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DESIGNING SAFER ROADS TO COMBAT DRIVER ERRORS – RURAL CRASHES

C-MARC

**CURTIN - MONASH
ACCIDENT RESEARCH CENTRE**

School of Public Health

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Hayman Road

Bentley WA 6102

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MONASH UNIVERSITY ACCIDENT RESEARCH CENTRE
REPORT DOCUMENTATION PAGE

Report No.	Date	ISBN	ISSN	Pages
	September 2013		1835-4815 (online)	58

Title and sub-title: Designing safer roads to combat driver errors – rural crashes

Author(s): Candappa, N., Devlin, A., Logan, D. and Corben, B.

Sponsoring Organisation(s):

This project was funded through C-MARC

Abstract:

The incidence of serious casualty run-off-road crashes in rural Western Australia is significant. Driver behaviour including inadvertent error and deliberate unsafe behaviour compound this issue. Many countermeasures were identified in the literature to address driver error in WA along remote and regional areas. These ranged from perceptual countermeasures such as transverse lines and wide centreline marking to physical measures such as rumble strips and increased lighting. A taxonomy was developed to link the areas of concern with respect to road design and driver error, with available countermeasures.

Key Words:

Driver error, road design, rural roads, run-off-road crashes, perceptual countermeasures, speed

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Preface

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Contributorship Statement

- Literature reviews were completed by Anna Devlin and Nimmi Candappa
- The crash analysis was completed by David Logan
- The taxonomy was developed by Nimmi Candappa, David Logan and Bruce Corben
- The report was written by Nimmi Candappa, Anna Devlin and David Logan
- Bruce Corben provided expert advice and guidance for the project completion

Ethics Statement

Ethics approval was not required for this project.

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EXECUTIVE SUMMARY

The incidence of serious casualty run-off-road crashes in rural Western Australia is significant. High-speed, alcohol consumption, lower incidence of seat belt wearing contribute significantly to this crash concern. Long, monotonous routes with little traffic and little stimuli further exacerbate the situation, creating ready conditions for fatigue, drowsiness and driver error.

A main challenge in creating road designs to minimise such crash occurrence and severe crash consequence is anticipating and accommodating driver error - be the errors inadvertent or arising from deliberately unsafe behaviours. Behaviour change programs have been successful in the past but their effects are slowing and it is timely to seek new ways of designing and operating roads to accommodate the inevitable human errors.

Typical errors and deliberate unsafe behaviour in relation to rural driving identified in the literature included:

- Inappropriate speed
- Exceeding posted speed limit
- Non-wearing of seatbelt
- Unlicensed driving
- Impaired driving
- Fatigue
- Drowsiness
- Inattention and distraction
- Conflict with animals
- Night-time driving, and
- Driving on poor road surfaces

However, in keeping with Safe System philosophy of engineering road design to create road networks *forgiving* of driver error, it is more apt to define the crash scenarios in terms of poor, or inadequate, road design factors. That is:

- Poor choice of speed within the posted speed limit - road layout designed such that higher speeds are encouraged and permitted; inadequate signage provided to warn driver of impending hazard which would require lower speeds, road not designed to include forgiving barriers to prevent serious injury resulting from vehicles running off the road;
- Travelling over the posted speed limit - road layout designed such that higher speeds are encouraged and permitted; inadequate enforcement of speed limits, (keeping in mind that literature indicates driver speed behaviour is unlikely to change unless the posted speed limit appears credible to the driver and supported by the road design, or there is a tangible possibility of being caught by the police for travelling over the

speed limit); road not designed to include forgiving barriers to prevent serious injury resulting from vehicles running off the road;

- Driver impairment - road not designed to include forgiving barriers to prevent serious injury resulting from vehicles running off the road; inadequate enforcement of driver “fitness to drive”;
- External factors - road not designed to include forgiving barriers to prevent serious injury resulting from vehicles running off the road; designs constructed over key animal crossing paths; poor road surface.

The two primary recommendations of this study for the targetting of rural road crashes, typically run-off-road crashes, is the lowering of travel speeds to levels compatible with Safe System ideals and the installation of large-scale wire rope barrier to mitigate crash consequence. It is recognised that the implementation of these measures may not always be immediately practical. Some of the countermeasures identified in the body of the report are highlighted below. It is noteworthy that these alternative measures are rarely fully aligned with Safe System, and therefore likely to be far less effectiveness in addressing the issue of rural crashes.

- Modifying perceived traversable width of the road can affect driver travel speed choice;
- Perceptual linemarking innovations such as full lane width transverse lines can affect travel speed choice;
- A combination of 150 mg of caffeine and a 30 min nap was identified as having the most effect on driver alertness;
- Blue reflector markers introduced 300 m before a rest stop has been used to highlight to truck drivers of the upcoming informal rest stops;
- Potential restricting mobile reception in vehicles to only emergency contacts;
- The use of deterrent scents and animal fencing to minimise animal crossings;
- Edgelines and wide centre markings has been shown to have effect on crash reduction;
- Rumble strips has been shown to have effect on crash reduction;
- Increased lighting has been shown to have effect on crash reduction;
- Covert speed enforcement combined with presence of police over an identified target zone can affect mean speed;
- Reduction in posted speed limits combined with enforcement can affect mean speed;
- Night time speed limits might address poor night time speed perception.

Below is listed a small number of recommendations of measures believed to be worthy of further investigation.

Studies indicate lane widths, presence of sealed shoulders and the number of lanes can all influence driver speed choice.

- Review lane widths with design standards on subject routes to ensure the lane widths are up to standard but are not unnecessarily wider than required;
- Where lanes are wider than design standards, consider perceptual measures to visually reduce perceived width. Consider in particular:
 - Sections of full or peripheral transverse lines repeated intermittently using non-slip paint;
 - Sections of converging chevrons using non-slip paint;
 - Consider narrowing the lanes through edgeline marking while retaining wide shoulders.
- Given the often minimal volumes along remote and some regional routes, consider reducing the number of lanes to the minimum required;
- Where a traffic lane is to be made redundant, consider as options:
 - Reline marking the section of road to include a wide central median;
 - raised edgeline markings;
 - using the now redundant lane to incorporate a 2+1 flexible barrier trial.
 - as a suggestion from the authors, where a lane might be made redundant, or lane width reduced, consider line marking a flatter curve.
- Consider programs of dynamic speed alert signs combined with enforcement to lower travel speeds;
- Consider a trial of high frangible guideposts combined with reduced pavement width to perceptually reduce travel speed;
- Consider speed limit reductions in conjunction with the rumble strips at gateways to towns to produce the necessary braking and eventual speed reductions required;
- Consider a trial of reflective blue markers introduced 300 m before a rest stop to highlight to truck drivers of the upcoming informal rest stops.

