahane 2000).

2.4 Vehicle-based Crash Contributory Factors

2.4.1 Vehicle Type

Struck vehicle

Light trucks, including 4WDs, utilities and vans are more likely to be struck by a following vehicle (equating to an 18% higher risk of being struck than in a passenger car) (Yan et al. 2005). This is likely due to the striking driver’s restricted visibility of traffic ahead, preventing the driver from anticipating the actions of the lead vehicle by also viewing those ahead (Wang & Abdel-Aty 2006).

Sayer et al. (2000) found that passenger cars tended to keep a shorter headway when following light trucks (by an average of 5.6 m) at the same vehicle speeds. Thus, rather than keeping a larger headway to compensate for decreased visibility, drivers keep a shorter headway, further compromising their ability to respond in time to changes in traffic ahead.

Larger, heavier vehicles are less likely to be struck and have a 28% lower risk of being struck than passenger cars. Heavy vehicles come to a stop slowly over a longer distance and are more visible, accounting for their lower rate of being struck. Also, heavy vehicles are less likely to be trailed by aggressive drivers at greater risk of being involved in rear-end crashes, as such drivers are more likely to overtake heavy vehicles (Yan et al. 2005).

Striking vehicle

Larger vehicles are more likely to be the striking vehicle in a rear-end crash, with a 25% higher striking rate than passenger cars (Yan et al. 2005).

Larger vehicles have a higher mass and momentum, requiring the vehicle to take a longer time to stop. Therefore, larger vehicles are less able to respond to changes in traffic ahead, resulting in their high representation as striking vehicles in rear-end crashes (Yan et al. 2005).

Also, as larger vehicles have a greater field of view to anticipate changes in traffic ahead, drivers of these vehicles are more inclined to keep a shorter headway. With their higher vantage point and shorter headway, drivers of larger vehicles are less likely to view the brake lights of the vehicle ahead of them, resulting in reduced reaction times to changes in the lead vehicle’s behaviour (Yan et al. 2005).
Vehicle incompatibility

When passenger cars and trucks have differing heights and geometries that allow parts of the car in a collision scenario to travel under, or ‘underrun’ the truck structure, this is known as ‘vehicle incompatibility’ (Lambert & Rechnitzer 2002).

Passenger cars striking trucks in rear-end crashes may result in severe injuries or fatalities due to rear underrun. This is where the bonnet of the car is able to pass under the rear of the truck, and the first point of contact with the truck is at the occupant compartment, which results in intrusion into the occupant’s survival space. This significantly reduces any buffer for protection between the vehicle occupants and the truck (Lambert & Rechnitzer 2002).

When a truck strikes a passenger car and is able to overrun the bumper bar of the car, the car’s ability to absorb energy of the crash is compromised. This increases the likelihood of intrusion into the occupant compartment, which would lead to severe injuries and fatalities. Further, such a collision typically puts pressure on the fuel tank of the car and may lead to ruptures, increasing the risk of fire (Lambert & Rechnitzer 2002).

Austroads (2013a) reported that while collisions between cars and 4WDs or light trucks generally show a greater severity than car-to-car collisions, this is most pronounced for rear-end crashes. The injury risk for rear-end crashes involving a car and 4WD or light truck is 73% higher than a car-to-car rear-end crash. This research did not separate out collisions in which the car or light truck was the striking vehicle individually.

Abdelwahab and Abdel-Aty (2004) found that whilst light trucks striking cars had a higher fatality rate than two-car rear-end crashes, the fatality rate amongst cars striking light trucks was marginally lower than the two-car rate.

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The most recent update to the Australian Design Rules includes Rule 84/00, which prescribes front underrun protection for most new vehicles manufactured since 2011. Rear underrun protection requirements were not introduced at the same time.

2.4.2 Struck vs Striking Vehicles

In rear-end crashes involving two cars, occupants of the struck vehicle are more likely to require hospital treatment than occupants of the striking vehicle. The most common reasons for hospital treatment were neck pain and headaches (Baldock et al. 2005). Khattak (2001) found that in two-vehicle rear-end crashes, the driver of the lead vehicle was injured in 31% of collisions compared to the driver of the striking vehicle, who was injured in 12% of collisions.

However, occupants in both striking and struck vehicles are just as likely to sustain life threatening injuries, often involving intrusion into the occupant compartment (Viano & Parenteau 2012).

In three vehicle collisions (i.e. involving a lead vehicle and two following vehicles), the driver of the second (first following) vehicle receives two impacts acting in opposite directions. Drivers of the second vehicle are more likely to be injured (38% of collisions) than drivers of the first or third vehicle (24% and 17% of collisions, respectively) (Khattak 2001).

2.4.3 Vehicle Seat and Head Restraint Combination

The severity of injuries sustained in rear-end crashes is influenced by seat and head restraint design. A seat with low stiffness will absorb some of the impact as the occupant’s torso moves into the seatback, reducing the loads. A head restraint positioned close to the head and neck prevents excessive head movement relative to the torso, minimising forces in the neck and the risk of injury. A strong seat frame will retain the head restraint position close to the occupant’s head, minimising head deflection that increases risk of injury (Viano 2008).
Where a vehicle’s head restraint height is set below the centre of gravity of an occupant’s head, the severity of neck injuries sustained increases. This is most noticeable for females (Chapline et al. 2000).

Shugg et al. (2011) conducted a field survey recording the location of the posterior of drivers’ heads relative to their restraints as they performed several driving tasks whilst travelling around residential, arterial and highway routes. The average head-to-restraint distance was found to be 78.1 mm, 42% higher than the NHTSA guidelines of 55 mm, leading to an elevated risk of whiplash injuries. The distance was found to be highest during turning manoeuvres, particularly turns with the flow (93.6 mm).

As mentioned in Section 2.1.3, rear-end crash severity is higher when the lead vehicle is in motion at the time of the crash, even though crash energy should be lower. This appears to be due to the position of the driver’s head when performing various driving tasks as opposed to when the vehicle is stationary.

2.5 Road Engineering Countermeasures

Austroads (2009a) listed potential road engineering countermeasures for rear-end collisions, which can be found in Appendix B.

Section 1.1 discussed a number of factors that can increase the risk or severity of rear-end crashes. The root attributes of many of these contributory factors can be summarised under the following categories:

- traffic speed differential, such as can be experienced at intersections with low speed or stationary vehicles preparing for turning manoeuvres (see Section 2.2.1)
- short headways, as discussed in Section 2.2.3
- traffic congestion, as discussed in Section 2.2.4
- driver inattention, as discussed in Section 2.3.1
- incorrect driver expectations, such as anticipation that a lead vehicle will proceed through a yellow phase at a signalised intersection (see Section 2.2.2).

The recognised crash countermeasures available to reduce the incidence of rear-end crashes aim to mitigate at least one of the key contributory factors to this crash type.

2.5.1 General Intersection Treatments

Improved awareness of intersections

Rear-end crashes may occur when a driver is not anticipating an intersection or pedestrian crossing (Antonucci et al. 2004).

The first step needed to raise awareness of an intersection is to ensure that its layout, visibility and delineation is in accordance with the relevant standards, so as to meet driver expectations. Further options available to raise the awareness of an intersection’s presence, function and geometry include:

- Maintenance of signage and delineation to ensure visibility and legibility during day and night (Neuman et al. 2003).
- Improvements to the visibility of traffic signals, such as through the provision of mast-arm mounted supplementary signals. This treatment may reduce the rear-end crash rate by 30–40% (Navin et al. 2000).
- Installation of supplementary signage or traffic signals at more visible locations, such as over the roadway. Secondary traffic signals can reduce the rear-end crash rate by 30–45% (Navin et al. 2000).
- Warnings via pavement markings, such as ‘STOP AHEAD’ (Neuman et al. 2003).
- ‘Intersection Ahead’ warning signs (Neuman et al. 2003).
• Improvements to street lighting at intersections. This can reduce the rear-end crash rate by 20–30% (Navin et al. 2000).

• Improvements to the horizontal or vertical alignment of the approach (i.e. straightening or levelling the roadway). This can reduce the rear-end crash rate by 30–45% for the former, or 40–50% for the latter (Navin et al. 2000).

• Rumble strips on approach. These have been found to more than halve the rate of rear-end crashes (Neuman et al. 2003).

• Improvements to lighting and signage at pedestrian crossings. This may reduce the rear-end crash rate by 10–20% (Navin et al. 2000).

**Modify poor alignment of through traffic**

The presence of poorly aligned through lanes at an intersection can be at odds with driver expectations. This in turn may lead to sudden and erratic behaviour, such as braking and swerving, with the risk of rear-end crashes occurring. Improving the alignment of an intersection can therefore reduce the incidence of rear-end crashes (Antonucci et al. 2004).

**Lane assignment**

Neuman et al. (2003) suggested providing lane assignment signs and line markings to remove driver confusion, so reducing unnecessary lane changes and erratic driver behaviour, hence lowering the risk of rear-end crashes.

**Conversion of intersection to a roundabout**

Roundabouts have a lower incidence of rear-end crashes than signalised intersections, and so their provision may be a viable option to address a high rear-end crash rate at some locations. Roundabouts also force drivers to reduce their travel speed, thereby reducing the severity of any crashes that may occur (Antonucci et al. 2004).

Nambisan and Parimi (2007) compared the crash occurrence at intersections with, and without, roundabouts. The number of crashes and injury crashes of any type was lower at roundabouts than intersections. Moreover, the proportion of crashes occurring at roundabouts that were rear-end crashes was lower than that at other intersections (9% for the former, compared against 25% for the latter).

**Vehicle-activated signs**

Vehicle-activated signs can be used to detect and warn drivers that their vehicle is approaching an intersection and/or at too high a speed. Such signs can encourage a driver to both reduce their travel speed and improve their reaction time on the approach to an intersection (van Eysden 2012).

**2.5.2 Turning Treatments**

As previously identified, turning movements present a particular risk for rear-end crashes as they introduce a significant speed differential on the road between through traffic maintaining their speed, and vehicles preparing to turn that are either decelerating, slow-moving, or stationary (Baldock et al. 2005).

A number of engineering options are available to address this issue.
Exclusive turn lanes

Vehicles preparing to turn are slower moving than through traffic as they need to decelerate, travel slowly toward the intersection, and sometimes wait at the intersection before commencing their turn (either to receive a green arrow, or for opposing or adjacent traffic to present a gap). By introducing exclusive turn lanes, this slower moving traffic is physically separated from faster moving through traffic, thus reducing the risk of a rear-end crash arising from the conflicting travel speeds (Antonucci et al. 2004, Li & Tarko 2011, Neuman et al. 2003).

Figure 2.2 shows an example of an intersection featuring exclusive left- and right-turn lanes.

Li and Tarko (2011) reported that providing left-turn lanes can be particularly beneficial, and can reduce rear-end crashes by 95%.

Navin et al. (2000) indicated that exclusive turn lanes can reduce rear-end crashes by 20–40%.

Wang and Abdel-Aty (2006) indicated that exclusive left-turn lanes could reduce the rate of rear-end crashes by 31%. Protected right-turn lanes on the major road of an intersection can reduce rear-end crashes by 18%. However, it should be noted that protected right-turn lanes on the minor roadway could lead to an increase of 24%.

The report suggests that this contradiction is due to the relationship between protected turn lanes and the number of phases in a traffic signal cycle. The number of phases in a signal cycle is related to the number of approaches with protected right-turn lanes. As a higher number of phases in a cycle leads to an increased risk of rear-end crashes (see Section 2.2.2), the benefit of protecting turn lanes appears to only outweigh the cost on a major road, where turn demand would be higher.

Shielded acceleration lanes

Acceleration lanes at intersections allow vehicles to reach the operating speed before joining the main traffic lanes. This reduces the potential differential in speeds, driving down the risk of rear-end crashes (Neuman et al. 2003). Such a treatment could lead to a 50–80% drop in rear-end crashes at the site (Navin et al. 2000).

Figure 2.2 shows an example of an intersection featuring a shielded acceleration lane.

Figure 2.2:  Intersection featuring exclusive left- and right-turn lanes (arrowed red), and a shielded acceleration lane (arrowed yellow) for traffic turning left onto the major road

Source: Google Earth 2013, ‘New South Wales’, map data, Google, California, USA.
Turn lane length

Turn lanes that are of an insufficient length can lead to vehicles decelerating in through lanes to avoid vehicle queuing that exceeds the provided storage capacity. It may be necessary to lengthen turn lanes to better suit the demands of the intersection. Turn lane lengths can be determined by considering the appropriate taper, deceleration and storage lengths (Antonucci et al. 2004, Neuman et al. 2003).

Bypass lane

Neuman et al. (2003) suggested providing a bypass lane in the shoulder of the through road at a T-intersection (see Figure 2.3). This allows through traffic to bypass right-turning traffic, and essentially converts the original lane into a right-turn lane. This is a cheaper alternative to introducing turn lanes, when sufficient land is available.

Figure 2.3: Example of bypass lane in shoulder (arrowed)

Source: Google Earth 2013, 'New South Wales', map data, Google, California, USA.

Relocate or prohibit turning movements

An obvious solution to any increase in rear-end crashes related to the presence of turning traffic would be to relocate or prohibit the turn movement (Baldock et al. 2005).

Turn movements can be prohibited through the use of signage or physical barriers, such as raised medians to prevent right-turn movements (see Figure 2.4). When prohibiting a turn movement, consideration should be given to where a turn movement is now possible and how this will be achieved (Antonucci et al. 2004).

Relocated turns should be located to have a sufficient level of service to be able to accommodate the increased traffic without leading to a significant rise in congestion. A rise in congestion will result in an increase in rear-end crashes at this point, and will result in a relocation of this crash type, instead of an appropriate treatment (Antonucci et al. 2004).
Figure 2.4: Raised medians and barriers can be used to stop right-turns at inappropriate locations

Source: Google StreetView 2013, ‘New South Wales’, map data, Google, California, USA.

Redesign turn

There may be benefit in redesigning an intersection so as to improve the flow of turning traffic. For example, an intersection could be upgraded into a grade separated crossing with on- and off-ramps providing access to the adjacent roadways. Alternatively, right-turns at the intersection could be banned, but median U-turn crossings provided upstream to allow drivers to enter an adjacent street from the opposite direction (see Figure 2.5).

Figure 2.5: Medians and U-turn crossovers can be used to prevent traffic making right-turns and to provide safer detours via the U-turn crossover

Source: Google Earth 2013, ‘New South Wales’, map data, Google, California, USA.
Median turning lanes

Median turning lanes provide one lane in the centre of the carriageway in which traffic travelling in both directions may wait to turn right. This option allows for turning traffic to be removed from the primary travel lane at minimal cost (Noyce et al. 2006). Figure 2.6 shows a typical layout for median turning lanes.

When space allows, median turning lanes may be established by repainting the road without the need for resurfacing. For instance, the Minnesota Department of Transportation converted four lanes of traffic on a road into three lanes of through traffic, with one lane a two-way right-turn lane (Noyce et al. 2006).

Figure 2.6: Typical layout of median turning lane and median turning lane advisory sign (inset)

A trial at 154 sites across four US states found that introducing median turning lanes led to a 38.7% reduction in rear-end crashes. This is primarily a rural treatment option, as the benefits in urban environments were negligible. In rural environments, the decrease in rear-end crashes ranged from 16.7% to 51.2% (Lyon et al. 2008).

The New Zealand Transport Agency (NZTA 2013) uses flush medians, which may be used as median turn lanes for both side streets and driveways. Flush medians also provide a refuge for pedestrians and vehicles turning out of side streets and driveways. These have been found to reduce rear-end crashes by 66%.

Slip lanes

Slip lanes allow left-turning traffic to be dissipated faster, thus reducing traffic queues that contribute to rear-end crashes (Baldock et al. 2005). Wang and Abdel-Aty (2006) indicated that this treatment could reduce the incidence of rear-end crashes by 69%.

Care should be taken when introducing slip lanes. Turner (2013) reports that such a treatment, whilst effective at large signalised intersections, can lead to an increase in rear-end crashes at smaller intersections.

Angle of turn

Increasing the angle of entry for left-turning traffic into the adjoining road allows for improved visibility of traffic. This in turn aids appropriate gap selection, to assist in reducing left-turning traffic queues contributing to rear-end crashes (Baldock et al. 2005).
2.5.3 Signalised Intersection Treatments

Signal co-ordination

Co-ordination of signals along a route can reduce the frequency of stops (sometimes known as the creation of a ‘green wave’), and allows vehicles to travel in a platoon. This reduces speed differentials along the route, reducing the risk of rear-end crashes (Antonucci et al. 2004, Wang & Abdel-Aty 2006).

Poch and Mannering (1996) found that signal co-ordination led to a decrease in rear-end crashes in the CBD compared with metropolitan streets, where an increase would otherwise have been expected.

Removal of signals

Rear-end crashes are particularly common at signalised intersections. There may be justification to remove traffic signals at certain sites, to drive down the incidence of rear-end crashes. However, this may lead to an increase in other, potentially more severe crash types, such as right angle (side impact) crashes. Antonucci et al. (2004) suggested having a 90 day trial period in which the lights are left either covered or flashing yellow to both assess the effectiveness of the treatment and draw motorists’ attention to the changed conditions.

Removal of traffic signals also reduces the density of traffic signals along a route, which has been identified as being closely related to high rear-end crash risk (Wang & Abdel-Aty 2006) (see Section 2.2.2).

Turn arrow phasing

Signalising turn movements reduces rear-end crashes by removing conflict between lead and following drivers’ expectations about safe turning gaps (Antonucci et al. 2004).

When signalised turn arrow phases are already provided, increasing the phase length to ensure demand is accommodated can further reduce the rate of rear-end crashes (Ballock et al. 2005).

Cycle time

Longer yellow and all-red phases for signalised intersections can help to reduce sudden braking by drivers, leading to a drop in the incidence of rear-end crashes. However, care needs to be exercised to ensure that this treatment does not encourage more risk taking by drivers (Antonucci et al. 2004).

Longer cycle times reduce the frequency of fluctuations in traffic flow, and thus reduce the rear-end crash rate. Stevanovic et al. (2013) suggested that the maximum benefit in terms of crash reduction can be obtained when cycle time is at 180 s.

Use of combined red-light speed cameras

Combined red-light speed cameras reduce rear-end crashes over red-light cameras alone (see Section 2.2.2).

Whilst red-light cameras have been shown to lead to an increase in rear-end crashes, combined red-light speed cameras have been found to have no significant impact on the rear-end crash rate when introduced at previously unmonitored sites. Such cameras detect both red-light running and travelling over the speed limit (Budd et al. 2011).

It is believed that the improved speed limit compliance associated with the speed camera component acts to counteract the increase in rear-end crashes generally associated with red-light cameras (Budd et al. 2011). Such technology is useful to pre-empt any increase in rear-end crashes from introducing red-light cameras. Further, replacing existing red-light cameras with combined red-light speed cameras should reduce the rear-end crash rate.
2.5.4 Measures to Address Increased Risk at Work Zones

Rear-end crashes and crash fatalities are more prevalent at work zones (see Section 2.2.5) and so targeted measures at work zones may help to reduce the crash rate:

- Reduce vehicle exposure to work zones. This can be achieved by improving construction efficiency, diverting/detouring traffic away from the work zones, or scheduling work to low demand periods, such as during the night (Antonucci et al. 2005).

- Improve visibility of work zone and traffic controls. This can be achieved by providing advance notice of work zone activities, positioning advisory signs well ahead of approaches to roadworks, ensuring traffic signs are well maintained and visible under all conditions, and improving the visibility of personnel and construction vehicles (Antonucci et al. 2005).

- Improve driver compliance with signage and controls introduced. This can be achieved through visible enforcement via police patrol vehicles or visible variable speed limit cameras. Driver acceptance of signs will be improved when the signs and their positioning are standardised and the roadworks are visible throughout the work zone (Antonucci et al. 2005).

- If driver distraction at roadwork sites is a major or consistent issue, ‘anti-gawking’ screens shielding the public from viewing the roadworks progress could be an effective countermeasure (Raub et al. 2001). Whilst studies on the effectiveness of this measure are so far limited, the screens have been found to be effective in reducing delays, which should benefit the rear-end crash rate (Reid 2012). Such a screen in use is shown in Figure 2.7.

Figure 2.7: Screens can be used to block driver view of work zones or crash sites

Source: Reid (2012).
Congestion (end of queue) advisory system

Rear-end crashes can occur when drivers are unaware of stationary or slow moving traffic after a stretch of free flowing traffic. This could occur due to the site geometry, roadworks or a traffic incident. Where such slowing of traffic may be expected, such as at a roadworks site or where congestion is common, there is benefit to installing a congestion advisory system (National Transportation Safety Board (NTSB) 2001). Figure 2.8 shows a permanent congestion advisory system established at a location with common congestion issues.

Figure 2.8: Example of permanent congestion advisory sign

Care needs to be taken when installing such a system. The warning sign should be placed in a position that any queuing is unlikely to stretch beyond the sign. However, if the sign is placed too far ahead of queuing, the impact of the sign may be compromised before drivers reach the congestion (NTSB 2001).

Early merging

Meng and Weng (2011) identified that poor merging manoeuvres were a key factor contributing to rear-end crashes at work zones. They therefore suggested encouraging early merging ahead of the work zone in order to reduce the incidence of rear-end crashes at this high risk site.

2.5.5 Speed Management

Lower operating speeds provide drivers more time to decide on potential manoeuvres, such as turning down a side street or braking at an intersection. This may reduce the incidence of sudden, erratic behaviour, lowering the risk of rear-end crashes (Neuman et al. 2003).

Lower operating speeds can be achieved through:

- lower posted speed limits
- enforcement via appropriate patrols and speed cameras
- installation of traffic calming devices such as speed humps and road narrowing (Neuman et al. 2003).

Self-explaining roads, where the road design encourages drivers to travel at the speed limit, will also assist in ensuring appropriate operating speeds.

Speed limit enforcement has been found to be effective at improving vehicle headway times in work zones. Wang et al. (2011) looked at the effect on headway of a mobile speed enforcement van operating in a work zone. The study found that the presence of this van increased the headway provided by drivers of cars in the median lane and for trucks in the shoulder lane. There were benefits for the headway maintained by trucks in the median lane and for cars in the shoulder lane, however these findings were not statistically significant.

Point-to-point speed enforcement tracks a vehicle’s movements along a stretch of road and derives an average vehicle travel speed based on the time taken for the vehicle to travel between at least two points. This system has been found to improve vehicle headway and speed variability compared against traditional speed cameras. Traffic around speed cameras generally involves braking prior to the speed camera site and accelerating after passing this specific point. By tracking vehicle speed beyond one specific point, point-to-point enforcement eliminates this behaviour (Austroads 2012).

Combined red-light speed cameras seem to have addressed the increase in rear-end crashes at signalised intersections found with red-light cameras alone (see Section 2.2.2). The conversion of red-light cameras to red-light speed cameras was found to reduce rear-end crashes by 20%, and had an overall positive benefit on other crash types as well (Chen et al. 2012).

### 2.5.6 Treatments for Tailgating

**Advisory signs**

An option for reducing tailgating at a particular location would be to provide advisory signs reminding drivers not to tailgate.

Michael et al. (2000) reported on a study of two possible signs to reduce tailgating. The first sign stated ‘Please don’t tailgate’, whilst the second sign stated ‘Help prevent crashes, please don’t tailgate’. The effectiveness of both signs was tested on urban streets.

The first sign led to no significant change in headway distance, whilst the second resulted in a 16% increase in those keeping a two second gap, and a 59% drop in those travelling less than one second from the vehicle ahead (Michael et al. 2000).

This indicates that whilst signs may be effective, the wording on them needs to alert drivers to the consequences. Michael et al. (2000), however, warned the reader that even the effective sign may not be effective in the long-term, as drivers become acclimatised to the sign without experiencing any negative feedback from tailgating (i.e. actual crashes).

**Vehicle-activated signs**

Helliar-Symons & Ray (1986) reported on a field trial of vehicle activated warning signs to target tailgating. These signs were activated when detecting headways below 1.6 s. At this point, a warning saying either ‘following too closely’ or ‘too close move apart’ would be activated. The study found that these signs led to an approximately one-third reduction in drivers travelling under one second behind the next vehicle.

Such a measure was supported by Young and Regan (2007) as a potential countermeasure to reduce tailgating.
Headway distance markings

A number of trials have been conducted of headway guidance markers on the roadway. Such a system features markers at regular intervals (see Figure 2.9), and drivers are expected to keep a two marker distance from the vehicle ahead when travelling at the speed limit. A chevron marking trial has been commissioned in Queensland (Eveleigh 2010) and the RAC (2014) is campaigning for a similar trial to be conducted in Western Australia.

The chevron marking trial in Queensland found 8% less vehicles travelling with a headway less than 1.0 seconds after installation. However, the benefits were primarily at the site of the chevron markings themselves, with little residual effect downstream. The report on the trial did not document any changes in rear-end or other crash rates at the site (Eveleigh 2010).

Figure 2.9: Possible headway distance marker options, with chevron markings to the left and bar markers to the right

In the UK, chevron markings were installed on two different sections of the M1 motorway at 40 m distances, and signs were installed advising drivers to ‘Keep apart, 2 chevrons’. As the speed limit was 70 mph (113 km/h), this distance amounted to a two second gap (Helliar-Symons & Butler 1995).

The trial found that there was a 40% decrease in multi-vehicle collisions, most of which would have involved rear-end crashes. This benefit lasted until the second motorway junction after the treatment, 18 km away, by which point there would have been significant mixing with vehicles that were not exposed to the treatment (Helliar-Symons & Butler 1995).

Despite the success of the UK trial, a similar trial conducted in Victoria, Australia found only marginal benefits from the chevron markers during daylight hours. During the trial, drivers indicated that they found the chevron markings to be hypnotic in nature, and a distraction to their driving (Fenner & Broekman 1999).

Komonews (2006) referred to a similar program conducted by Washington State Department of Transportation (WSDot), in which dots were painted 80 feet (24 m) apart, and drivers were asked to keep a two dot gap between them in a 60 mph (97 km/h) speed zone. This amounts to approximately a two-second headway. On the second day of the program, long backups were experienced as traffic speeds had slowed, yet drivers maintained the same headway distance and the project was cancelled.

A similar system was implemented by the Minnesota Department of Transportation (MDoT), where dots were spaced 225 feet (66 m) apart in a 55 mph (89 km/h) speed zone. Motorists were directed to keep two dots between them, amounting to a three second gap. The project proved effective, with an increase in headway gap of 0.22 s from an initial average gap of 2.35 s. The road targeted did not have any prior congestion problems, which may have assisted in the program not experiencing the same issues as the WSDot program (Minnesota Department of Transportation 2006).

Song and Wang (2010) conducted a survey to determine driver preference for headway distance markers. The majority preferred painted horizontal bars on the road with dynamic messages explaining the system.
Headway enforcement

There is difficulty in enforcing headways as the guidance provided by Australian Road Rules is unquantified. Only a distance for which a driver can avoid a collision is required. The various jurisdictions provide guidance for drivers to keep a distance ranging from two to three seconds from the vehicle ahead, depending on the jurisdiction. Internationally, an acceptable safe headway can be as low as one second (Hutchinson 2008).

In order to enforce a safe headway distance, the critical headway distance for which a penalty would be enforced would need to be quantified. Internationally, this distance ranges from 0.5–1.0 s. The concern is that mandating the accepted 2–3 s headway would be impractical and result in too many penalties for the system to be accepted by the public. However, enforcing too low a headway gap may suggest that any headway higher than this is considered safe and result in driver complacency (Hutchinson 2008).

One of the earliest headway enforcement systems, called ‘Marom’, was developed in Israel. The system detects breaks in reflected beams to determine the speed and headway gap of vehicles passing. During an initial six month trial period of Marom, including a publicity campaign, there was a 40–45% drop in collisions (McManus 1996). The technology has been used in the Netherlands, Sweden and Israel, and similar technology is being developed in the UK (McManus 1996, Young & Regan 2007).

Victoria has trialled a handheld device that can measure the distance between two moving vehicles to monitor headway (Young & Regan 2007) and have begun investigating using hand-held cameras to detect tailgating on a long-term basis (Mulder 2013).

2.5.7 Treatments for Congestion

Congestion is a prime contributing factor to rear-end crash rates (see Section 2.2.4) and a number of options are available to address congestion in order to reduce the risk of such crashes.

Variable speed sign systems

Variable speed sign systems can be installed along motorways to lower speeds during periods of congestion. Loop detectors detect periods of high demand, when the risk of a flow breakdown or collision is higher. Once demand reaches a certain threshold, variable speed signs reduce the speed limit. This assists in distributing traffic over the available road space, improving capacity and smoothing traffic flow (Abdel-Aty et al. 2008, Highways Agency 2006).

As traffic flow disruptions are minimised, the risk of rear-end collisions is also reduced. Abdel-Aty et al. (2008) reported that this treatment was effective at reducing both rear-end and lane-change crash risks. The most effective treatment was reducing speed limits by 5 mph (8 km/h) upstream and by increasing them by 5 mph (8 km/h) downstream.

Automatic incident detection systems

Automatic incident detection systems detect very slow moving or stationary traffic, on otherwise high speed roads such as motorways and toll roads. Such disturbances in traffic would be indicative of a breakdown or collision. The system provides warnings to approaching drivers and reduces speed limits in the area. By reducing approaching vehicle speeds and providing warnings, the system aims to prevent queued vehicles from being struck from behind (Highways Agency 2006).

Convert two-way roads to one-way

Antonucci et al. (2004) suggested that converting a pair of two-way roads into a pair of one-way roads (one running in each direction) should ‘smooth’ the stream of traffic and reduce congestion, thus reducing the incidence of rear-end crashes.
Remove on-street parking

On-street parking disrupts the flow of traffic as drivers move into and out of parking spaces. Further, on-street parking may impede visibility, preventing a driver from anticipating changes in traffic conditions ahead, and may increase merging manoeuvres as drivers try to avoid vehicles pulling into or out of a space. This all increases the drivers’ cognitive workload, and disrupts the flow of traffic, resulting in an increased risk of rear-end crashes. Restricting parking at high risk locations may help to reduce the incidence of this crash type by 20–30% (Antonucci et al. 2004, Navin et al. 2000).

2.5.8 Improved Skid Resistance

Inattentive drivers are at risk of rear-end crashes when they fail to notice stopped or decelerating traffic ahead early enough. Providing an improved level of skid resistance on the roadway helps all road users, but in particular, allows these drivers to brake harder, improving their chances of avoiding a collision (Baldock et al. 2005).

Navin et al. (2000) reported that treating for skid resistance can reduce the rear-end crash rate by 30–40%. The effectiveness can be as high as 30–60% when treating on a steep gradient.

It should be noted that providing drivers with the ability to brake harder to avoid a rear-end crash may simply transfer the impact to different vehicles. Davis and Swenson (2006) observed that rear-end crashes often began with an otherwise uninvolved vehicle braking hard downstream in order to avoid a collision. With a steady stream of traffic, this hard braking has a flow-on effect, with following vehicles required to brake just as heavily. When one of the following vehicles has perception and reaction time larger than their headway allows for, even maximum braking may be insufficient to avoid a rear-end crash.