The findings in the literature are not necessarily clear-cut. One road feature can have both beneficial and adverse effects on safety concurrently: for example, increasing lane width can reduce potential of side-swipes while increasing likelihood of higher travel speeds. The astute road designer will need to optimise the feature to optimise overall safety while not compromising another aspect of safety.

1. INTRODUCTION

The economic burden as well as the social burden from road crashes is staggering. In high income countries such as Australia, the driver and passenger are typically the victims of road crashes. There are not only psychological and physical consequences for the injured person, road crashes also impact on the lives of families and communities. It has recently been acknowledged that in Australia road trauma can be reduced by enforcing the use of safer vehicles, promoting community acceptance of a low tolerance for risky driver behaviour, and improving Australia's road transport system (1).

Rural crashes on the Australian road transport system are a major and persistent crash concern and are distinct to urban crashes. Urban areas characteristically have higher traffic density, more conflict points and higher-density living compared to rural areas. However, there is evidence to suggest that in rural areas of Australia, road crashes result in more severe injuries and are more likely to result in a fatality compared to crashes in urban areas (2). Data from the United States have indicated a similar pattern with injury fatality rates reported to be up to three times higher in rural areas compared to urban areas (3). The injuries are typically more severe in rural areas due to factors such as, higher impact speeds and slower access to after-crash treatment. Road user factors such as speed, alcohol, fatigue and lack of restraint use also contribute to increased injury severity in rural areas. These road user factors can be differentiated into inadvertent errors and unsafe driver behaviours.

In particular, the incidence of serious casualty run-off-road crashes in rural Western Australia is significant. High-speed, alcohol consumption, lower incidence of seat belt wearing contributes to this crash concern. Long monotonous routes with little traffic and little stimuli further exacerbate the situation, creating ready conditions for fatigue, drowsiness and driver error.

A main challenge in creating road designs to minimise such crash occurrence and crash consequence is anticipating and accommodating driver error - be the errors inadvertent or arising from deliberately unsafe behaviours. Behaviour change programs have been successful in the past but their effects are slowing and it is timely to seek new ways of designing and operating roads to accommodate the inevitable human errors.

This study was completed to explore the crash situation in regional and remote WA within the context of driver error. It seeks potential countermeasures available through literature to address the identified crash problems and create a safer road environment for travel through rural WA.

1.1. OBJECTIVES OF THE STUDY

The objectives of the study were:

- To assess the respective roles of inadvertent errors and unsafe driver behaviour – specifically, speed and speeding in rural road crashes in WA; and
- To identify road design features which aim to minimise the occurrence of inappropriate speeds, as well as driver error and its consequences

1.2. METHOD

Task 1 – Literature Review on Errors

A literature search was undertaken to identify from the available research, the range of errors underlying key serious casualty crashes in rural areas. So far as the literature permitted, these errors were classified as either (i) inadvertent or (ii) arising directly from deliberate, unsafe behaviours. The potential role of travel speed, inattention and fatigue as a source of error was examined in particular.

Task 2 – Analysis of Crash Data

The initial literature search was supplemented by an analysis of crash data provided by WA Main Roads to identify the typical serious casualty crashes occurring on rural roads in WA.

Task 3 – Literature Review on Road Design Features

A second literature search was conducted, this time focussing on road design features and their capacity to reduce driver errors and/or the consequences of those errors. Design features which aim to produce compliance with posted speed limits and safe travel speeds were targeted. The list of identified design features were categorised under the range of inadvertent errors and deliberate non-compliance.

It is noted that much literature exists on the various safety issues relating to rural safety. As well, many studies and literature reviews have been completed on the effectiveness of some of the measures trialled. *Both literature reviews are not considered to be exhaustive* in highlighting the relevant literature in this report. Instead, the reviews focussed on presenting a summary of the issues that exist and many of the countermeasures available.

Task 4 – Workshop and Development of a Taxonomy of Behaviour

The list of driver errors and road design countermeasures were presented at a half-day workshop attended by available stakeholders, with a view to developing a prioritised suite of road design improvements and countermeasures. Presentation of identified countermeasures and the practicality of implementation were discussed at the workshop as were other available treatment options. Treatments were presented with respect to Safe System and non-Safe System compatible measures.

A taxonomy of behaviour and potential countermeasures was developed in regard to the key crash problem of WA rural region - single-vehicle crashes. The taxonomy attempted to readily categorise the driver error as well as the related design error and list potential countermeasures that can be utilised by traffic engineers as well as policy makers, to address this crash type in a systematic approach. It was presented also as a template to help facilitate treatment of other high priority crash types.

1.3. DEFINING RURAL ROADS IN WESTERN AUSTRALIA

ARIA+ classification

The Western Australian rural road network was subdivided into regions, in accordance with the Accessibility and Remoteness Index of Australia, 2006 version, known as 'ARIA+'(4). This geographical schema divides Australia into regions, as shown in Table 1, in accordance with road distance measures to over 12,000 populated localities.

Table 1 - ARIA+ regions of Australia

Region	ARIA+ score	Example localities
Major cities	$ARIA+ < 0.2$	Perth
Inner Regional	$0.2 \leq ARIA+ < 2.4$	Bunbury, Busselton
Outer Regional	$2.4 \leq ARIA+ < 5.92$	Margaret River, Albany, Kalgoorlie, Geraldton
Remote	$5.92 \leq ARIA+ < 10.53$	Port Hedland, Broome, Esperance
Very Remote	$ARIA+ \geq 10.53$	Tom Price, Kununurra

Figure 1 and Figure 2 show the regions graphically. In this analysis, ‘Major Cities’ were not included, since the study targeted rural routes, nor were Inner Regional areas considered to lie within the Perth metropolitan area. Furthermore, Inner and Outer Regional areas were combined into a single category called, ‘Regional’. In a similar manner, the Remote and Very Remote regions were combined and are hereafter referred to as ‘Remote’.

Killed and seriously injured persons in WA

The analysis focussed on those road users killed and seriously injured (serious casualties) for the five-year period 2006 to 2010. Regional and remote serious casualties, despite occurring across practically the entire area of the state (the Perth metro area comprises only 5400 km² of the total 2,650,000 km² of WA), comprise 35% of state’s serious casualties. Single-vehicle serious casualties are more prevalent in regional and remote areas, making up 53% of all single-vehicle serious casualties while one fifth of multiple-vehicle serious casualties occur outside of the Perth area.

A total of 21% of serious casualties occurred in regional WA compared with 15% in remote WA. Single-vehicle serious casualties were similar in proportion between the two regions, with 28% of all single-vehicle serious casualties occurring in regional areas and 25% in remote areas. Multiple-vehicle serious casualties were more common in regional WA, with 15% occurring in this region compared with just 6% in remote areas.

More detail about the characteristics of killed and seriously injured persons in Western Australia can be found in Section 2.2, Crash Types.

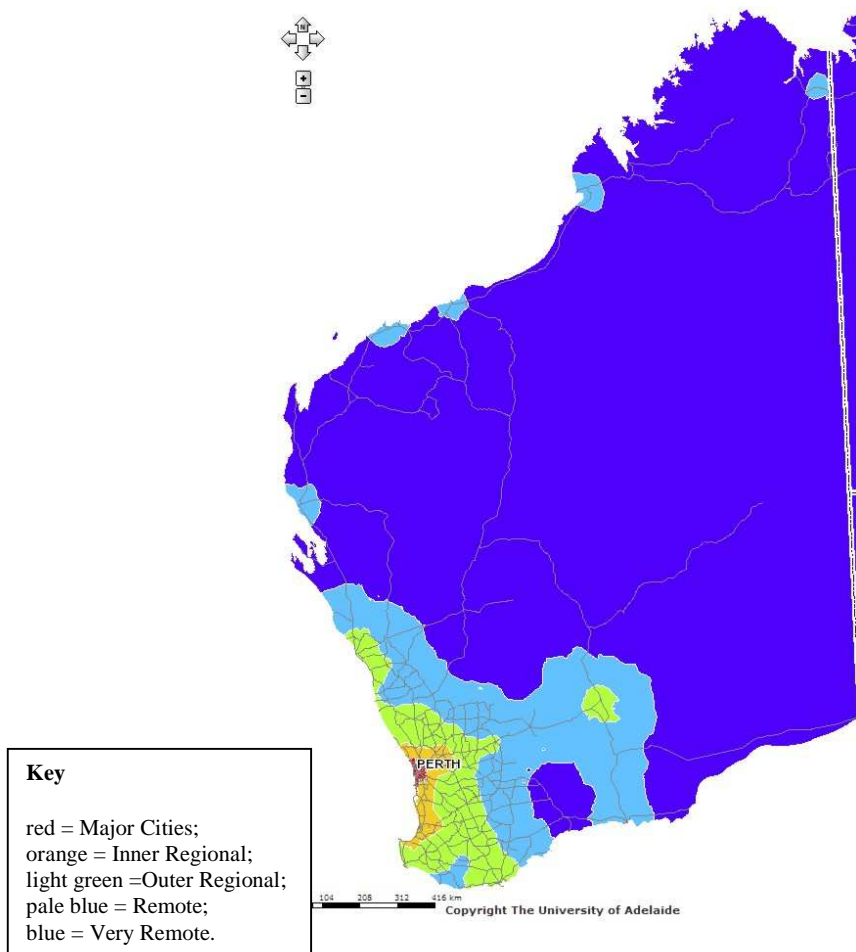


Figure 1 - ARIA+ regions of Western Australia.

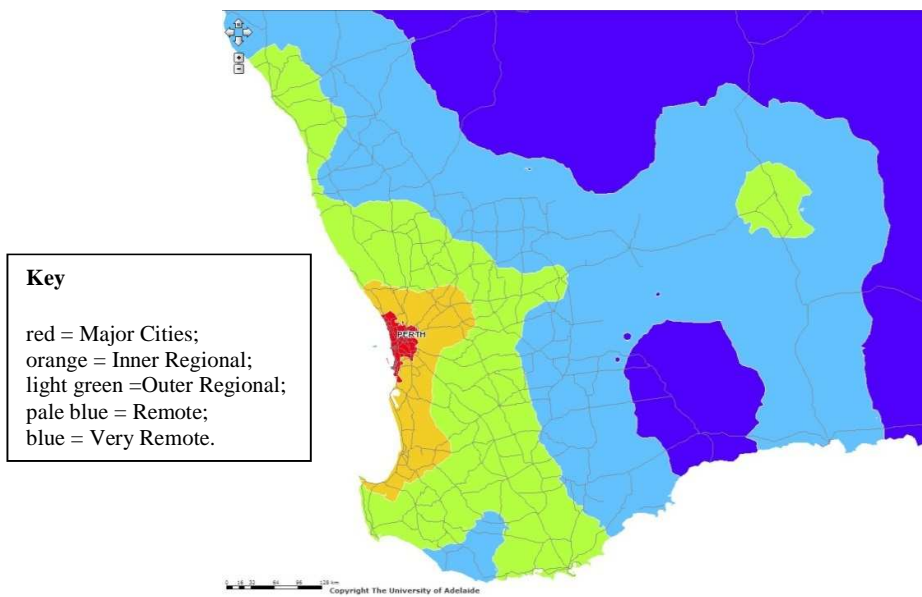


Figure 2 - ARIA+ regions of south-west Western Australia.

2. MAJOR CRASH TYPES

2.1. CRASHES AND INJURY ON RURAL ROADS

A number of behavioural factors have been identified as significant contributors to rural crashes (5). For example, the high crash rates in rural areas have been associated with driver fatigue (6), drivers disobeying road rules such as failing to wear a seatbelt (7) (8), and travelling at a speed in excess of the posted speed limit (9). In addition, there is a growing body of evidence to indicate a relationship between unlicensed drivers and high severity crashes in rural areas (5, 10). Particularly in remote areas of Australia, indigenous populations are more likely to engage in unlicensed driving, unrestrained seatbelt wearing and drink-driving (11).

Crash outcomes in rural areas have been associated with more severe outcomes. Results from an earlier study on WA crashes indicated the rates of serious injury crashes increasing for those involved in a crash in very remote areas compared to highly accessible and moderately accessible areas (12). It has been argued that the increased crash outcomes in rural areas could be attributed to drivers having limited access to medical treatment compared to drivers in urban areas (13) or physicians working in rural areas not being as adequately equipped or experienced to treat trauma victims as physicians in urban centres (14). However, it is important to note that this issue and the associated severity of crash risk remains contentious (15).