2.5.9 Improved Driveway Delineation

Retting et al. (1997) reported on a trial to highlight vehicle demand for left-turns into commercial activity centres at midblock locations. Pavement markers were installed downstream of these mid-block locations. The markers used were standard left-turn and through lane arrow pavement markings normally used at intersections to designate vehicle movements.

Three of the four sites demonstrated a 5–6% decrease in potential conflicts. However, one site with complex geometry experienced a 9% increase in potential conflict, where it is believed drivers misunderstood the message of the pavement markers (Retting et al. 1997).

Collisions decreased at three of the sites by an average of 41%. However, at the site with complex geometry, there was a 210% increase in collisions (Retting et al. 1997).

Warning signs highlighting the presence of driveways could also achieve similar benefits in addressing rear-end crashes.

2.6 Vehicle-based Countermeasures

Section 2.5 discussed road engineering and traffic management treatments that can be used to reduce the incidence and severity of rear-end crashes. Recent advances in automotive technology such as ITS and better vehicle design as showcased briefly in this section, also show potential for addressing this crash type and may complement the road environment-based treatments. Whilst these systems provide obvious potential, robust evaluation will be needed once the technology is widespread enough to collect sufficient on-road data.
2.6.1 Forward Collision Avoidance and Warning Systems

There are a range of options on the market to address forward collisions. This technology uses sensors to detect vehicles ahead. The prime systems are:

- **Forward Collision Warning System (FCWS)** which provides an advisory warning to alert the driver to take evasive action. The alert may be visual, audible, haptic or a combination. Some systems may prime the brakes to ensure that full braking is effective once triggered.

- **Forward Collision Avoidance Technology (FCAT)**, which automatically attempts to avoid the collision, generally through emergency braking (Anderson et al. 2012).

FCWSs have been found to be less effective at preventing collisions. The warnings generally come on too late, and drivers fail to brake sufficiently to avoid a collision. Muhrer et al. (2012) conducted a simulator based study which found that FCAT acted to prevent all simulated collisions that the FCWS failed to prevent.

Despite its limitations in avoiding crashes once the event becomes critical, FCWS may still help to reduce crashes by encouraging drivers to keep a greater headway, reducing the incidence of critical events. Zhang et al. (2007) reported that FCWS installed on buses led to drivers keeping a larger headway from the vehicle ahead.

Depending on the type of system used, FCAT can reduce the incidence of rear-end injury collisions by 39–80% in 50–60 km/h areas, by 54–100% in 70–90 km/h areas, and by 79–100% in 100–110 km/h areas. The most effective system was one that has long range sensors and applies a high emergency braking force (Anderson et al. 2012).

A more moderate estimate suggests that a combined FCAT system should reduce the striking speed differential by 34%, prevent 7.7% of rear-end crashes, and halve the number of moderately to fatally injured drivers (Kusano & Gabler 2011).

Heavy vehicles featuring a forward collision warning system have been found to keep a 4.6 m larger headway. The rear-end crash risk for such vehicles is at least 21% lower than heavy vehicles not equipped with such a system, and could be even lower, depending on the warning system used (Rakha et al. 2010).

According to research by Kusano and Gabler (2010), autonomous emergency braking (AEB) in a forward collision avoidance system could avoid up to 14% of rear-end crashes and reduce the incidence of injury in drivers of striking vehicles by between 19% and 57%. More recent research (Roadsafe 2013) suggests that AEB could avoid at least one quarter of rear-end crashes, suggesting an even higher reduction in injuries.

2.6.2 Adaptive Cruise Control

Adaptive Cruise Control uses similar technology to forward collision avoidance systems. When set to cruise mode, sensors in the vehicle monitor the speed of the vehicle ahead. The system will decide whether to maintain the pre-set cruise speed or whether to reduce the speed in order to maintain a safe headway. Once safe to do so, the system will return to the pre-set cruise speed (Anderson et al. 2011).

Whilst marketed as a consumer convenience, the potential benefits to road safety are obvious as the system ensures that vehicles slow when the vehicle ahead slows, and maintains a safe headway (NTSB 2001).

Some systems will only slow vehicles to within 25% of the posted speed limit, and will not apply maximum braking. Without drivers being aware of the capabilities of the system, they may not respond appropriately when traffic conditions are outside of the capabilities of the system (NTSB 2001).

This technology must be manually activated, and would generally only be effective in environments where cruising is to be expected, such as highways (Anderson et al. 2011).
2.6.3 Following Distance Warning

It is possible to introduce to vehicles a headway feedback device that alerts a driver when the headway falls below a critical headway distance. Shinar and Schechtman (2002) reported on such a device that produces a red-light warning when headway falls below 1.2 s and sounds a buzzer when headway falls below 0.8 s. The feedback device led to drivers travelling with a larger headway, reducing time spent in headways under 0.8 s by 25% and increasing time spent with a headway over 1.2 s by 20%. This was found to be effective in both urban and rural environments, as well as for varying driver age and gender.

Design of a headway feedback device should be carefully considered to factor in driver usability. Regan et al. (2005) reported that a group of drivers that trialled such a device found it gave too many unnecessary warnings, particularly when vehicles merged into their lane.

A visual display showing whether the vehicle headway falls in a safe, short, or dangerous range may be a potential option. McGehee et al. (1993) found that a visual headway display increased the average headway gap from 1.4 s to 2.7 s. Figure 2.10 below shows such a display, as developed by Mobileye (2007).

![Figure 2.10: Example of headway monitoring device](Source: Mobileye (2007)).

2.6.4 Rearward Headway Monitoring

Stone and Billingsley (1999) discussed the introduction of a rearward headway monitoring device. The report suggested that this may have a more widespread adoption, as it helps protect the user vehicle from impact, without requiring a change in driving performance. The device works similarly to a forward headway monitoring device, but would flash the brake or auxiliary brake lights to warn the driver following that the headway has fallen within the short-range (when necessary).

Without widespread adoption and understanding, there is the risk that such a system would not be understood by the following driver, and driver response may be difficult to predict.

2.6.5 Brake Assist

Brake assist utilises a sensor in the braking system to determine when the driver is applying braking that is heavier than normal. When this is detected, the system will apply maximum braking force to the vehicle in order to minimise stopping distance. This helps to avoid rear-end crashes or, when the collision is unavoidable, reduce the impact speed and therefore the severity (Anderson et al. 2011).
2.6.6 Enhanced Rear Signal Systems

A number of enhancements to brake lights have been considered to alert trailing drivers of heavy braking at critical times.

Lee et al. (2003) proposed an enhanced rear signal system to complement the current rear signal lighting. This system would feature three distinct lights. The central light is proposed as a high-level signal intended for activation during rapid deceleration or when a rear-end crash is imminent. It was proposed to use an incandescent traffic clearing lamp in an M-sweep pattern for this light (Lee et al. 2003). LED technology is now more readily available than at the time of the study, and has been demonstrated to be more effective (Wierwille et al. 2009).

The two signals to the sides are proposed to activate when the vehicle is stopped or slowly moving. These signals were proposed as high output halogen lamps, however LED lamps would likely be as effective (Lee et al. 2003).

A study commissioned by NHTSA compared a range of proposed enhanced brake lights using LED technology against incandescent TCL systems that had been previously proposed and proven effective. Flashing LED lights were found to be even more effective in gaining a following driver’s attention (Wierwille et al. 2009).

Llaneras et al. (2010) reported on a simulator based trial of a number of different options for enhanced braking signals. The most effective treatment considered was a brake configuration in which all brake lamps, including the centre high mounted lamps, flashed simultaneously at 5 Hz. This was found to reduce rear-end crash incidence by up to 5.1% and rear-end injuries by up to 10.1%.

The effectiveness varied based on the brightness of the lamps and the activation criteria. Higher illumination of the brake lamps improved the effectiveness. The system was most effective when activated at moderately heavy braking of 0.35 g. The effectiveness was compromised when a higher braking threshold was required, or when the system activation was based on a measure of time-to-collision (Llaneras et al. 2010).

The report highlighted that the effectiveness of the system may be compromised if drivers are exposed to too many false alarms, reducing their trust in the signal (Llaneras et al. 2010).

2.6.7 Improved Rear Visibility

Since December 1993, the trailers of heavy vehicles operating in the USA are required to feature reflective material around the sides and rear. This measure was extended to apply to all on-road trailers in June 2001. Generally, red-and-white retro-reflective tape has been used to meet the requirements. This measure was introduced to make these vehicles more visible to motorists during the dark. Without the tape, many trailers are not visible until the following vehicles are dangerously close (Morgan 2001).

This treatment was found to decrease both side and rear impacts, with the greatest benefit being a reduction in rear impacts. On average, the rate of rear impacts was reduced by 43%. The benefit was most pronounced in unlit night-time conditions, when there was a 51% reduction in rear-end crashes, compared with the 43% reduction for all night-time rear-end crashes (Morgan 2001).

For vehicles with well-maintained, clean retro-reflective tape, the reduction in night-time rear impacts was 53% (62% in unlit environments), compared with only 27% for dirty tape (33% in unlit environments) (Morgan 2001).

The introduction of tape had a particular benefit in reducing more severe crashes. The tape resulted in a 41% reduction in casualty crashes at night time, and a 68% reduction in night-time fatalities. In unlit night-time conditions, the results were even more significant (54% drop in casualty crashes and 71% drop in fatal crashes) (Morgan 2001).
The United Nations Economic Commission for Europe (UNECE) has worked towards harmonising requirements for retro-reflectivity on light trucks and heavy vehicles through UN Vehicle Regulation 104: Uniform Provisions Concerning the Approval of Retro-Reflective Marking for Vehicles of Category M, N and O.

2.6.8 Head-restraint/Seat Combination-based Mitigation

Head-restraint/seat combination design

Head restraints were originally designed to support the head during sudden acceleration, reducing the differential motion between the head and neck, so as to reduce the risk of whiplash injuries (see Section 2.1.4). Head restraints are most effective when generally positioned higher and closer to the head. Ideally positioned head restraints can reduce whiplash injury by 18%, and by 37% for females only (Farmer et al. 2003).

As noted in Section 2.4.3, head restraints are generally not well-positioned. Active head restraints have been developed to optimise positioning at the time of a crash. These respond during a rear-end crash to limit head movements, and have been found to reduce whiplash injury claims by 43%. Benefits are even higher amongst female drivers, with a 55% reduction in whiplash claims for this group (Farmer et al. 2003).

Head-restraint/seat combination assessments

The Insurance Institute for Highway Safety (IIHS) regularly conducts assessments of seat/head restraint combinations for their location relative to the head of an average-size man. Those that have good or acceptable geometry are then tested in a simulated rear impact to assess their protection in rear impacts. The dynamic testing considers the peak acceleration of the dummy’s torso, time from impact to head restraint contact, and tension and shear forces recorded acting on the dummy’s neck (IIHS 2004).

IIHS (2008) compared the real-world benefits of seat/head restraint combinations against the ratings provided by IIHS based on dynamic testing. Seat/head restraint combinations that received a ‘good’ rating from IIHS were associated with a 15% lower incidence of neck injury against those rated ‘poor’. The incidence of long-term neck injuries lasting over three months was even lower, at 35% less than those rated ‘poor’.

In Australia, the Australian New Car Assessment Program (ANCAP) began testing seat/head restraint combinations in 2012. The assessment features both a geometric assessment and a dynamic test of the seat/head restraint combination during a simulated rear-end crash. An ‘acceptable’ whiplash performance is required for five star rated vehicles. In 2014, this will be updated to require a ‘good’ performance, with four star rated vehicles requiring an ‘acceptable’ performance (ANCAP 2012).
3. Crash Data Analysis

An analysis of crash data was conducted for the five-year period 2006–10, across the Australian and New Zealand jurisdictions.

Considerations during data analysis

The crash data analysed in this project was not used to compare jurisdictions. This is due to a number of local variations in:

- exposure (due to factors such as population and size of the road network)
- the definitions of ‘urban’ which were used
- the level of exposure to various road environments (e.g. peak hour traffic or wet weather conditions).

As the various data sets used varied across jurisdictions, it was considered inappropriate to use raw crash numbers for most findings. Instead, most findings are presented as a proportion of crashes from the data set.

Some of the crash characteristics considered in the analysis have not been recorded by all jurisdictions. Where possible, categories of crash characteristics have been combined to allow greater inclusion of data. In other cases, the analysis did not include all jurisdictions.

Disaggregation based on road environment

To consider both urban and rural environments, crash data was disaggregated based on road environments.

Across jurisdictions, the crash data does not provide an urban or rural classification consistently. Also, the jurisdictional data does not provide road environment factors that can be applied across jurisdictions to define such environments in a consistent manner. To provide greater consistency in crash analysis, a protocol for defining rural and urban environments has been prepared by ARRB Group to be applied across a number of Austroads projects and reports. This can be found in Appendix C.

Disaggregation based on crash severity

Various jurisdictions have different methods for coding degree of severity of injury crashes. To reflect the Safe System approach, results have been separated according to minor injury (MI) crashes and fatal and serious injury (FSI) crashes.

At the time of writing, New South Wales does not have data indicating the degree of severity of injuries in crashes (of all types), making it difficult to disaggregate non-fatal crashes into minor and serious injury categories. To achieve a working estimate of this distinction, the NSW Centre for Road Safety has developed and applied a suite of local factors, according to crash type and speed environment. For example, for rear-end injury crashes in a 50 km/h environment, 8.9% would be attributed as serious injury crashes and the remainder as minor injury crashes. The research methodology used to derive these factors has not been reviewed as part of this project.

The local disaggregation of injury crashes by severity does not take into account all of the causation and contributory factors. For example, with respect to rear-end crashes, some of the factors considered in this research, such as vehicle size and road alignment, are not taken into account. The NSW Centre for Road Safety is conscious of this limitation, and is continually improving its protocols to ensure that ultimately more robust insights can be gained from the crash analysis process.
Considerations when interpreting crash data

When interpreting the crash data, it is important to recognise that exposure has not been considered. For instance, whilst the analysis will report on the number of crashes occurring in wet conditions, it will not report on the average exposure of drivers to wet conditions. It is therefore not possible to determine the relative contribution of wet versus dry conditions to crash occurrence. Whilst the number of fatal rear-end crashes is minimal compared to injury crashes, this information has been included to allow the reader to compare conditions that may exacerbate crash severity.

Also, when comparing graphs, the reader should be aware that the axes of the various graphs vary based on the scaling and display requirements of that graph.

Crash codes used to define rear-end crashes

Table 3.1 provides a breakdown of the crash codes used to define rear-end crashes across the jurisdictions considered.