Crash severity is dependent upon the physical forces on the body at the time of the impact. A greater emphasis is now placed on designing vehicles that aim to minimise this impact on the driver and passenger in the event of a crash. There is evidence to suggest that drivers in rural areas are less likely to update their vehicles and are therefore driving vehicles that have less than adequate safety features compared to drivers who update their vehicles in urban areas (3). However, the degree to which driver vehicle age contributes to crash risk in urban areas is yet to be quantified.

Excessive speed in rural areas has received wide attention in the research literature and remains a significant problem for both rural and urban drivers (16-18). Typically, speed limits in rural areas comprise freeways with posted speed limits of 100 to 110 km/h and consequently drivers are more exposed to high speed roads. It may be argued there is also greater propensity to engage in excessive travel speeds when driving on rural roads to avoid the onset of driver fatigue due to the long distances that need to be covered. Driver speed and excessive speeding is discussed in further detail in Section 2.5.

On highways, main roads and local roads the majority of crashes in rural and remote regions of WA occurred on straight sections of road rather than curves. This finding is in agreement with a study conducted in South Australia (19) where approximately 58% of rural crashes occurred on straight roads compared to 25% of crashes which occurred on curved roads. The findings from the Queensland study (5) concurred with this, indicating that around 30% of fatal crashes in rural and remote areas occurred on curves with an obscured view. This was not found to be statistically significant however. Of particular note, the majority of fatal crashes (87%) occurred on roads with no significant road feature, suggesting that road geometry did not play an overly significant role in the majority of crashes. These data do not necessarily control for the relative lengths of straights and curves within the network. It is possible that the perception of risk may be reduced on straight highway roads in rural areas where there is less traffic on the roads than in urban areas.

Nonetheless, negotiating curves on the road network can present a present a significant challenge for many drivers, particularly when driving at high speed, in inclement weather, or when the driver's 'fitness to drive' levels are under par. Curve radius, curve length, the number of adjoining curves, driver expectation of curvature of road ahead can all influence the ease with which the driver negotiates the curved road. Curves with a smaller radius are associated with greater crash rates than curves with a larger radius. On the other hand, other studies suggest increasing curve length is associated with greater crash rates (20). This indicates a potential design conflict: lengthening the curve to minimise the radius can create safety issues as can reducing the curve length by tightening the curve.

2.2. CRASH TYPES

Typically, crashes fall in to two major categories: single-vehicle crashes or multivehicle crashes. Single-vehicle crashes involve a vehicle colliding with an object or animal on or off the road, or overturning. Multi-vehicle crashes involve collision with at least one other vehicle and would generally involve an error in judgement by at least one of the drivers.

SINGLE-VEHICLE CRASHES

There is considerable research to demonstrate that a large proportion of crashes on rural roads encompass single-vehicle crashes (19, 21, 22), crash data from South Australia from 1998 to 2000 found that the most common crash type in rural areas comprised single-vehicle crashes (44%), followed by head on (16%) and right-turn (19%) crashes (19). The prevalence of single-vehicle crashes in rural areas is understandable. Given the lower traffic volumes and far reduced number of intersections, the likelihood of conflict with another vehicle is limited, and the long monotonous stretches of road can be conducive to fatigue and drowsiness and distraction, key factors in rural roads crashes.

It is also clear that single-vehicle crashes typically result in more severe injury outcomes compared to multi-vehicle crashes. Single-vehicle crashes in rural areas of Queensland, accounted for three quarters of all crashes in rural roads in Queensland, and 65% of fatal crashes (5).

Single-vehicle crashes often involve young drivers and occur on high-speed roads. In New South Wales, Chen et al. (23) compared the risk of younger drivers involved in single-vehicle crashes by locality and found the risk of severe injuries is significantly higher for young drivers in rural areas compared to young drivers in urban areas. This risk remained high even after adjusting for risky driving behaviour, driver exposure and driving experience. One reason for the high risk of younger drivers in single-vehicle crashes may be the contribution of either exceeding the designated speed limit or driving at an inappropriate speed for the road conditions (23). Information relevant to compliance with speed limits and travelling at safe speeds is discussed in Section 2.5.

Hit-Object Crashes

A large proportion of single-vehicle crashes in rural and remote areas involve vehicles hitting roadside objects, including trees, fences, embankments, poles and rails. The contributory factors are varied and can include: driver fatigue, poor vehicle handling, poor observation, driver inexperience and risky driver behaviour, such as driver speed and driver impairment (24).

A similar pattern was established by Baldock (19) in their study of rural crashes in South Australia, finding that approximately 37% of 160 single-vehicle crashes involved a vehicle colliding with a tree. A large proportion of these crashes (81%) occurred on roads with speed limits at or above 100 km/h. The researchers were also interested in the distance of the tree from the roadside. Approximately 40% of single-vehicle crashes that involved trees hit trees that were less than three metres from the roadside, while 90% of single-vehicle crashes comprised vehicles that struck trees located within nine metres from the road side (19). An earlier study on rural and remote crashes in Victoria from 1997-2001 supports these findings, reporting trees to be the most commonly struck object. According to the researchers, more than half of the crashes involving trees resulted in fatalities or serious injuries (25).

Loss-of-Control and Rollover Crashes

Research has shown that a large proportion of rollover crashes typically involve heavy vehicles rather than passenger vehicles (26).

TYPICAL CRASH PATTERNS IN RURAL WA

As was highlighted in Section 1.1, the predominant crash type in both regional and remote areas is that involving a single vehicle. Multiple vehicle crashes are more common in regional areas. The following sections briefly summarise the characteristics of these two broad crash types in non-metropolitan Western Australia.

Considering both crash types together to provide some perspective, Table 2 shows the top five crash types in regional and remote areas for all crash types.

Table 2 - Breakdown of Western Australian serious casualties involving all crash types in regional and remote areas. Average per annum, 2006-2010.

Regional WA			Remote WA			All non-metropolitan WA		
Type	No.	%	Type	No.	%	Type	No.	%
Hit object	247	41%	Non-collision	151	36%	Hit object	394	39%
Right angle	80	13%	Hit object	146	35%	Non-collision	226	22%
Non-collision	75	13%	Head on	24	6%	Right angle	100	10%
Head on	50	8%	Right angle	20	5%	Head on	74	7%
Rear end	41	7%	Hit pedestrian	17	4%	Rear end	50	5%
<i>other</i>	<i>105</i>	<i>18%</i>	<i>other</i>	<i>62</i>	<i>12%</i>	<i>other</i>	<i>174</i>	<i>17%</i>
Total		100%	Total		100%	Total		100%

Single vehicle

In the WA data analysis, pedestrian and animal impacts appeared as two additional types. Pedestrian impacts comprised 7% of serious casualties in regional areas and 5% in remote areas, while animal impacts made up just 2% in regional areas and 3.5% in remote areas. It is likely that animals could be involved in a greater percentage of single-vehicle crashes where driver took evasive action to avoid an animal and ran off the road as a consequence.