Table 3.1: Breakdown of crash codes used across jurisdictions

<table>
<thead>
<tr>
<th>Crash Description</th>
<th>NSW</th>
<th>Vic/Tas</th>
<th>QLD</th>
<th>WA</th>
<th>SA</th>
<th>NT</th>
<th>ACT</th>
<th>NZ</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rear-end into straight travelling vehicle</td>
<td>30</td>
<td>130</td>
<td>301/310</td>
<td>31</td>
<td>30</td>
<td></td>
<td></td>
<td>FA (Rear-end: Slower vehicle)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>FB (Rear-end: Cross traffic)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>FC (Rear-end: Pedestrian)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>FD (Rear-end: Queue)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>FE (Rear-end: Signals)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>FF/FO (Rear-end: Other)</td>
</tr>
<tr>
<td>Rear-end into left-turning vehicle</td>
<td>31</td>
<td>131</td>
<td>302</td>
<td>32</td>
<td>31</td>
<td>302</td>
<td></td>
<td>GA (Rear of left-turning vehicle)</td>
</tr>
<tr>
<td>Rear-end into right-turning vehicle</td>
<td>32</td>
<td>132</td>
<td>303</td>
<td>33</td>
<td>32</td>
<td>303</td>
<td></td>
<td>GD (Near centre line)</td>
</tr>
<tr>
<td>Rear-end when pulling out</td>
<td>55</td>
<td>154</td>
<td>505</td>
<td>55</td>
<td>55</td>
<td>505</td>
<td>–</td>
<td></td>
</tr>
<tr>
<td>Collision into parked vehicle in path</td>
<td>60</td>
<td>160</td>
<td>601</td>
<td>61</td>
<td>60</td>
<td>601</td>
<td></td>
<td>EA (Collision with parked vehicle)</td>
</tr>
<tr>
<td>Collision into double parked vehicle in path</td>
<td>61</td>
<td>161</td>
<td>602</td>
<td>62</td>
<td>61</td>
<td>602</td>
<td></td>
<td>ED (Collision with workman’s vehicle)</td>
</tr>
<tr>
<td>Collision into accident or broken down vehicle in path</td>
<td>62</td>
<td>162</td>
<td>608</td>
<td>63</td>
<td>62</td>
<td>603</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
3.1 Overview

3.1.1 Average Annual Rear-end Casualty Crashes by Jurisdictions

Figure 3.1 and Figure 3.2 show a breakdown of the average annual rear-end casualty crash count across the jurisdictions for a five year period (2006–10 inclusive).

Urban

For urban rear-end crashes:

- Australia had an annual average of 2055.1 FSI crashes (2024.7 SI and 30.4 fatal). This equates to 39.4 FSI crashes per week.
- New Zealand had an annual average of 79.6 FSI crashes (76.4 SI and 3.2 fatal), i.e. 1.5 FSI casualty crashes per week.

![Figure 3.1: Average annual number of urban rear-end casualty crashes for each jurisdiction by severity (2006–10 inclusive)](image)

Rural

For rural rear-end crashes:

- Australia had an annual average of 394.6 FSI crashes (368.6 SI and 26 fatal), i.e. 7.6 FSI crashes per week.
- New Zealand had an annual average of 63 FSI crashes (53.8 SI and 9.2 fatal), i.e. 1.2 FSI crashes per week.
3.1.2 Rear-end Crash Severity by Road Environment

Whilst Section 3.1.1 reported that rear-end crashes were more common in urban environments, Figure 3.3 shows that rear-end collisions were likely to have more severe outcomes in rural environments:

- In Australia, rear-end casualty crashes were 2.5 times as likely to result in a serious injury (SI), and 8.5 times as likely to result in a fatality in rural environments, compared to urban environments.

- In New Zealand, rear-end casualty crashes were 1.4 times as likely to result in a serious injury (SI), and 5.3 times as likely to result in a fatality in rural environments, compared to urban environments.

This is consistent with the findings of the literature that rear-end collisions are more common in urban environments (see Section 2.1.2). In addition to the findings of the literature, this result indicates that rear-end crashes result in more severe outcomes in rural environments.

Figure 3.3: Breakdown of rear-end casualty crashes by severity, based on road environment (2006–10 inclusive)
3.1.3 Rear-end Crash Trends over Study Period

Figure 3.4 and Figure 3.5 show the proportion of fatal and SI crashes that were rear-end collisions by year, for urban and rural environments, respectively.

There has been a noticeable decrease in the proportion of fatal crashes that were rear-end collisions in urban environments in New Zealand. There does not appear to have been any significant changes outside of normal fluctuations for fatal rear-end crashes in any other environment, or for SI crashes in any environment considered.

**Urban**

Figure 3.4: Proportion of urban rear-end SI and fatal crashes to total urban SI and fatal crashes by year

<table>
<thead>
<tr>
<th>Year</th>
<th>SI</th>
<th>Fatal</th>
</tr>
</thead>
<tbody>
<tr>
<td>2006</td>
<td>16.4%</td>
<td>4.1%</td>
</tr>
<tr>
<td>2007</td>
<td>15.5%</td>
<td>6.6%</td>
</tr>
<tr>
<td>2008</td>
<td>15.8%</td>
<td>5.3%</td>
</tr>
<tr>
<td>2009</td>
<td>15.5%</td>
<td>5.2%</td>
</tr>
<tr>
<td>2010</td>
<td>15.9%</td>
<td>4.5%</td>
</tr>
</tbody>
</table>

**Rural**

Figure 3.5: Proportion of rural rear-end injury and fatal crashes to total rural SI and fatal crashes by year

<table>
<thead>
<tr>
<th>Year</th>
<th>SI</th>
<th>Fatal</th>
</tr>
</thead>
<tbody>
<tr>
<td>2006</td>
<td>7.6%</td>
<td>0.9%</td>
</tr>
<tr>
<td>2007</td>
<td>7.4%</td>
<td>1.0%</td>
</tr>
<tr>
<td>2008</td>
<td>7.5%</td>
<td>0.6%</td>
</tr>
<tr>
<td>2009</td>
<td>6.8%</td>
<td>1.1%</td>
</tr>
<tr>
<td>2010</td>
<td>8.5%</td>
<td>1.2%</td>
</tr>
</tbody>
</table>
3.1.4 Breakdown of Rear-end Casualty Crash Types

Australia

For both urban and rural rear-end casualty crashes in Australia between 2006 and 2010, rear-end crashes into vehicles travelling straight were the most common, followed by rear impacts with turning vehicles.

Rear-end collisions after pulling out (e.g. from an intersection), and collisions into parked vehicles or vehicles stopped in the roadway (e.g. through an incident or mechanical breakdown), were over-represented in the breakdown of FSI crashes, suggesting that these collisions result in a higher degree of severity (Figure 3.6 and Figure 3.7).

Figure 3.6: Breakdown of rear-end casualty crashes (on left) and rear-end FSI crashes (on right) in Australian urban environments (2006–10 inclusive)
Figure 3.7: Breakdown of rear-end casualty crashes (on left) and rear-end FSI crashes (on right) in Australian rural environments (2006–10 inclusive)

New Zealand

For urban rear-end casualty crashes in New Zealand between 2006 and 2010, rear-end crashes into queuing vehicles was most prominent, followed by rear-end crashes into parked or right-turning vehicles (Figure 3.8). The trend was similar in rural environments. However, rear-end collisions into slower vehicles was more prominent, and collisions with parked vehicles less so (Figure 3.9).

Considering FSI crashes, rear-end collisions into right-turning or slower vehicles, or collisions into parked vehicles were over-represented in both urban and rural environments. This suggests that these collisions result in a higher degree of severity.
Figure 3.8: Breakdown of rear-end casualty crashes (on left) and rear-end FSI crashes (on right) in New Zealand urban environments (2006–10 inclusive)

Figure 3.9: Breakdown of rear-end casualty crashes (on left) and rear-end FSI crashes (on right) in New Zealand rural environments (2006–10 inclusive)
3.2 Timing and Environmental factors

3.2.1 Day-of-week

Figure 3.10 and Figure 3.11 show the proportion of rear-end casualty crashes between 2006 and 2010 for the day-of-the-week for urban and rural environments, respectively.

For both environments, in both Australia and New Zealand, rear-end crashes were generally more common on weekdays than the weekend. The crash rate peaked on Fridays and was lowest on Sundays.

This is consistent with the findings of the literature review, which indicates that rear-end crashes are most likely during periods of higher traffic density (see Section 2.2.4), and such periods are generally more common on weekdays.

Urban

Figure 3.10: Proportion of urban rear-end casualty crashes (2006–10) in Australia and New Zealand by day-of-week

Rural

Figure 3.11: Proportion of rural rear-end casualty crashes (2006–10) in Australia and New Zealand by day-of-week
3.2.2 Time-of-day

Figure 3.12 and Figure 3.13 show the proportion of rear-end casualty crashes for the period 2006–2010 inclusive, that occurred at different times of the day for both urban and rural environments, respectively.

For both environments, the crash rate was highest between 6 am and 8 pm, with peaks identifiable between 8 am and 9 am, and 3 pm and 6 pm.

These times are periods of high traffic flow. This result is consistent with the findings of the literature review that rear-end crashes are more common when traffic density is higher (see Section 2.2.4).

**Urban**

Figure 3.12: Proportion of urban rear-end casualty crashes in Australia and New Zealand by time-of-day (24hr clock) (2006–10 inclusive)
Rural

Figure 3.13: Proportion of rural rear-end casualty crashes in Australia and New Zealand by time-of-day (24hr clock) (2006–10 inclusive)

FSI crashes by time-of-day

FSI crashes in both urban and rural environments follow a similar trend (Figure 3.14). For both environments, the FSI crash rate was highest between 6 am and 8 pm, with peaks between 8 am and 9 am, and 3 pm and 6 pm.

The proportion of rear-end crashes resulting in an FSI during peak periods is lower than the proportion during periods of lower traffic density. The relationship between hours of highest traffic density and urban casualty crashes is not as clearly pronounced for urban fatal crashes. This may be related to travel speeds during these periods of congestion, which will likely be lower. As will be discussed in Section 3.2.5, rear-end crash severity increases with higher travel speeds.
3.2.3 Lighting Conditions

Figure 3.15 and Figure 3.16 show the proportion of rear-end casualty crashes that occurred under different lighting conditions, for both urban and rural environments, respectively.

For both environments, the crash occurrence was substantially higher during daylight hours, which is consistent with the time-of-day crash trend reported in Section 3.2.2.
Urban

Figure 3.15: Proportion of urban rear-end casualty crashes in Australia and New Zealand by lighting conditions (2006–10 inclusive)

<table>
<thead>
<tr>
<th>Lighting Conditions</th>
<th>Australia</th>
<th>New Zealand</th>
</tr>
</thead>
<tbody>
<tr>
<td>FSI</td>
<td>11.4%</td>
<td>4.5%</td>
</tr>
<tr>
<td>MI</td>
<td>67.3%</td>
<td>72.1%</td>
</tr>
</tbody>
</table>

Rural

Figure 3.16: Proportion of rural rear-end casualty crashes in Australia and New Zealand by lighting conditions (2006–10 inclusive)

<table>
<thead>
<tr>
<th>Lighting Conditions</th>
<th>Australia</th>
<th>New Zealand</th>
</tr>
</thead>
<tbody>
<tr>
<td>FSI</td>
<td>16.0%</td>
<td>8.3%</td>
</tr>
<tr>
<td>MI</td>
<td>62.0%</td>
<td>70.5%</td>
</tr>
</tbody>
</table>
3.2.4 ‘Rain Condition’

Figure 3.17 and Figure 3.19 show the proportion of rear-end casualty crashes by ‘rain condition’ (i.e. raining or not raining) for urban and rural environments, respectively.

Figure 3.18 and Figure 3.20 show the proportion of rear-end casualty crashes that occurred when the road surface was wet or dry for urban and rural environments.

The literature review found that rear-end crash risk increased with wet weather. The lower crash rates for wet weather conditions are likely related to driver exposure to wet weather, and do not refute the findings of the literature.

The results indicate a slightly lower rate of FSI crashes in wet weather, particularly in rural environments. This is likely a result of drivers adjusting their speeds to account for the weather.

Urban

Figure 3.17: Proportion of urban rear-end casualty crashes in Australia and New Zealand by rain conditions (2006–10 inclusive)
Figure 3.18: Proportion of urban rear-end casualty crashes in Australia and New Zealand by road condition (2006–10 inclusive)

<table>
<thead>
<tr>
<th></th>
<th>Australia</th>
<th></th>
<th>New Zealand</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Wet</td>
<td>2.8%</td>
<td>1.3%</td>
<td>5.6%</td>
<td></td>
</tr>
<tr>
<td>Dry</td>
<td>12.8%</td>
<td>72.7%</td>
<td>75.7%</td>
<td></td>
</tr>
</tbody>
</table>

Figure 3.19: Proportion of rural rear-end casualty crashes in Australia and New Zealand by rain conditions (2006–10 inclusive)

<table>
<thead>
<tr>
<th></th>
<th>Australia</th>
<th></th>
<th>New Zealand</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Raining</td>
<td>3.3%</td>
<td>2.2%</td>
<td>19.6%</td>
<td></td>
</tr>
<tr>
<td>Not raining</td>
<td>23.8%</td>
<td>17.3%</td>
<td>75.7%</td>
<td></td>
</tr>
</tbody>
</table>

Rural
Figure 3.20: Proportion of rural rear-end casualty crashes in Australia and New Zealand by road condition (2006–10 inclusive)

<table>
<thead>
<tr>
<th></th>
<th>Australia</th>
<th></th>
<th>New Zealand</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Wet</td>
<td>FSI</td>
<td>4.7%</td>
<td>2.6%</td>
<td>8.1%</td>
</tr>
<tr>
<td>Dry</td>
<td>MI</td>
<td>17.9%</td>
<td>56.6%</td>
<td>65.4%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>20.8%</td>
<td>23.9%</td>
<td></td>
</tr>
</tbody>
</table>

3.2.5 Speed Zone

Figure 3.21 shows the proportion of urban rear-end casualty crashes that occurred at various speed zones in Australia and New Zealand, respectively.

Figure 3.22 shows the proportions for rural environments in Australia and New Zealand by speed zone.

Urban

In urban environments, the vast majority of rear-end casualty crashes occurred in 60 km/h zones (Australia) and 50 km/h zones (New Zealand).

It appears that New Zealand urban roads are more commonly classed as 50 km/h speed environments than in Australia, resulting in a higher level of exposure to this speed zone (Austroads 2008a).
Rural

In rural environments, rear-end crashes were most prominent in 80 km/h zones (Australia) and 100 km/h zones (New Zealand).

This finding may be related to relative level of exposure of drivers to the various speed zones. That is, more vehicle-kilometres may be travelled on 100 km/h rural roads in New Zealand, and in Australia, more vehicle-kilometres may be travelled on 80 km/h rural roads.
Proportion of casualty crashes that were fatal

Figure 3.23 and Figure 3.24 show the proportion of rear-end casualty crashes that resulted in a fatality or serious injury, by speed limit, for both Australia and New Zealand.

Not unexpectedly, it was found that the proportion of fatal to injury crashes increased with increasing speed limits. This trend was more noticeable in urban environments.

Just under one in four rear-end crashes in 90 and 100 km/h urban environments in Australia resulted in an FSI. In rural environments in Australia, almost half of rear-end crashes resulted in an FSI in 100 km/h speed zones. Whilst the patterns remained similar in New Zealand, the proportion of FSI crashes to all casualty crashes was much lower.

Figure 3.23: Proportion of urban casualty rear-end crashes that were fatal in Australia and New Zealand by speed limit (km/h) (2006–10 inclusive)

Figure 3.24: Proportion of rural casualty rear-end crashes that were fatal in Australia and New Zealand by speed limit (km/h) (2006–10 inclusive)
3.2.6 Road Alignment

Figure 3.25 and Figure 3.27 show the proportion of rear-end casualty crashes that occurred at various vertical alignments on urban and rural roads, respectively.

Figure 3.26 and Figure 3.28 show the proportion of rear-end casualty crashes that occurred at various horizontal alignments on urban and rural roads, respectively.

The graphs support the findings of the literature that rear-end collisions are most common on straight, level roads. The review found that this is most likely due to a higher presence of intersections on straight, level roads than roads with curves or gradients (see Section 2.2.6).

In urban environments, rear-end crashes on crests and dips appear to have more serious outcomes than on level or graded roads, with about one in four crashes resulting in an FSI for the former two, compared to about one in seven for the latter two. This difference is not as apparent in rural crashes.

Urban

Figure 3.25: Proportion of urban rear-end casualty crashes in Australia and New Zealand by vertical road alignment (2006–10 inclusive)
Investigation of Key Crash Types: Rear-end Crashes in Urban and Rural Environments

Figure 3.26: Proportion of urban rear-end casualty crashes in Australia and New Zealand by horizontal road alignment (2006–10 inclusive)

Rural

Figure 3.27: Proportion of rural rear-end casualty crashes in Australia and New Zealand by vertical road alignment (2006–10 inclusive)
3.2.7 Road Surface in Rural Environments

Figure 3.29 shows the proportion of rear-end casualty crashes that occurred on sealed and unsealed roads in rural environments.

The overwhelming majority of collisions occurred on sealed roads. This is not surprising, as rear-end collisions are most common in areas of high traffic density (see Section 2.2.4). These findings are consistent with the literature.

Figure 3.29: Proportion of rural rear-end casualty crashes in Australia and New Zealand by road surface (2006–10 inclusive)
3.2.8 Crash Location Type

Figure 3.30 and Figure 3.32 show the proportion of rear-end casualty crashes that occurred at various road features for urban and rural environments, respectively.

Figure 3.31 and Figure 3.33 show the proportion of rear-end casualty crashes that occurred at intersections with various types of control for urban and rural environments, respectively.

For both environments, rear-end casualty crashes most commonly occurred at mid-block locations. When considering all intersection configurations, such crashes most commonly occurred at T-intersections.

In urban environments in Australia, rear-end casualty crashes at intersections most commonly occurred at signalised intersections.

For rural environments and urban environments in New Zealand, such crashes most commonly occurred at unsignalised intersections.

The literature review found that rear-end collisions were more common at intersections, and that these intersections were more likely to be signalised (see Section 2.2.1). The higher occurrence of rear-end casualty crashes at mid-block locations and at unsignalised intersections is likely related to driver exposure to such locations.

Urban

Figure 3.30: Proportion of urban rear-end casualty crashes in Australia and New Zealand by road feature (2006–10 inclusive)
Investigation of Key Crash Types: Rear-end Crashes in Urban and Rural Environments

Figure 3.31: Proportion of urban rear-end casualty crashes at intersection in Australia and New Zealand by intersection control (2006–10 inclusive)

<table>
<thead>
<tr>
<th>Intersection Control</th>
<th>Australia</th>
<th>New Zealand</th>
</tr>
</thead>
<tbody>
<tr>
<td>Signalised</td>
<td>4.7%</td>
<td>4.2%</td>
</tr>
<tr>
<td>Unsignalised</td>
<td>5.0%</td>
<td>55.6%</td>
</tr>
<tr>
<td>Roundabout</td>
<td>0.7%</td>
<td>0.4%</td>
</tr>
</tbody>
</table>

Rural

Figure 3.32: Proportion of rural rear-end casualty crashes in Australia and New Zealand by road feature (2006–10 inclusive)

<table>
<thead>
<tr>
<th>Road Feature</th>
<th>Australia</th>
<th>New Zealand</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mid-block</td>
<td>17.8%</td>
<td>73.5%</td>
</tr>
<tr>
<td>X-intersection</td>
<td>2.3%</td>
<td>0.5%</td>
</tr>
<tr>
<td>T-intersection</td>
<td>4.5%</td>
<td>15.0%</td>
</tr>
<tr>
<td>Y-intersection</td>
<td>0.0%</td>
<td>0.1%</td>
</tr>
<tr>
<td>Mult. Intersection</td>
<td>0.1%</td>
<td>0.1%</td>
</tr>
<tr>
<td>Roundabout</td>
<td>0.1%</td>
<td>1.8%</td>
</tr>
<tr>
<td>Intercrake</td>
<td>0.3%</td>
<td>0.8%</td>
</tr>
<tr>
<td>Other</td>
<td>0.3%</td>
<td>1.2%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Road Feature</th>
<th>Australia</th>
<th>New Zealand</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mid-block</td>
<td>8.5%</td>
<td>2.9%</td>
</tr>
<tr>
<td>X-intersection</td>
<td>0.5%</td>
<td>8.6%</td>
</tr>
<tr>
<td>T-intersection</td>
<td>1.5%</td>
<td>3.0%</td>
</tr>
<tr>
<td>Y-intersection</td>
<td>0.2%</td>
<td>0.4%</td>
</tr>
<tr>
<td>Mult. Intersection</td>
<td>0.0%</td>
<td>1.0%</td>
</tr>
<tr>
<td>Roundabout</td>
<td>0.0%</td>
<td>0.0%</td>
</tr>
</tbody>
</table>
3.2.9 Temporary Change to Environment

Figure 3.34 and Figure 3.35 show the proportion of rear-end casualty crashes that occurred at locations with temporary changes to the road environment for urban and rural situations, respectively. The temporary changes were defined:

- in Australia, as sites with roadworks present compared to no roadworks
- in New Zealand, as sites with and without temporary speed limits.

Incidences of a temporary change were found to be very uncommon in all environments.

The literature reviewed indicated a higher risk of rear-end collisions at sites with roadworks (see Section 2.2.5), and the findings presented are likely related to driver exposure rather than absolute risk.
Urban

Figure 3.34: Proportion of urban rear-end casualty crashes in Australia and New Zealand by presence of roadworks or temporary speed limits (2006–10 inclusive)

<table>
<thead>
<tr>
<th></th>
<th>Australia</th>
<th>New Zealand</th>
</tr>
</thead>
<tbody>
<tr>
<td>Roadworks</td>
<td>0.1%</td>
<td>6.9%</td>
</tr>
<tr>
<td>No roadworks</td>
<td>17.7%</td>
<td>92.8%</td>
</tr>
<tr>
<td>Temporary speed limit</td>
<td>0.1%</td>
<td>0.3%</td>
</tr>
<tr>
<td>No temporary speed limit</td>
<td>81.9%</td>
<td>92.8%</td>
</tr>
</tbody>
</table>

Rural

Figure 3.35: Proportion of rural rear-end casualty crashes in Australia and New Zealand by presence of roadworks or temporary speed limits (2006–10 inclusive)

<table>
<thead>
<tr>
<th></th>
<th>Australia</th>
<th>New Zealand</th>
</tr>
</thead>
<tbody>
<tr>
<td>Roadworks</td>
<td>0.1%</td>
<td>10.4%</td>
</tr>
<tr>
<td>No roadworks</td>
<td>27.6%</td>
<td>85.4%</td>
</tr>
<tr>
<td>Temporary speed limit</td>
<td>0.3%</td>
<td>3.9%</td>
</tr>
<tr>
<td>No temporary speed limit</td>
<td>71.8%</td>
<td>85.4%</td>
</tr>
</tbody>
</table>
3.3 Crash Factors

3.3.1 Number of Vehicles Involved

Figure 3.36 and Figure 3.37 show the proportion of rear-end crashes by number of vehicles involved, for urban and rural environments, respectively.

The vast majority of rear-end collisions involved two vehicles only (i.e. a striking and a struck vehicle).

Urban

Figure 3.36: Proportion of urban rear-end casualty crashes in Australia and New Zealand by number of vehicles involved (2006–10 inclusive)

Rural

Figure 3.37: Proportion of rural rear-end casualty crashes in Australia and New Zealand by number of vehicles involved (2006–10 inclusive)
Figure 3.38 shows the proportion of rear-end casualty crashes across Australia and New Zealand that resulted in a fatal or serious injury only, for urban and rural environments by the number of vehicles involved.

In urban environments, crash severity increased with increasing numbers of vehicles involved. This is consistent with the expectation that a multiple vehicle collision would generally involve more energy than a two-vehicle collision.

**FSI crashes only**

**Figure 3.38: Proportion of urban and rural rear-end casualty crashes resulting in an FSI across Australia and New Zealand by number of vehicles involved (2006–10 inclusive)**

<table>
<thead>
<tr>
<th>Vehicles Involved</th>
<th>Urban FSI (%)</th>
<th>Rural FSI (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>14.0</td>
<td>15.9</td>
</tr>
<tr>
<td>3</td>
<td>16.0</td>
<td>17.1</td>
</tr>
<tr>
<td>4</td>
<td>18.9</td>
<td>19.4</td>
</tr>
<tr>
<td>5+</td>
<td>24.5</td>
<td>23.1</td>
</tr>
</tbody>
</table>

**3.3.2 Lead Vehicle Movement**

Figure 3.39 shows the proportion of rear-end casualty crashes that occurred in urban and rural environments in Australia, based on whether the lead (struck) vehicle was in motion or stationary at the time of impact. Only three jurisdictions (Victoria, Queensland and South Australia) provided this information, so the sample size was quite small.

In urban environments, there were slightly more collisions into moving vehicles than into stationary vehicles. In rural environments, rear-end collisions into stationary vehicles were generally more common.

This is in contrast to the findings of the literature review, which found a large majority of rear-end crashes involved the struck vehicle being originally stationary (see Section 2.1.3).

Also in contrast with the findings of the literature review, the FSI crash rate was similar in both urban and rural environments, regardless of whether the vehicle was originally moving or stationary. The literature review found that crash severity was higher when the struck vehicle was in motion at the time of collision.
3.3.3 Driver Involvement

Figure 3.40 shows the ratio of drivers of the striking and first struck vehicles that were injured and killed in urban and rural environments.

Whilst rear-end crashes involving multiple vehicles were included in this analysis, only the passengers and occupants of the first striking and first struck vehicles were considered in order to ensure a comparable sample size between both groups.

It appears that the driver of the striking vehicle more frequently sustained a fatal or serious injury, in contrast with the findings of the literature review, which reported that occupants of the struck vehicle are more likely to require hospital treatment than occupants of the striking vehicle (see Section 2.4.2).

In Australian rural environments, approximately an equal number of striking and struck drivers sustained fatal injuries in rear-end collisions, consistent with the literature.
3.4 Vehicle Factors

3.4.1 Vehicle Age

Figure 3.41 and Figure 3.42 show the distribution of striking and struck vehicles by vehicle age for urban and rural environments, respectively.

There is a general trend that striking vehicles are more likely to be older than struck vehicles.

In urban environments, vehicles older than ten years are more commonly the striking vehicle than the struck vehicle.

In rural environments, vehicles older than twelve years are more commonly the striking vehicle than the struck vehicle. This is likely to reflect a generally older mean vehicle age in rural environments.

It is likely that the higher average age for striking vehicles compared to struck vehicles would be related to in-vehicle crash avoidance technology, such as anti-lock braking systems, that would not have been as widespread in earlier vehicles. Other factors related to drivers of older vehicles (such as driver age) may also be related to this trend. This may be worthy of further investigation.
Urban

Figure 3.41: Proportion of urban rear-end casualty crashes in Australia and New Zealand by striking and struck vehicle age (years) (2006–10 inclusive)

![Urban Rear-end Casualty Crashes Graph]

Rural

Figure 3.42: Proportion of rural rear-end casualty crashes in Australia and New Zealand by striking and struck vehicle age (years) (2006–10 inclusive)

![Rural Rear-end Casualty Crashes Graph]
3.4.2 Vehicle Types Involved

Figure 3.43 and Figure 3.45 show a breakdown of striking vehicle type in urban and rural environments, respectively. Figure 3.44 and Figure 3.46 show the breakdown for struck vehicles.

For both urban and rural environments, private cars and 4WDs are more commonly struck than striking. Consistent across both environments, there is a slight trend that larger vehicles, such as utes and trucks, were more commonly the vehicle striking than being struck. This is consistent with the literature review, which found that larger vehicles are more likely to be the striking vehicle in a rear-end collision (see Section 2.4.1).

Urban – Striking

Figure 3.43: Proportion of urban rear-end casualty crashes in Australia and New Zealand by striking vehicle type (2006–10 inclusive)

Urban – Struck

Figure 3.44: Proportion of urban rear-end casualty crashes in Australia and New Zealand by struck vehicle type (2006–10 inclusive)
Rural – Striking

Figure 3.45: Proportion of rural rear-end casualty crashes in Australia and New Zealand by striking vehicle type (2006–10 inclusive)

Rural – Struck

Figure 3.46: Proportion of rural rear-end casualty crashes in Australia and New Zealand by struck vehicle type (2006–10 inclusive)
Proportion of cars in Australian rear-end collisions that were four wheel drives

The literature review identified a relationship between four wheel drives (4WDs) and rear-end crashes (see Section 2.4.1).

Figure 3.47 shows the proportion of cars that were 4WDs for Australian and New Zealand jurisdictions where such information was available (i.e. NSW, WA, SA, NT and NZ). Four wheel drives appear to be more commonly the struck vehicle than striking, and also appear to be over-represented in FSI rear-end crashes.

**Figure 3.47: Proportion of striking and struck cars involved in urban and rural rear-end casualty crashes in Australia that were 4WDs, by crash severity (2006–10 inclusive)**

<table>
<thead>
<tr>
<th></th>
<th>Urban Struck</th>
<th>Urban Striking</th>
<th>Rural Struck</th>
<th>Rural Striking</th>
</tr>
</thead>
<tbody>
<tr>
<td>M1</td>
<td>9.0%</td>
<td>7.7%</td>
<td>12.1%</td>
<td>10.6%</td>
</tr>
<tr>
<td>FSI</td>
<td>8.5%</td>
<td>8.7%</td>
<td>15.0%</td>
<td>11.3%</td>
</tr>
</tbody>
</table>

3.5 Driver Factors

Figure 3.48 and Figure 3.50 show a breakdown of the ages of striking and struck drivers for urban and rural environments in Australia, respectively. Figure 3.49 and Figure 3.51 show the same parameters for New Zealand.

For all environments, drivers under the age of 30 and over the age of 75 were more likely to be the striking driver in a rear-end collision, than being the driver of a struck vehicle. This was most pronounced for drivers under the age of 24. Drivers aged 25–29 years and over 75 years had only a slightly higher involvement as striking than struck drivers.

Drivers between the ages of 30 and 75 are more commonly the struck driver in a rear-end collision.

These findings are consistent with the findings of Yan et al. (2005), discussed in Section 2.3.4, which found drivers under the age of 26 and over the age of 75 to be more likely to be the striking than struck driver.
3.5.1 Driver Age

Urban

Figure 3.48: Proportion of urban rear-end casualty crashes in Australia by striking and struck driver age (2006–10 inclusive)

![Driver Age Graph for Australia](image)

<table>
<thead>
<tr>
<th>Driver Age</th>
<th>Striking</th>
<th>Struck</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-16</td>
<td>0.4%</td>
<td>0.4%</td>
</tr>
<tr>
<td>17-24</td>
<td>27.2%</td>
<td>19.0%</td>
</tr>
<tr>
<td>25-29</td>
<td>13.0%</td>
<td>11.7%</td>
</tr>
<tr>
<td>30-39</td>
<td>21.8%</td>
<td>22.7%</td>
</tr>
<tr>
<td>40-49</td>
<td>17.0%</td>
<td>21.1%</td>
</tr>
<tr>
<td>50-59</td>
<td>11.2%</td>
<td>15.0%</td>
</tr>
<tr>
<td>60-74</td>
<td>7.1%</td>
<td>8.5%</td>
</tr>
<tr>
<td>75+</td>
<td>2.4%</td>
<td>1.6%</td>
</tr>
</tbody>
</table>

Figure 3.49: Proportion of urban rear-end casualty crashes in New Zealand by striking and struck driver age (2006–10 inclusive)

![Driver Age Graph for New Zealand](image)

<table>
<thead>
<tr>
<th>Driver Age</th>
<th>Striking</th>
<th>Struck</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-16</td>
<td>5.0%</td>
<td>1.2%</td>
</tr>
<tr>
<td>17-24</td>
<td>33.0%</td>
<td>16.9%</td>
</tr>
<tr>
<td>25-29</td>
<td>11.2%</td>
<td>9.0%</td>
</tr>
<tr>
<td>30-39</td>
<td>16.5%</td>
<td>22.4%</td>
</tr>
<tr>
<td>40-49</td>
<td>15.3%</td>
<td>23.4%</td>
</tr>
<tr>
<td>50-59</td>
<td>9.2%</td>
<td>15.9%</td>
</tr>
<tr>
<td>60-74</td>
<td>6.5%</td>
<td>8.8%</td>
</tr>
<tr>
<td>75+</td>
<td>3.3%</td>
<td>1.8%</td>
</tr>
</tbody>
</table>
Rural

Figure 3.50: Proportion of rural rear-end casualty crashes in Australia by striking and struck driver age (2006–10 inclusive)

3.5.2 Driver BAC

Blood alcohol content (BAC) of striking and struck drivers was considered in the data analysis.