‘Hit object’ serious casualties numbered 68% in regional WA, with a further 21% ‘non-collision’. Of the non-collision crashes, 93% of these were documented as involving a rollover. In remote WA ‘hit object’ serious casualties were considerably lower, at 44%, while non-collisions comprised 46% of the single vehicle crash sample. The vast majority of these (97%) were rollover crashes.

Table 3 shows the primary struck object recorded for single vehicle crashes in regional and remote areas.

Table 3 - Breakdown of single vehicle ‘hit object’ serious casualties, regional and remote areas

Regional WA		Remote WA	
tree or shrub	51%	embankment or ditch	36%
embankment or ditch	18%	tree or shrub	34%
traffic island or kerb	10%	sign, post or pole	12.5%
sign, post or pole	10%	traffic island or kerb	9.5%
other	11%	other	8%
Total	100%	Total	100%

Based on the results in the table above, it is apparent that around 70% of both regional and remote single vehicle struck object serious casualties could be avoided by preventing errant vehicles from coming into contact with natural features on the roadside.

Multiple vehicle

Multiple-vehicle serious casualties are a significantly smaller problem in regional and remote WA, comprising only 20% of the all multiple-vehicle serious casualties in the state. Nevertheless, a short analysis was carried out as part of this study to understand their nature. This crash type has not been further addressed within this report, however, the focus remaining on the single-vehicle crash. Of the 20% of multi-vehicle crashes occurring in remote and rural regions, Table 4 summarises the primary crash types in each of regional and remote areas.

Table 4 - Breakdown of multiple vehicle serious casualties, regional and remote areas

Regional WA		Remote WA	
right angle	34%	head-on	26.5%
head-on	21%	right angle	22%
rear end	17%	rear end	10.5%
right turn through	12%	right turn through	10.5%
other/unknown	16%	other/unknown	30.5%
Total	100%	Total	100%

Multiple-vehicle crashes in regional areas show similar characteristics to those occurring in metropolitan Perth, with right-angle and right-turn-against serious casualties (primarily occurring at intersections) comprising almost half (46%) of the total. The absolute number of multiple-vehicle crashes over the five-year period in remote WA was smaller by a factor of 2.5 (457 versus 1171), with the main crash type being head-on crashes. Right-angle and right-turn-against crashes made up just under a third (32.6%) of remote area multiple-vehicle crashes.

2.3. CRASH CONTRIBUTORY FACTORS

2.4. INADVERTENT ERRORS

Driver Age and Gender

While not an error in itself, road safety researchers have long sought to identify any differences in age and gender believed to be associated with crash involvement (3, 27). There is emerging research to suggest that older drivers are at a significant risk for involvement in serious and fatal crashes in rural areas (21, 28). Remoteness, lack of access to alternative transport options (29) and limited medical facilities have all been identified as contributing to increased risk of crashes for older drivers in rural areas. In particular, there is strong empirical support for older adults being involved in high-severity crashes due to the increased frailty and inability to sustain forces on the body (30). Recently, Thompson and colleagues (2010) reported on crash data from 2004-2008 in South Australia to determine the nature of older driver crash involvement in rural areas (28). Overall, the researchers found a greater number of older driver crashes in rural areas compared to urban areas. This finding represented a linear relationship between driver age and crash involvement when total number of crashes were taken into account. However, once the researchers viewed the number of crashes in the context of the total number of license holders per age group a different pattern started to emerge. Older driver crash rates started to plateau and even slightly increase over the age of 65 years. Furthermore, this trend was greater for rural areas than urban areas. Further analysis of drivers aged above 75 years revealed that drivers living in rural areas were involved in a greater proportion of serious casualty crashes compared to their age-matched counterparts in urban areas. Similarly, a recent study from Kansas in the United States found that drivers aged above 85 years were at a significantly higher risk for crashes of greater severity (21). It is noteworthy that younger drivers have also been identified as being overrepresented in serious casualty crashes in rural and urban areas (31, 32), being associated with inappropriate speeds (15), being disproportionately represented in night-time crashes (33), and are less likely to wear seatbelts (34).

Using the current WA dataset, older drivers made up 9.6% of regional serious casualties and 5.6% of remote serious casualties, compared with 7.3% in metropolitan Perth. Younger drivers between the age of 15 and 24, comprised 27% of serious casualties in regional areas, similar to proportion in Metropolitan Perth (26%). In remote areas, the corresponding figure was 25%. These figures are comparable with those observed in the rest of Australia (35).

Crash characteristics often highlight male drivers as more risk prone (36, 37), young males generally found to be more involved in speed-related crashes, the most likely group to have their vehicle impounded (38), and less likely to be wearing seatbelts (34).

Driver Fatigue and Drowsiness

Drowsiness, driver fatigue and sleep disorders have been identified as important factors which can affect driving performance (39) and contribute to an increased risk of road crashes, particularly for commercial drivers; (40, 41) the performance deteriorating as the night progressed and fatigue increasing with the continuation of the driving task. One definition of fatigue is the “loss of alertness which eventually ends in sleep (42)” though Mabbott reports that the definition and measure of fatigue has been a research dilemma for decades (43). The particular inadvertent error in driving when fatigued and drowsy is the decision to drive when lacking sleep or fatigued and the errors that result from driving when physically unfit to do

so. According to Matthews (2002), disturbed states of driving behaviour can be classified as either: stress and anxiety, or fatigue. Any of these altered mind states can result in maladaptive behaviour that places the driver at an increased risk for making an error (44).

A driver population particularly susceptible to fatigue is truck drivers who are typically on the road for a prolonged period of time, increasing the likelihood of fatigue. The increase in freight trucks on Australian roads in recent years has coincided with an increase in the number of kilometres travelled by truck drivers (45). A survey of 1249 truck drivers was conducted to establish the incidence of driving with sleep debt. The study found that in a 24-hour period around 4 out of every 10 drivers exceeded 14 hours of driving, and 1 in every 2 exceed 14 hours of driving plus other non-driving work. Around 10% of drivers had less than 4 hours sleep on one or more working days. Around 20% reported having less than 6 hours of sleep before driving and nearly 40% of these drivers were involved in dangerous events on the journey ($p < 0.05$). Interestingly, many drivers and company representatives reported fatigue to be a problem for other drivers, but not for themselves (46). These figures compare well with analysis results of fatal crashes in rural and remote parts of Queensland where fatigue was attributed to 12% of non-fatal crashes and 16% of fatal crashes (5).