However, there was a large number of null entries for both striking and struck drivers. It is unclear whether these entries were due to the driver not being tested, having a zero reading, or a matter of oversight. As such, these results were considered unreliable and hence, no results are presented for this category.
3.5.3 Driver Gender

Figure 3.52 and Figure 3.53 show the gender of the driver of the striking and struck vehicle in urban and rural environments, respectively.

Male drivers are overrepresented as both the striking and struck driver, which may be related to driver exposure. It was also found that male drivers were more commonly the operator of the striking rather than struck vehicle.

Females were found to be more commonly the operator of the struck rather than striking vehicle. This is consistent with the findings of the literature (Section 2.3.5).

Urban

Figure 3.52: Proportion of urban rear-end casualty crashes in Australia and New Zealand by striking and struck driver gender (2006–10 inclusive)
3.6 Key Findings of the Crash Analysis

The analysis of crash data has identified those road factors and parameters that influence the occurrence and severity of rear-end crashes in urban and rural environments. It is suggested that this knowledge be used to review road design and traffic engineering practices. It will also offer important insights into the management of vehicle fleets, vehicle technology and driver behaviour.

Supporting the findings of the literature review, key findings derived from this analysis of crash data include:

- Rear-end crashes were far more common in urban environments, yet the rate of rear-end crashes resulting in FSI outcomes was higher in rural environments.
- Rear-end crashes were more common during periods of high traffic flow, such as weekdays and peak-hour periods.
- Rear-end crashes were most common on straight, level roads.
- Four wheel drives were over-represented as both the striking and the struck vehicle in FSI crashes.
- Male drivers and drivers under the age of 30 or over the age of 75 years were more likely to be drivers of striking vehicles than struck vehicles in rear-end collisions.
- Rear-end crashes resulted in a greater rate of fatal and serious injury crashes in higher speed zone environments.

There were some areas where the findings of the literature review and the crash data analysis appeared to diverge:

- Whilst the literature review found that a majority of rear-end crashes involved the struck vehicle originally moving, and found that such crashes were generally of greater severity, the data analysis found that struck vehicle motion prior to impact had minimal impact on crash rate or severity.
• The literature review concluded that intersections were related to a higher risk of rear-end crashes, while the data analysis found that such crashes occurred more often at mid-block locations. This may be due to drivers having a higher rate of exposure to mid-block locations, and likely does not reflect the relative crash risk of mid-block locations.

• Drivers of striking vehicles more frequently sustained a fatal or serious injury. This is inconsistent with the findings of the literature review, which reported that occupants of the struck vehicle were more likely to require hospital treatment than those of the struck vehicle, and that drivers of both the striking and struck vehicle had an equal risk of receiving life threatening injuries.

Key findings derived from studying this crash data analysis, which were not previously discussed in the literature review, include:

• Rear-end crashes were more severe
  – in rural environments
  – when multiple vehicles were involved.

• Striking vehicles were more likely to be older than struck vehicles.
  – It is suggested that trends identified in this report may well benefit from more statistically robust and contemporary analysis, to account for the following issues:

• The rear-end fatality sample size was relatively small, which may have resulted in the fatality data being skewed due to unidentified factors.

• NSW crash data does not currently provide a distinction between serious and minor injury crashes, but rather the analysis relied upon a disaggregation of the data based on crash type and speed environment. More reliable crash severity data should be available in the future.

• The data set only ran until 2010, after which time, opportunities for, and hence interest in, driver distraction have escalated. A re-evaluation of driver distraction data once more information comes to light may be of benefit.

• The definition for serious injuries was whether or not the police crash report indicated that at least one person was admitted to hospital. Without detailed investigation, it is unlikely that police would have this information, or have made an assumption based on either the person’s injuries or whether or not they were taken away by ambulance. Further, admittance to hospital does not necessarily indicate a lifelong debilitating injury.

• The rate of exposure was not considered and this may influence results. For example, whilst the data identified that a minimal number of rear-end crashes occurred near roadworks sites, the literature review identified an increased risk of rear-end crashes at such sites. Likely, this discrepancy is due to driver exposure to such sites and should not be viewed as contradicting the established literature.
4. Site Investigations

Investigations were undertaken at key sites featuring a high incidence of rear-end crashes in the states of New South Wales, Victoria, and Queensland. It was not feasible to inspect sites in other states/territories and New Zealand. Being the most populous in Australia, these three jurisdictions were selected for this study.

The purpose of the site inspections was to identify common factors in the road environment that may have contributed to their high rear-end crash rates. This may seek to identify issues not previously identified in the literature review and crash analysis, or confirm their existing findings.

Sites were selected to allow the identification of factors that may have contributed to the occurrence and/or severity of rear-end crashes. The sites were selected based on their known crash record in recent years. The list of sites selected are included as Appendix D.

Twenty-seven of the 30 rear-end crash sites identified (90%) were at intersections. The crashes were generally concentrated on one or two legs. Each leg that featured a high rear-end crash rate was treated as a separate study site. This allowed for the factors contributing to a high crash rate for a particular approach to be isolated from the rest of the intersection.

The five-year crash period 2006–10 was used. This is the most recent period for which crash data is available across the three jurisdictions. Sites were selected using a prioritisation tool, based on crash severity. Each crash was assigned a score based on severity, with less severe crashes receiving lower ratings, and fatal crashes receiving the highest. The highest ranked sites were considered for inspection.

Those sites with the highest crash score during the five-year study period were selected first. The minimum number of rear-end crashes occurring at any selected site during the five-year period was six.

Whilst all selected sites featured a high concentration of rear-end casualty crashes, none of the sites had recorded a rear-end fatality during the five-year crash period. As discussed in Section 3.2.2, whilst higher traffic density contributes to a higher rear-end crash rate, it also leads to lower travel speeds, thereby reducing crash severity.

Rural road environments were not excluded when selecting sites. However, the sites identified as featuring a high rear-end crash rate lay within the main metropolitan areas of the states considered. This is considered to be consistent with the predominantly urban nature of rear-end crashes discussed previously.

As a minimum, all sites were inspected via drive-through and were filmed using in-car video. Where it was considered safe to do so, sites were also inspected on foot.

Sites were assessed using a spreadsheet developed for this project, which is provided in Appendix E.

Traffic congestion is a key issue for rear-end crashes. However, it was not feasible for all sites to be inspected at periods of peak congestion. Therefore, the surveys focused on static issues of road and intersection design rather than congestion. Notwithstanding, any congestion issues identified at sites were noted and are discussed in the report.

4.1 Findings

4.1.1 Road Environment

Consistent with the findings of the literature review, the vast majority of sites identified were located at signalised intersections (Figure 4.1) (see Section 2.2.1). Of the 30 sites selected, 26 (~87%) were at signalised intersections, when including two sites at the left-turn slip lane of the intersection. Of the remaining four sites, three sites were on motorways and one was at an unsignalised intersection.
Consistent with the findings of the literature review, all sites were located on roads that would attract high traffic volumes (see Section 2.2.4). Twenty-three of the 30 sites (~77%) were located on arterial roads (Figure 4.2).

Such roads would be likely to attract a higher concentration of heavy vehicles, which the literature review has shown to be related to an increased rear-end crash risk (see Section 2.4.1).

The posted speed limits at the identified crash cluster sites were generally between 60 and 80 km/h (Figure 4.3). This aligns with the speed environment for arterial roads.
All identified rear-end crash cluster sites were found on highly trafficked roads featuring a high proportion of heavy vehicles, such as shown in Figure 4.4.

**Figure 4.3:** Number of crash cluster sites by posted speed limit (km/h)

**Figure 4.4:** Typical mix of traffic found at identified rear-end crash cluster sites
4.1.2 Road Design

As noted, the identified rear-end crash cluster sites were found to be on highly trafficked roads. Consistent with such conditions, these roads were generally well designed and maintained. It was noted that:

- there were no sight distance issues, with the shortest sight distance corresponding to a travel time of over four seconds
- street lighting, surface and drainage conditions were all considered appropriate
- all roads had well maintained and appropriate line markings
- on-street parking was not typically provided (only 3 of the 30 sites (10%) provided this facility).

Road geometry

The identified crash cluster sites generally occurred on straight, level roads, as shown in Figure 4.5.

Figure 4.5:  Typical road alignment at the identified rear-end crash cluster sites

Twenty-nine of the 30 sites (~97%) were assessed as being generally straight or moderately curved horizontal alignment (Figure 4.6), and were found to be located at least six seconds travel time from the nearest upstream curve.
Twenty-five of the 30 sites (~83%) were generally level or marginally downhill. The remaining five were located on crests or slight uphill grades (Figure 4.7).

Figure 4.8 shows a breakdown of the crash cluster sites by the measured vertical gradient at the site.

Fifteen of the sites (50%) were classed as either being on a downhill continuous grade, or being level with a marginal downhill gradient. It is possible that this slight downhill incline has contributed to the rear-end crash rate at the sites by reducing the driver braking efficiency. This may be worthy of further investigation.
Cross-section

The majority of sites identified were of a divided carriageway (Figure 4.9). This is consistent with the crash cluster sites having been located on highly trafficked roads.

The sites varied in the number of approach lanes, with up to seven lanes in the direction for which the rear-end crash cluster occurred (Figure 4.10). This is considered to be consistent with the crash cluster sites having been located on highly trafficked roads.
Twenty-nine of the 30 sites (97%) included lane widths below the recommendation of Austroads (2010) of 3.5 m (Figure 4.11).

It is unclear whether this was a contributory factor in the rear-end crash rate at the locations, or rather indicative of generally narrow lanes in Australian urban environments. This may be worthy of further investigation.
4.1.3 Disruptions to Traffic Flow

Variations in traffic speeds have been identified as a rear-end crash factor (see Section 2.2.4). Road features that could disrupt the flow of traffic have been considered in this investigation, and include:

- changes to speed limit
- bus stop facilities
- high demand driveways.

Changes to speed limit

Five of the 30 sites (~17%) featured a reduction in the posted speed limit in close proximity to the identified crash concentration (Figure 4.12).

Figure 4.13 shows a typical example of the speed limit change in close proximity to the crash cluster site.

It is considered possible that some drivers may not slow their vehicles sufficiently in response to the change, resulting in a differential in travel speeds and hence, an increased rear-end crash risk. This could indicate some benefit in relocating speed limit reductions to locations further from rear-end crash clusters. This issue is worthy of further investigation.

Figure 4.12: Number of crash cluster sites by change in speed limit
Presence and type of bus facility

Ten of the 30 sites (~33%) featured bus stops that would typically require buses to travel at a different speed to the rest of the general traffic flow.

In eight of the 30 sites (~27%), bus stops were located in the kerbside traffic lane (Figure 4.14).

At a further two locations, bus stops were located within bus bays. It is considered that this would give rise to buses decelerating in the adjacent traffic lane, also leading to a differential in travel speeds, in this case, between the bus and through traffic.

One site of the 30 featured a bus stop located within a bus lane. As buses would be separated from the general traffic, it is considered unlikely that a bus stop at this location would have contributed to rear-end crashes.

There appears to be a high proportion of sites featuring bus facilities that would interfere with the general flow of traffic. The relationship between bus facilities and rear-end crash risk would be worthy of further investigation.
High demand driveways

Eight of the identified crash cluster sites (~27%) featured a high demand driveway (i.e. providing access to a well trafficked commercial premise) alongside their approach (Figure 4.15). In many cases, the driveway provided access to a petrol station or fast food restaurant along a major road that did not otherwise have any adjacent developments (Figure 4.16). It is considered possible, therefore, that drivers may not anticipate that lead drivers may decelerate to access these driveways.

Relocating the access point to an adjacent minor street or providing a deceleration lane could help reduce the crash risk at these sites. This issue would be worthy of further investigation.
4.1.4 Intersection Configuration

Number of legs to intersection

Twenty-seven of the sites (90%) were at intersections. The intersections had either three or four legs (Figure 4.17).

Figure 4.17: Number of crash cluster sites by number of legs at intersection
Right-turn provision

There were 19 intersections for which right-hand turns were allowed. Of these, 12 (~63%) featured one exclusive right-turn lane (Figure 4.18).

In some cases, the turn lane’s capacity is exceeded during periods of high demand (Figure 4.19). This can create a conflict with through traffic as the right-turning traffic overflows into the general traffic lane. Extending the right-turn lane or adding an additional lane may be effective in reducing the rear-end crash rate.

Figure 4.18: Number of crash cluster sites by number of exclusive right-turn lanes at intersection

![Number of crash cluster sites by number of exclusive right-turn lanes at intersection](image)

Figure 4.19: Rear-end crash site where aerial imagery shows the right-turn lane does not appear to meet capacity

![Rear-end crash site where aerial imagery shows the right-turn lane does not appear to meet capacity](image)

Of the 19 right-turn sites at intersections, only four sites featured combined right-turn/through traffic lanes (Figure 4.20). As the roads catered for high volumes of traffic, they appear to have been designed to separate right-turning traffic from the main traffic flow to improve capacity.
Investigation of Key Crash Types: Rear-end Crashes in Urban and Rural Environments

Figure 4.20: Number of crash cluster sites by presence of combined right-turn/through lane

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**Left-turn provision**

Exclusive left-turn lanes were less common. Ten of the 25 (40%) sites where left-turn traffic was apparent did not feature a dedicated left-turn lane (Figure 4.21). A further 14 (56%) featured one left-turn lane only. Therefore, it is possible that introducing or adding an additional left-turn lane may be effective in reducing the rear-end crash rate.

Figure 4.21: Number of crash cluster sites by number of exclusive left-turn lanes at intersection

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Ten of the 25 left-turns (40%) featured combined left-turn/through lanes (Figure 4.22). At these sites, the through traffic would have a different travel speed to left-turning traffic, which needs to decelerate in order to safely conduct the turn. This difference in travel speeds would increase the rear-end crash risk. There may be benefit to separating these traffic streams.
4.1.5 Signalised Intersection Design

Spacing of signalised intersections

The literature review indicated a higher incidence of rear-end collisions when signalised intersections were closely spaced together (see Section 2.2.2).

There was a slightly higher concentration of rear-end crash sites located where signalised intersections were spaced within 200 m of each other (about 23% of sites) (Figure 4.23).

Whilst the pattern is not clear, the findings appear generally supportive of the literature.
Left-turn control

As seen in Figure 4.24, of the 26 signalised intersections at identified crash cluster sites, 20 (~77%) featured unsignalised left-turn slip lanes. Left slip lanes, such as seen in Figure 4.25, allow traffic to filter into the adjacent road at irregular intervals. This introduces an unsteady traffic flow to the intersection and may have led to an increased rear-end crash risk.

The large proportion of slip lanes at identified rear-end crash cluster sites is in contrast to the findings of the literature review (see Section 2.5.2). The latter found that left-turn slip lanes act to reduce the rear-end crash rate at major intersections (such as those identified in this study). It may be possible that the higher proportion of slip lanes may be related to the high traffic volume nature of these sites. The slip lanes may be more common at such sites to improve traffic flow, and perhaps the rear-end crash rate would have been higher without the slip lanes. The relationship of slip lanes to rear-end crash risk would be worthy of further investigation to clarify this apparent discrepancy.

Figure 4.24: Number of crash cluster sites by left-turn treatment

[Bar chart showing the number of crash cluster sites by left-turn treatment for NSW, VIC, and QLD.]

Figure 4.25: Example of a left-turn slip lane common at a crash cluster site
Right-turn control

The majority of right-turns at the signalised intersections did not permit filter turns (Figure 4.26). This is likely a result of the rear-end crash cluster sites being located on high volume roads, and the sites being designed to cater for such capacity. It would be expected that filtered right-turns would be related to a higher crash risk than signalised turns.

The literature review identified that the incidence of rear-end crashes is related to the number of phases present at a signalised intersection (see Section 2.2.2), e.g. two-phase intersections do not adequately control movements and result in an increase in rear-end crashes; eight-phase intersections increase cycle time, resulting in excessive queueing and driver frustration, leading to an increase in rear-end crashes.

The number of turn arrows was considered an indication of the number of phases at the signalised intersections studied. The identified signalised intersections featured an average of 3.7 turn arrows (see Figure 4.27). This is a moderate number of turn arrows. It appears that the number of signal phases has not had a significant impact on rear-end crash risk at these sites. This is inconsistent with the findings of the literature review.
At the signalised intersections, the yellow phase time was measured and compared to the guidelines in Table H2 of Austroads (2014). As this table provided phase times for two different reaction times, the reaction time yielding the shortest yellow phase (1 s) was adopted. Of the 26 signalised intersections considered, 12 (~46%) fell below the minimum required by these guidelines (Figure 4.28).

As discussed earlier, all identified sites were on major thoroughfares, and were generally well designed in accordance with their significance. It would be expected that such significant well designed sites would feature traffic signal phases meeting or exceeding the requirements of the Austroads guidelines. The fact that so many sites that were otherwise well designed featured yellow phase times below the guidelines suggests that substandard phase times could be contributing to rear-end crashes at these sites. A more detailed examination of the role of yellow phase times is warranted.

It is possible that motorists experienced a red-light earlier than they anticipated, and braked more heavily as a result. If the trailing vehicle did not respond fast enough, or was unable to brake efficiently enough, a rear-end collision may have resulted. Extending the yellow phase time at these sites would likely be of benefit.

The relationship between yellow phase time and rear-end crash rates would be worthy of further investigation.

4.1.6 Automated Enforcement

Figure 4.29 provides a breakdown of the crash cluster sites by the type of automated enforcement present during the majority of the crash study period. Most sites did not feature any permanent automatic enforcement.
Towards the end of the site study period (2010), both red-light cameras in NSW were converted to red-light speed cameras. An additional two previously unenforced sites in NSW had red-light speed cameras introduced (NSW Centre for Road Safety 2013).

The effectiveness of the red-light speed cameras varied significantly, as seen in Table 4.1. On average, there was a 39% decrease in rear-end crashes at these sites following the installation of the cameras (NSW Centre for Road Safety 2013).

Table 4.1: Decrease in rear-end crash rate after introduction of red-light speed cameras by site

<table>
<thead>
<tr>
<th>Site #</th>
<th>Enforcement prior</th>
<th>Decrease in rear-end crash rate</th>
<th>Post-installation study period</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Red light camera</td>
<td>19%</td>
<td>2 years 3 months</td>
</tr>
<tr>
<td>2</td>
<td>Red light camera</td>
<td>42%</td>
<td>2 years 5 months</td>
</tr>
<tr>
<td>3</td>
<td>None</td>
<td>73%</td>
<td>2 years 5 months</td>
</tr>
<tr>
<td>4</td>
<td>None</td>
<td>22%</td>
<td>2 years 5 months</td>
</tr>
</tbody>
</table>

Note: Pre-installation study period was five years for all sites.
Source: NSW Centre for Road Safety (2013).

In an email to ARRB Group on 20 December 2013, the Department of Justice in Victoria confirmed that a red-light speed camera was introduced towards the end of the crash study period at a crash cluster site. Previously no automated enforcement was present at this site. The Department also confirmed that one red-light safety camera was installed towards the beginning of the crash study period. This has been noted in Figure 4.29.

A red-light speed camera treatment has been applied to the site shown in Figure 4.30, resulting in a 19% reduction in rear-end crashes.
4.1.7 Pedestrian Provision

Pedestrian activity did not appear to contribute to the rear-end crash rates. Pedestrian activity was generally either low (e.g. industrial areas) or medium (e.g. residential areas) (Figure 4.31). Pedestrian crossings were generally well separated from the traffic flow (Figure 4.32).

Figure 4.31: Number of crash cluster sites by likely pedestrian activity
4.2 Key Findings of the Site Inspections

The detailed inspection of identified rear-end crash cluster sites has identified a number of road design factors that may influence the occurrence of rear-end crashes.

It is suggested that this knowledge be used to review road design and traffic engineering practices.

Supporting the findings of the literature review, key findings derived from the site inspections include:

- The majority of the selected (high incidence rear-end crash sites) had the following features
  - were in an urban environment
  - were on straight, level roads
  - involved signalised intersections
  - were major thoroughfares.

- Combined red-light speed cameras have been effective at reducing the rear-end crash rate both when replacing existing red-light cameras and when introduced at sites that previously did not feature automated enforcement.

A number of issues have been identified that would be worthy of further investigation. These have not been well addressed in the reviewed literature.

- Almost all identified sites featured lanes narrower than the minimum recommendation of Austroads (2010).

- A large proportion of sites contained features that would likely disrupt traffic flow, such as:
  - bus stops in the general traffic lane or dedicated bus bays
  - high demand driveways
  - left-turn slip lanes
  - reductions in the posted speed limit.
• About half of the identified sites featured yellow phase times below the minimum required by Austroads (2014). This is surprising considering that most sites were otherwise well-designed in accordance with the high traffic demand they catered for. This suggests that substandard yellow phase times may be contributing to rear-end crashes at these sites.
5. Key Findings and Discussion

Rear-end crashes are one of the most common crash types occurring on roads in Australia and New Zealand. Given their prevalence at intersections, and that about a quarter of all injury rear-end crashes result in fatality or serious injury outcomes, they are a focus of the Australian National Road Safety Strategy.

This project has conducted a literature review, crash data analyses (for a five-year period, 2006–2010 inclusive), and site inspections of typical crash clusters. From this research, contributing factors to the incidence and severity of rear-end crashes were identified. Within this final report, contributory factors have been categorised using an industry-standard humans, vehicles and road environment (HVE) model.

5.1 Rear-end Crash Contributory Factors

5.1.1 Humans

The project has identified the following human factors associated with rear-end crashes:

- **Driver inattention**: Driver inattention is considered the most common driving error associated with rear-end crashes. This can originate from:
  - driver distraction, such as from mobile phone usage
  - cognitive inattention, sometimes described as when a driver ‘looked but failed to see’
  - inappropriate division of driving tasks, such as when a driver is checking the rear view mirror or conducting a lane change, and fails to notice changes in traffic conditions ahead.

- **Poor headway maintenance**: Drivers routinely maintain headways below the safe minimum of 2–3 seconds.

- **Driver age**: Drivers under the age of 26 and over the age of 75 are most likely to be the driver of a striking vehicle in a rear-end crash.

- **Driver gender**: Males are more likely to be the operator of the striking vehicle in a rear-end crash.

- **Blood alcohol content**: Drivers affected by alcohol intake are more likely to be the operator of a striking vehicle in a rear-end collision.

5.1.2 Vehicles

The project has identified the following vehicle factors associated with rear-end crashes:

- **Vehicle type**:
  - Light trucks, 4WDs and utilities have an increased risk of being struck by a following vehicle. Drivers travelling behind such vehicles have a restricted view of traffic ahead, preventing their ability to anticipate changes in traffic, yet paradoxically maintain a shorter headway behind these vehicles.
  - Heavy vehicles have a reduced risk of being struck, as they decelerate more gradually than other vehicles. However, for the same reason, they have an increased risk of being the striking vehicle in a rear-end collision.
  - When rear-end collisions occur between light and heavy vehicles, vehicle underrun can occur, increasing the severity of the collision. This is being addressed through the introduction of front underrun protection in the Australian Design Rules since 2011. However, rear underrun protection has yet to be similarly mandated.
• **Vehicle seat and head restraint combination**: The ideal seat and head restraint combination features:
  – a seat with low stiffness to absorb some of the impact
  – a head restraint positioned close to the head and neck, at the head’s centre of gravity, to prevent excessive head movement relative to the torso.

• In practice, most drivers maintain a head position at a greater distance from the head restraint than is considered safe.

• **Vehicle age**: Striking vehicles are more likely to be older than struck vehicles.

### 5.1.3 Road Environment

The project has identified the following road environment factors associated with rear-end crashes:

• **Intersections**: Rear-end crashes are more common at intersections, where there is a greater presence of, and interaction between, slow-moving and stationary traffic.

• **Signalised intersections**: Signalised intersections present a greater risk of rear-end crashes. The risk of rear-end crashes at signalised intersections is increased when:
  – the lead vehicle’s position at the beginning of the yellow phase is such that the decision to decelerate or proceed through the intersection is unclear
  – red-light cameras without accompanying speed cameras are present
  – signalised intersections are closely spaced together.

• As signalised intersections are generally placed where the alignment is straight and level, there is a higher incidence of rear-end crashes on straight, level roads.

• **Road geometry**: After accounting for the influence of signalised intersections, rear-end crash risk increases on curves and slopes.

• **Traffic density**: Rear-end crashes are more common when traffic density is higher, such as during peak hours and on urban arterial roads.

• **Work zones**: Work zones introduce complexity and uncertainty, disrupt the regular flow of traffic and lead to an increase in traffic density. Also, work sites may feature a higher portion of heavy vehicles in the traffic flow. These factors all contribute to a higher rear-end crash risk.

• **Lighting**: Rear-end crash risk increases during times of darkness. Heavy vehicles are particularly prone to being struck during darkness.

• **Speed environment**: Rear-end crash risk increases in higher speed zones.

As many of these factors are particularly prevalent in urban environments, rear-end crashes are more common in these areas.

### 5.2 Factors Affecting Crash Severity

Data analysis conducted for this project has attempted to separate fatal and serious injury crash data from other crash data in order to compare the severity of crashes against various factors. More needs to be done to ensure that serious injury crashes are accurately documented.

A number of factors have been found to be related to the severity of rear-end crash outcomes including:

• **Road environment**: Whilst rear-end crashes are less frequent in rural than urban environments, higher travel speeds and potential for a greater speed differential between impacting vehicles mean that crashes in rural environments are associated with more severe outcomes.

• **Driver age**: Elderly drivers are more likely to sustain severe injuries, even in low impact rear-end collisions.
- **Driver gender:** Females are more likely to sustain injuries in rear-end collisions.
- **Speed environment:** Rear-end crash severity increases in higher speed zones.
6. Conclusions and Recommendations

6.1 Conclusions

The National Road Safety Strategy has identified intersection crashes as one of the most frequent crash types occurring on Australian roads (Australian Transport Council (ATC) 2011). As rear-end crashes are a common collision type at intersections, and since about a quarter of all injury rear-end crashes result in fatality or serious injury outcomes, they have been targeted as part of this strategy (ATC 2012).

Rear-end crashes feature heavily in road agency crash statistics for FSIs, and when viewed more widely, about two-fifths of CTP insurance claims are for rear-end crashes, amounting to a quarter of all CTP costs.

The characteristics of rear-end crashes were investigated. This was achieved through an extensive literature review, analysis of data from all jurisdictions across Australia and New Zealand, and inspections of sites where crash patterns had emerged.

Investigation of the predominant characteristics of these crash types provided the basis to identify road factors that may have contributed to the occurrence or severity of these types of crashes.

As recognised in the Safe System approach, a well-designed road can reduce the risk of rear-end collisions occurring in the first instance, and where they do occur, their severity. From a road engineering perspective, there are a number of options available to road engineers to reduce the occurrence of rear-end crashes. Fewer options are available to reduce the severity of such crashes, with speed management being the most effective tool. To achieve greatest results, an array of available tools should be used together to reduce both rear-end crash rates, and their severity.

6.1.1 Recommended Actions to Reduce the Incidence of Rear-end Crashes

Road maintenance programs

Maintenance programs should provide priority to the most highly trafficked roads, and particularly at any signalised intersections. Programs should ensure the regular maintenance of:

- delineation and visibility of signalised intersections, including surrounding street lighting
- the road surface (i.e. skid resistance/surface texture).

Capital works and road safety programs

As part of road agencies’ capital works and road safety programs, it is suggested that an increased emphasis be placed on:

- reviewing the appropriateness of speed limits based on visibility and crash history
- targeted treatment of intersections that are highly trafficked or known to operate at unusual levels of risk
- treatments to improve traffic flow, such as:
  - improved co-ordination of traffic signals along a route
  - variable speed limits

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2 Vehicle design measures that can reduce the severity have been discussed in Section 2.6.8 of this report.
• increased yellow and all-red phase time
• replacement of red-light cameras with combined red-light and speed cameras
• improved delineation and visibility of intersections and high-use driveways, including rumble strips and pavement markings on approach
• improved alignment on the approach to intersections
• conversion of high-risk intersection to a roundabout
• application of turn treatments such as provision of, or extension of, exclusive turn lanes.

6.2 Issues for Consideration as Part of the Austroads Guides Updates

The series of Austroads Guides to Traffic Management, Road Design, and Road Safety have been reviewed to identify areas that could be updated to incorporate the findings of this research project. It is suggested that the following changes be implemented:


• Table 2.4 discusses various intersection options, but does not discuss median turning lanes. Median turning lanes have been identified as a low cost treatment to minimise the incidence of rear-end crashes and should be an addition to the existing table.
• The same table provides a discussion on the signalisation of intersections, including a list of bullet points summarising the key features of such a treatment. It is suggested that the following bullet point be added:
  – ‘has the potential to lead to an increase in rear-end crashes, whilst reducing the incidence of other intersection crash types’.
• Table 3.2 provides possible treatment options to meet certain objectives at unsignalised intersections. This table should include the following:
  – Objective: Reduce rear-end crashes.
  – Possible treatment: Install turning lanes or median turn lanes.
  – Comments: Segregate slow moving traffic preparing for a turn from the general traffic stream.

Guide to Traffic Management Part 8: Local Area Traffic Management (Austroads 2008b – under review)

In Section 2.3, the last bullet point on page 11 should be reworded to state:
  – ‘Protect or manage parking, driveway access and bus facilities on distributor roads and other connective streets’.

Guide to Road Safety Part 8: Treatment of Crash Locations (Austroads 2009a – under review)

• Table 8.5 lists possible contributory factors for different types of crashes. Under ‘straight ahead rear-end collisions’, the following points should be included:
  – Inadequate yellow phase time at traffic signals.
  – Disturbance to traffic flow, such as from driveways and bus stops.
• Table 9.1 lists countermeasures for crashes at intersections and major driveways. Under ‘straight ahead rear-end collisions’, the following countermeasures should be included:
– Where there is a red-light camera at a signalised intersection, remove or replace with a red-light speed camera.
– Where there is a speed limit reduction located near an intersection, relocate further downstream.

- Table 9.2 lists countermeasures for non-intersection crashes. Under ‘rear-end collisions’, the following countermeasure should be included:
  – Provide auxiliary lanes for access to driveways and bus stops.


Section 6.3.4 discusses bus stops. The first sentence of the last paragraph on page 42 should be reworded to state that:

In order to maintain traffic flow and reduce both delay and risk of collisions, wherever practical, bus stops should be located outside the general traffic lanes (e.g. within a parking or exclusive bus lane, or within a bus bay that is indented into the kerb).