Police reported crash data from WA from 2006-2010 indicated that police identified fatigue to be related to approximately 3% of crashes in metropolitan WA, and 11% of crashes in both regional and remote areas of WA. It is important to acknowledge that the contribution of fatigue to a large proportion of crashes in the dataset was unknown.

Mabbott and Hartley studied the incidence of drug use among truck drivers in WA. Based on 236 survey responses, results indicated around a third of operators and drivers used stimulants to counter fatigue. The most common stimulant was amphetamine, and interstate drivers were more likely to use illicit and prescription stimulants compared to their intrastate counterparts (42). No data of drug use was available within the current WA database.

Driver Inattention and Distraction

Driver distraction is a prominent type of driver error that can increase the possibility of a crash occurring. The role of inattention and distraction is difficult to clearly defined, available data indicating that distractions have been attributed to between 20-30% of collisions in the US, and around 13% in Australia (47). Garder (48) reported distraction being a factor in 28% of crashes in head-on crashes on a two-lane rural road in the US. In Queensland, inattention and distraction was attributed to around 20% of rural fatal crashes (5). Distractions include mobile phones, text messaging, in-vehicle Internet facilities, sound systems and visual devices like DVD players, as well as eating, drinking, smoking and interacting with other occupants (49). External distractions can include dynamic and static billboards, drivers and riders, and buildings (50). A 2006 NHTSA report on distraction found risk of collision increased by 9 times when reaching for a moving object inside the vehicle, around 4 times when looking at an external object, and around 3-4 times when dialling on a mobile phone (47). Slower reaction times, more intense braking, greater inconsistencies in maintaining speed and greater levels of non-response to traffic signals have been reported to contribute to distractions while driving, increasing risk of collision. While the use of a mobile phone is also considered detrimental to driving performance, and can be equivalent to driving while drunk (51), Crooke reports on a study by Horberry et al. (52) which clarifies that distractions other than the use of mobile phones pose a greater risk of collision (47).

The WA data analysis did not examine driver inattention or distraction as a contributing factor to serious casualty crashes, as this variable is known to be recorded unreliably.

Conflict with Animals

Hit-object crashes involving animals typically occur in rural areas of Australia. The inadvertent error involved in this crash type is selection of the best means of approaching this hazardous situation, an option of swerving, braking, hitting the animal straight-on to be selected often in a split-second decision. There are thousands of crashes involving animals each year in Australia, however, this is likely to be an underestimate of the true number that are reported by the police. The lack of reporting, combined with inconsistencies in reporting, have led to a lack of rigorous studies on the prevalence and evaluation of countermeasures for hit-object crashes that involve animals. One Australian study which addressed this analysed data relating to crashes in Queensland and reported 532 road crashes, 29 of which involved collisions with animals. In an earlier Australian study, Rowden et al. (53) analysed Australian data (1994-1997) and found that 94 fatal crashes and 1392 injury crashes involved animals. Of these, around 80% occurred in 'rural' areas, 70% involved a large stock animal, and 40% involved drivers needing to swerve to avoid collision with an animal. While identifying that much of the data are underestimates and acknowledging recording discrepancies between state agencies, a brief summary of data available from the various states was also provided (53). The majority of animal crashes in northern Queensland (60%) occurred during dusk, night and dawn hours, on roads with speed limits of 100 km/h or above, and involved a high proportion of motorcyclists. This is compared to US data analysis on animal crashes where similarly nighttime crashes comprised around 65% of total animal crashes, predominantly in rural areas (90%) occurring on straight stretches of road. Nearly half the drivers swerved to avoid an animal and collided with a roadside object. Around a third involved motorcyclists. In summary, while empirical data on the prevalence of animal related crashes is limited, there is some evidence to indicate that a greater proportion of crashes occur in rural areas, in the dark and on high-speed roads (53). It has also been suggested that the majority of animal-related crashes result in minor injuries rather than serious casualty crashes (54).

Within the WA dataset, between 1994 and 2000, as a result of animal involvement in crashes, 46 patients were hospitalised, one third of these involving motorcyclists, 90% of these occurring at night time and three quarters of these occurring in rural areas. More recent data between 2001 and 2005, indicated 7 fatal crashes and 101 hospitalisation crashes involved hitting an animal (53). The contribution of animals to rural crashes in WA from 2006-2010 was found to be 0.6% of single-vehicle crashes in metropolitan areas, compared to 2.2% of single-vehicle crashes in regional areas, and 3.4% of single-vehicle crashes in remote areas. The majority of these crashes occurred at night time (58.6%) (35).

Road Surface

Siskind, (5) 2011 found that 14% of fatal crashes involved unsealed roads though none of these involved wet surfaces.

In WA from 2006 to 2010, 7% of serious casualties occurred on unsealed roads in regional WA and just under a quarter (23%) in remote WA. No data are available on traffic volumes on sealed versus unsealed roads in WA, so it is unclear whether unsealed roads are over-represented (35).

Night-time Conditions

Elvik and Vaa (20) cite many studies that suggest the potential for a crash to occur at night is 1.5-2 times greater. It has been found that travel speed can increase in the night time as it is more difficult to gauge driving speed (20).

In WA, crash data from 2006 to 2010 indicated around 30-40% of serious casualty crashes occurred in the dark, highlighting the need for better lighting or more retro-reflective signage within the road network to assist drivers in the dark (35).

2.5. DELIBERATE AND UNSAFE DRIVER BEHAVIOUR

To date, evidence suggests that unsafe driver behaviour increases risk for rural crashes. For example, unrestrained drivers, drivers who engage in drink driving, drivers who drive unlicensed and drivers who exceed the speed limit are all recognised as being at greater than average risk. Unsafe driver behaviour is usually deliberate and often involves disobeying road rules. The following section describes some of the common unsafe behaviours that drivers engage in that have been identified as contributing to rural road crashes.

Speed and Speeding

The relationship between driver speed and road crashes has been widely researched (17, 55). Intuitively, the faster drivers choose to travel, the more likely they are to be involved in a crash and consequently suffer from severe injuries. Higher driving speeds reduce predictability and reduce a driver's ability to control the vehicle, negotiate intersections and stop in time to respond to external stimuli. Higher speeds are typically not enforced on rural roads compared to urban roads, which is a likely contributor to increased rates of fatalities in rural areas. Studies based on hospital data, police data and fatality data indicate that higher speeds on rural roads can contribute to fatality rates up to three times higher than in urban areas (3, 15). Similarly, Perera & Dissakye (21) reported that the likelihood of a high severity injury from speeding is slightly higher on rural roads compared to urban roads (21).

High-speed collisions are also an issue for younger driver crashes. Donaldson et al. (15) investigated 514 648 crashes in Kansas for the period, 1996-2001. The study revealed that a greater proportion of fatal crashes occurred in rural areas, and the rural crashes comprised a large number of young drivers who disobeyed laws such as driving without a licence and exceeding the posted speed limit (15). In addition to failure to obey road rules, driver inexperience has been identified as another contributing factor to young drivers losing control of the vehicle at high speeds in rural areas (7). In Australia, it is also clear that younger driver speed is associated with single-vehicle crashes on rural roads (56). Meanwhile, in an earlier study, Baldock et al. (19) reported that unsealed shoulders increased the risk for high speed crashes for younger drivers on roads with a posted speed limit of 100 km/hr or 110 km/hr. There is good reason to suspect that younger driver inexperience, lack of training, combined with loss of control of the vehicle contribute to a higher incidence of crash involvement.

Non-Use of Seatbelts

Seatbelts are an effective measure for reducing the severity of injury in a crash (57). It has been estimated that seatbelt wearing can reduce the rate of a fatality by up to 45-50% for drivers of light vehicles (20). Seatbelt wearing behaviour can be classified into three types; the consistent wearers, the inconsistent wearers and the non-wearers (57). Australia has a high rate of compliance for seatbelt wearing among adults compared to other countries, seatbelt wearing rates in the front seat now consistently above 90% (49). Unfortunately there remains to be an over representation of adults who are seriously or fatally injured who resist wearing a seatbelt, and unrestrained drivers are typically over represented in fatal rural crashes (5).

A lower incidence of seatbelt wearing is recorded in WA compared to other Australian states, for example 69% compared to 84% in Victoria and 93% in ACT (58). It is noted also that WA data on seatbelt usage is unknown for almost one-third of all drivers, the highest percentage for any Australian State. Data from WA demonstrate that the non-wearers typically comprise males over the age of 17 years (59), with a larger proportion involving indigenous people (58).

Seatbelt wearing can be dependent as well on the accessibility of the area, illegal driver behaviours such as riding unrestrained in the back of a utility vehicle, as well as driving while intoxicated and speeding, were more likely to be associated with residents who resided in very remote areas compared to those who resided in rural areas (12, 24).

Internationally, seatbelt non-wearers are typically found to be those in the younger age group (60, 61). A study conducted by Roberts et al. (34), investigated non-seatbelt wearing in WA and similarly found higher rates of non-seatbelt wearing for males aged 17-29 years compared to those aged 30-59 years (34). The reasons for the younger age group resisting wearing seatbelts may be related to psychosocial factors, such as sociocultural influences, developmental stage, increased propensity to engage in risk taking behaviour, and geographic location.

Alcohol

It is well established that driving under the influence of alcohol can impair driving performance. Driving performance can become compromised with a blood alcohol concentration at, and even below 0.05% (62). Drink driving can contribute to increased deviation in speed, slowed reaction time, reduced information processing, and increased lateral deviation while driving. There is evidence from a variety of studies using crash data to indicate that drink driving is a serious problem for communities in rural and remote areas (5, 63). There is good reason to suspect that the true numbers of drivers engaging in drink driving are underreported as the driver is not routinely examined for the presence of alcohol in their blood. The problem of fatal alcohol-related crashes in rural areas is around seven times greater than in urban areas and around 1.5 times greater when considering all injury types (64). Citing several studies dating from 1985 to 2008, Elvik and Vaa (20) find young drivers and men are overrepresented in alcohol crashes (20).

In rural and remote areas of Queensland between 2004 and 2007, alcohol was found to be a contributing factor in approximately 30% of fatal crashes (5). Even once driver speed, driver age, driver experience, and seatbelt wearing were taken into account, alcohol impairment was still found to be a strong risk factor of injury severity. A study of New South Wales data

investigated 20,822 younger drivers and calculated the risk for single and multi-vehicle crashes according to whether drivers resided in urban versus rural areas. Results indicated a greater proportion of participants who lived in rural areas reported alcohol dependency and risk-taking behaviours than those people who lived in urban areas (56). It is important to consider the contextual differences between rural and urban areas as well. For example, Clapham (11), noted that alcohol and drugs often contribute to crashes involving Indigenous road passengers and drivers. Consequently, socio-cultural factors are likely to act as motivators towards individual attitudes and beliefs about driving when impaired by alcohol.

Within the current WA dataset from 2006-2010, blood-alcohol concentrations were unknown for between one fifth and one quarter of regional and remote serious casualties. Of those that were tested, illegal BAC levels (> 0.05) were recorded in 16% of regional serious casualties and 24% of remote serious casualties. Furthermore, one in every 22 tested in regional areas, and one in every 9.5 in remote areas drivers, had very high BAC levels (> 0.15).

Unlicensed Drivers

There appears to be a higher incidence of crashes among unlicensed drivers. An extensive population-cohort study of 1,616,621 younger drivers (aged 18-27 years) conducted in Sweden, investigated police-reported crashes from 1998-2004 (10). More specifically, the study focused on distinguishing between the crash circumstances of licensed and unlicensed drivers. The study demonstrated that unlicensed drivers were more likely to be involved in crashes on roads with speed limits greater than 70 km/h compared to licensed drivers, and were twice as likely to be involved in single-vehicle crashes where the driver lost control of the vehicle. In addition, unlicensed drivers in rural areas had a greater risk of injury severity compared to licensed drivers in rural areas.

3. ROAD INFRASTRUCTURE SOLUTIONS

3.1. PHILOSOPHY OF ROAD SAFETY SOLUTIONS

Of the highly motorised countries, Sweden and the Netherlands lead the world in road safety performance. During the mid to late 1990s both countries created and adopted fundamentally new and ambitious approaches to reducing road trauma. *Vision Zero*, the Swedish strategy, and *Sustainable Safety*, the Dutch approach while differing in their relative emphases, are both founded on a strong ethical platform and acknowledge the limitations and vulnerability of humans in the road-transport setting. The Australasian formulation of the Safe System combines the best elements of Sweden's *Vision Zero* and the Netherlands' *Sustainable Safety* road safety philosophies. This is an approach adopted generally by WA to work towards its Towards Zero Road Safety Strategy goals.