6.3 Further Austroads Work

A number of issues have been identified from the inspection of sites featuring a high number of rear-end crashes. As these inspections did not account for contributory factors such as traffic volume and composition, further investigations would be required to clarify the following identified relationships:

- **Disruptions to traffic flow**: A large proportion of sites inspected contained features that would likely disrupt traffic flow, such as bus stop facilities and high-demand driveways.

- **Short yellow phase times**: A large proportion of signalised intersections inspected featured unexpectedly short phase times (falling below the minimum required by Austroads (2009c)).

It is recommended that measures to reduce tailgating, particularly headway distance markings on the roadway and vehicle-activated signs, be further investigated. On-site trials should again be conducted in Australia to consider their effectiveness in today’s road environments.

Whilst the previous trial of chevron markings to highlight headway distance only had marginal success (Fenner & Broekman 1999), the authors of the trial identified a few deficiencies, most notably poor signage explaining the markings. Other trials in the UK (Helliar-Symons & Butler 1995) and USA (Minnesota Department of Transportation 2006) appear to have been more successful. Different markers, such as horizontal bars, have been preferred by others (Song & Wang 2010) and their efficacy could again be reviewed.

Jurisdictions may also find benefit in trialling automated headway enforcement. Victoria is already considering such measures (Mulder 2013). The difficulties in enforcing headway times are recognised and have been outlined in this project’s literature review.
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Appendix A  Rear-End Crash Contributory Factors from Austroads (2009a)

Straight ahead rear-end crashes:
- queued right-turn vehicles further ahead
- traffic signals around curve or over crest
- other unexpected cause of delay further ahead
- inadequate skid resistance or pavement drainage
- wrong offset timing of linked signals
- ‘see through’ effect of consecutive traffic signals
- inadequate inter-green phase on signals
- presence of parked cars
- unstable flow on high speed road.

Right- or left-turn rear-end crashes:
- turning vehicles where they are not expected (e.g. just before or just after signals)
- a left-turn slip lane permitting high-speed turns.

Crashes involving a parked vehicle:
- unexpected parked vehicle in traffic lane
- edgeline not visible
- lanes too narrow.
Appendix B  Rear-End Crash Countermeasures from Austroads (2009a)

Straight ahead rear-end collisions at intersections:

- Check if these collisions are due to queuing by uninvolved right-turn vehicles. If this is the case, consider banning the turn or provision of protected auxiliary turn lane. This may include a right-turn just after a signalised intersection.
- Where a high frequency of night-time crashes is involved, consider street lighting.
- If there is a high involvement of wet weather crashes, check skid resistance and pavement drainage.
- At signalised intersections, check stopping sight distance to the ‘tail of queue’, adequacy of yellow phase or all-red clearance time. If there is poor visibility to signal aspects, consider provision of overhead mast arm signal.
- Where closely spaced linked signals occur, check offset timing.
- Where signalised intersections or crossings are close but can operate separately, check for ‘see through’ effect of a distant green and near red signal.
- Check the speed limit is appropriate.

Midblock rear-end collisions:

- On busy roads, check forward visibility.
- On freeways, take action to provide stable flow, including added lanes on uphill grades, balancing numbers of lanes, adequate merge and diverge capacity, shifting traffic from the left lane prior to heavy on-flow, variable speed limits or ramp metering.
- Check the speed limit is appropriate.

Right or left-turn rear-end collisions:

- Provide protected right/left-turn auxiliary lanes or extend existing ones.
- Consider prohibition of right-turn if this can be adequately catered for at other locations without adverse safety or environmental effects.
- If at a left-turn slip lane, modify the intersection angle of the lane with the intersecting road to 70 degrees minimum, or consider signalising it, or provide an added lane in the road being entered.
- Improve skid resistance.
- Check the speed limit is appropriate.

Crashes involving a parked car:

- Prohibit parking.
- Indent parking, clear of the traffic lane.
- If angle parking is involved, consider conversion to parallel parking.
- Consider increasing the clearance between the parking and through traffic lanes.
- Delineate the edge of traffic lane past the parking area.
- If there is high night-time crash involvement, prohibit parking or consider adequacy of, or the provision of, street lighting.
- Check the speed limit is appropriate.
Appendix C  Urban and Rural Road Environment Classification Rules

C.1 Rules as a Decision Tree

C.1.1 New South Wales, Victoria, Western Australia, South Australia and Northern Territory

Notes:
Refer to table for definitions of built-up/open and divided/undivided/intersections.
For Victoria: Central Activity District and Melbourne Statistical Division (MSD) areas only; for NSW: Sydney, Newcastle and Wollongong metropolitan areas only; WA, SA, NT and NZ: all areas in the 'mainly built-up' category.
For Victoria: provincial cities, non-MSD cities/towns and small towns; for NSW: country urban areas.
C.1.2  Queensland and Tasmania

Note: Refer to table for definitions of built-up/open and divided/undivided/intersections.

C.1.3  Australian Capital Territory

For the ACT, all roads are considered 'mainly built-up'. However, no fields are available to indicate level of urbanisation, divided/undivided or speed limit. All roads have been assumed to be urban.

C.1.4  New Zealand

Note: Refer to table for definitions of built-up/open and divided/undivided/intersections.
## C.2 Data Definitions Used

Table C 1: Data definitions for level of development/urbanisation and divided/undivided/intersection

<table>
<thead>
<tr>
<th>Jurisdiction</th>
<th>Variable</th>
<th>Values used to define mainly built-up</th>
<th>Values to define mainly open</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>New South Wales</td>
<td>Urbanisation (CRA_URBAN_CODE)</td>
<td>• Sydney metropolitan area • Newcastle metropolitan area • Wollongong metropolitan area • Country urban areas</td>
<td>• Country non-urban areas • Country unknown</td>
<td>Divided/undivided ✓ determined from Type of location (CRA_LOC_CODE)</td>
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<tr>
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<td></td>
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<td></td>
<td>Divided</td>
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<tr>
<td></td>
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<td></td>
<td></td>
<td>13 Divided road</td>
</tr>
<tr>
<td></td>
<td></td>
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<td></td>
<td>15 Dual freeway</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>11 1-way street</td>
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<td></td>
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<tr>
<td>Victoria</td>
<td>Urbanisation class</td>
<td>• Melbourne (Central Activity District (CAD)) • Urban Melbourne excluding CAD e.g. suburbs • Other urban areas in Melbourne Statistical Division (MSD) • Large provincial cities • Small provincial cities • Other non-Melbourne (MSD) cities/towns • Small towns</td>
<td>• Hamlets • Rural (‘open road’)</td>
<td>Divided/undivided ✓ Road character (divided is one of the field options) (yes/no)</td>
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<td>Values to define mainly open</td>
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<td>Queensland</td>
<td>ABS_REMOTENESS</td>
<td>Major cities</td>
<td>Inner regional</td>
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<td>C’way field.</td>
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<td>Kimberley</td>
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<td>Values to define mainly open</td>
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<td>-----------------------------------------------------------------------</td>
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<tr>
<td>Tasmania</td>
<td>LGA</td>
<td>Burnie, Devonport, Clarence, Glenorchy, Hobart, Launceston</td>
<td>Other LGAs</td>
<td>Urban/rural ✔️</td>
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<td>Local/state × (previous project used DIERRoadNo but field not included)</td>
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<td>Speed limit ✔️</td>
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<td>Urban</td>
<td>Rural</td>
<td>Divided/undivided ✔️</td>
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<td></td>
<td>ROAD_DIVIDED (Y = divided)</td>
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<td>Speed limit ✔️</td>
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<tr>
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<td>Divided/undivided ×</td>
<td>Not in our data</td>
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</tr>
<tr>
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<td>Urban</td>
<td>U</td>
<td>O</td>
<td>Speed limit ✔️</td>
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<td>However NZ defines urban (U) as roads where speed limit &lt; 80 km/h and open (O) as ≥ 80 km/h</td>
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### Appendix D Sites Selected

#### D.1 New South Wales

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<tr>
<th>GPS Co-ordinates</th>
<th>Site</th>
<th>Approach</th>
</tr>
</thead>
<tbody>
<tr>
<td>−33.869364, 151.10884</td>
<td>Great Western Highway after Shaftesbury Road intersection, Burwood</td>
<td>Eastbound after intersection</td>
</tr>
<tr>
<td>−33.84347, 151.043588</td>
<td>M4 and Silverwater Road interchange, south of Motorway, Silverwater</td>
<td>Left slip lane</td>
</tr>
<tr>
<td>−33.84347, 151.043588</td>
<td>M4 and Silverwater Road interchange, south of Motorway, Silverwater</td>
<td>Right turn from off-ramp to Silverwater Rd northbound</td>
</tr>
<tr>
<td>−33.865088, 151.041667</td>
<td>Olympic Drive after Vaughan Street intersection, Lidcombe</td>
<td>Northbound</td>
</tr>
<tr>
<td>−33.889698, 150.973239</td>
<td>Hume Highway and Woodville Road, Villawood</td>
<td>Westbound</td>
</tr>
<tr>
<td>−33.89081, 150.973454</td>
<td>Hume Highway and Woodville Road, Villawood</td>
<td>Left slip lane to Woodville Road northbound</td>
</tr>
<tr>
<td>−33.758538, 151.049079</td>
<td>M2 and Pennant Hills Road, West Pennant Hills</td>
<td>Southbound</td>
</tr>
<tr>
<td>−33.792814, 151.132377</td>
<td>Epping Road and Ryrie Street, North Ryde</td>
<td>Westbound</td>
</tr>
<tr>
<td>−33.89215, 151.216963</td>
<td>South Dowling Street and Cleveland Street, Moore Park</td>
<td>Westbound</td>
</tr>
<tr>
<td>−33.901281, 151.215052</td>
<td>South Dowling Street 30 m south of Dacey Avenue, Moore Park</td>
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#### D.2 Victoria

<table>
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<th>GPS Co-ordinates</th>
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<th>Approach</th>
</tr>
</thead>
<tbody>
<tr>
<td>−37.900678, 145.231531</td>
<td>Dandenong Valley Hwy and Ferntree Gully Road, Scoresby</td>
<td>Westbound</td>
</tr>
<tr>
<td>−37.923384, 145.137783</td>
<td>Princes Highway East and Blackburn Road, Clayton</td>
<td>South-eastbound</td>
</tr>
<tr>
<td>−37.915906, 145.125799</td>
<td>Wellington Road and North Road, Clayton</td>
<td>North-westbound</td>
</tr>
<tr>
<td>−37.915906, 145.125799</td>
<td>Wellington Road and North Road, Clayton</td>
<td>South-eastbound</td>
</tr>
<tr>
<td>−37.827544, 145.286286</td>
<td>Dorset Road and Canterbury Road, Bayswater</td>
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<td>−37.836239, 145.171456</td>
<td>Springvale Road and Canterbury Road, Forest Hill</td>
<td>Westbound</td>
</tr>
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<td>−37.886248, 145.066138</td>
<td>Princes Highway East and Murrumbeena Road, Carnegie</td>
<td>Westbound</td>
</tr>
<tr>
<td>−37.744666,144.997494</td>
<td>St Georges Highway and Bell Street, Preston</td>
<td>Northbound</td>
</tr>
<tr>
<td>−37.694391,144.91515</td>
<td>Western Ring Road near Pascoe Vale Road, Glenroy</td>
<td>Eastbound</td>
</tr>
<tr>
<td>−37.691975,144.959015</td>
<td>Metropolitan Ring Road near Coburg-Cragieburn Road, Fawkner</td>
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### D.3 Queensland

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</thead>
<tbody>
<tr>
<td>–27.978542, 153.421683</td>
<td>Gold Coast Highway, 100 m north of Waterways Drive, Main Beach</td>
<td>Southbound</td>
</tr>
<tr>
<td>–27.558515, 153.020892</td>
<td>Beaudesert Road &amp; Granard Road/Riawena Road, Rocklea</td>
<td>Northbound</td>
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<tr>
<td>–27.560522, 153.079164</td>
<td>Kessels Road and McGregor Street, Mt Gravatt</td>
<td>Eastbound</td>
</tr>
<tr>
<td>–27.560578, 153.079384</td>
<td>Kessels Road and McGregor Street, Mt Gravatt</td>
<td>Westbound</td>
</tr>
<tr>
<td>–27.628521, 153.118496</td>
<td>Park Road and Kingston Road, Slacks Creek</td>
<td>Westbound (not left-slip lane)</td>
</tr>
<tr>
<td>–27.55988, 153.081066</td>
<td>Kessels Road and Logan Road, Mt Gravatt</td>
<td>Southbound</td>
</tr>
<tr>
<td>–27.559892, 153.080987</td>
<td>Kessels Road and Logan Road, Mt Gravatt</td>
<td>Eastbound</td>
</tr>
<tr>
<td>–27.48218, 153.030245</td>
<td>Pacific Motorway south of Brisbane River Bridge, Kangaroo Point</td>
<td>Northbound</td>
</tr>
<tr>
<td>–27.373278, 153.023092</td>
<td>Gympie Road and Webster Road, Aspley</td>
<td>South-eastbound</td>
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<td>–27.662532, 153.052843</td>
<td>Waller Road and Brown Plains Road, Browns Plains</td>
<td>Northbound left turn</td>
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## Appendix E  List of Fields Included in Site Inspection Spreadsheet

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<td>Address</td>
<td>One way/two way</td>
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<td>Approach</td>
<td>Total no. of app. lanes</td>
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<td>Suburb</td>
<td>Number of legs</td>
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<td>GPS latitude</td>
<td>Line marking quality</td>
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<td>GPS longitude</td>
<td>Narrowest lane width (m)</td>
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<td>Number of RECs (night)</td>
<td>Short merge lane</td>
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<td>Fatal RECs</td>
<td>Sight distance to nearest decision point</td>
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<td>Other crashes</td>
<td>Likely pedestrian activity</td>
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<tr>
<td>Number of other crashes</td>
<td>Proximity to a curve upstream (m) (excluding slip lane curve)</td>
</tr>
<tr>
<td>Site type</td>
<td>Steepest grade (approx. %)</td>
</tr>
<tr>
<td>Adjacent land use</td>
<td>Closest intersection type downstream</td>
</tr>
<tr>
<td>Road type</td>
<td>Distance to closest intersection downstream (m)</td>
</tr>
<tr>
<td>Speed limit</td>
<td>Closest intersection type upstream</td>
</tr>
<tr>
<td>Operating speed (as observed)</td>
<td>Distance to closest intersection upstream (m)</td>
</tr>
<tr>
<td>App. AADT (one way)</td>
<td>Distance to nearest upstream signalised intersection</td>
</tr>
<tr>
<td>Ambiguous/unclear signage</td>
<td>Nearest intersection:</td>
</tr>
<tr>
<td>Signage visibility issue</td>
<td>Signalled intersection:</td>
</tr>
<tr>
<td>Unnecessary signage</td>
<td>Layout</td>
</tr>
<tr>
<td>Insufficient signage</td>
<td>LT slip lane?</td>
</tr>
<tr>
<td>Advisory/warning signs</td>
<td>Major/minor road on intersection</td>
</tr>
<tr>
<td>Poor curve delineation</td>
<td>Position to intersection</td>
</tr>
<tr>
<td>Bus stop</td>
<td>Dedicated RT lanes for approach</td>
</tr>
<tr>
<td>Traffic signs obscured</td>
<td>Dedicated LT lanes</td>
</tr>
<tr>
<td>External driver distractions</td>
<td>Combined LT/thru lane?</td>
</tr>
<tr>
<td>High demand driveway</td>
<td>Combined RT/thru lane?</td>
</tr>
<tr>
<td>Traffic signs obscured</td>
<td>Any other factors or treatments that may be considered relevant</td>
</tr>
<tr>
<td>External driver distractions</td>
<td></td>
</tr>
</tbody>
</table>