The Safe System (65) comprises four key principles:

1. **The limits of human performance.** Approaches to road safety so far, have focussed heavily on preventing poor human behaviour such as drink-driving, speeding, and restraint use. Despite the partial success of such initiatives, these and other forms of human behaviour that often rely on good judgment, such as choosing appropriate travel speeds, safe gap selection at intersections, staying within travel lanes, or not driving while fatigued, have not been possible to target using behaviour change programs. Therefore, a guiding philosophy that acknowledges and accommodates for poor human behaviour and judgment is essential for future road safety success.

2. **The limits of human tolerance to violent forces.** Humans have a limited biomechanical tolerance to excessive forces and energy exchanges such as those which occur in a traffic crash. This not only applies to vehicle occupants, but more so to vulnerable road users such as pedestrians, bicyclists and motorcyclists whose biomechanical limits are more aggressively tested during an impact. When tolerance limits are exceeded, serious injury or death results. Acknowledging this, the Safe System seeks to create a road-transport system where ideally, only tolerable forces are generated during a foreseeable collision, thereby increasing a human's chance of survival in the event of a crash. To achieve this, the ability of a vehicle to protect its occupants must be known and taken into account during road system design and operation.

3. **Shared responsibility.** Traditionally, the responsibility of using the road system safely has been placed upon the individual road user. The Safe Systems approach aims to distribute the responsibility for safety performance of the road-transport system with the system designers and operators. In the long-term, however, the Vision Zero target (of no deaths or serious injuries resulting from road crashes) can only be achieved if road users themselves comply with key behaviours such as: speed limit observance, restraint use, driving unimpaired and selecting vehicles with good safety features.

4. **A forgiving road-transport system.** The road-transport system is, fundamentally, a real-world illustration of the basic laws of nature governing the movement of objects, be they vehicles or humans, relative to the physical environment. How these objects interact is, ultimately, a matter of physics varied in time and space according to human intervention, which is particularly difficult to predict or control. It is therefore important that when structuring a road-transport system, it is made to be forgiving of road-user errors. The transport system should be such that, the energies created during the event of an impact, can

be dissipated conservatively between either the vehicle or environment, with minimal transfer to the human(s) involved.

There are four ‘cornerstones’ within the Safe Systems framework, namely:

- Safe Roads and Roadsides
- Safe Speeds
- Safe Vehicles
- Safe Road Use

While crashworthiness limitations of vehicles and the biomechanical tolerances of human are acknowledged, this study is focussed on presenting infrastructural and speed mitigating interventions to address the incidence of rural road crashes in WA.

While converting existing infrastructure to more Safe System compatible designs may be regarded as unrealistic by some, it is noteworthy that:

- Designing and utilising a road-transport network that tolerates high-levels of serious trauma, as is currently done, is unethical. Further, it continues to perpetuate the acceptance of a poor road transport system by road designers, operators and users;
- Importantly in the context of funding of road safety initiatives, converting the existing road network to one that is Safe System compatible through Safe System infrastructure will produce a marked and enduring reduction in fatal and serious injury costs in the long term.

3.2. TWO KEY SAFE SYSTEM COUNTERMEASURES FOR ADDRESSING RURAL ROAD CRASHES

The two primary recommendations of this study for the targetting of rural road crashes, typically run-off-road crashes and head-on crashes, is the lowering of travel speeds to levels compatible with Safe System ideals and the installation of large-scale wire rope barrier to mitigate crash consequence.

- **Speed Mitigation** – As highlighted in much literature, the appropriate setting of posted speed limits to reflect the Safe System standard of infrastructure, is the key means of combatting crash occurrence and crash consequence.^{113, 132} Through the design of an appropriate travel speed environment, the driver is provided with ample reaction time in order to take any evasive action necessary to avoid a crash. Should a crash eventuate, the lower travel speeds and resultant kinetic energy levels result in far less severe crash consequences. In this study, the primary recommendation is the lowering of travel speeds to levels that are compatible with Safe System approaches, supported by infrastructure that reflects Safe System design minimising if not eliminating the potential for law abiding road users to be involved in a crash that results in serious or fatal crash consequences. That is, it is recommended that appropriate posted speed limit be designed in to the infrastructure such that the injury outcome can only be minor should a crash occur.
- **Barrier Installation** - Alternatively, it is recommended that forgiving road system be created, such that the crash impact forces are accommodated in such a way that only minor injury can result. The large-scale installation of wire rope barrier is one proven means of reducing the incidence of serious casualty run-off-road crashes.¹⁶

It is recognised that the implementation of these measures may not always be immediately practical. Other less costly or less contentious interventions have therefore been highlighted below. It is noteworthy that these alternative measures are rarely fully aligned with Safe System, and therefore likely to be far less effectiveness in addressing the issue of rural crashes.

3.3. TREATMENTS TO COMBAT INADVERTENT DRIVER ERROR

Driver Fatigue

Driver fatigue is not always easy to self-monitor, and is difficult to address through infrastructural countermeasures. Direct infrastructural measures would involve barriers to mitigate crash consequence given vehicle departure from road, and design factors such as shoulder sealing and clear and traversable roadsides.

The most common means of addressing fatigue-related crashes directly are through regulated breaks and sufficient sleep (66). Elvik and Vaa recommend major rest stops (that contain tables and chairs and toilet) to be included along major highway every 45 km with minor rest stops – unequipped pull over bays - every 15 km (20). Only one study was found that specifically addressed the effectiveness of rest stops. However, this was with a different focus comparing crash incidence if the driver continued driving rather than pulled over on the hard shoulder (67). Phillips-Nelson et al. (40) studied the effect of taking breaks from night-time driving using a driving simulator, incorporating findings from other studies as well. The study found that breaks of around 30 minutes showed modest improvements in driving performance and subjective fatigue but did not reduce sleepiness. It was concluded that a combination of measures may be needed to target fatigue and sleepiness. Naps of between 7 minutes and 2 hours have been shown to improve factors such as reaction time, alertness and general driving performance (68). More challenging elements of driving have been found to reduce sleepiness, in contrast to monotonous driving tasks and scenery. Interestingly, it was found that the effects of large steering movements were comparable to driving through more varied scenery. This raises the question of the impact of power steering in vehicles on increased fatigue, where as a result of power steering gentler, subtler movements of the steering wheel have replaced large steering movements.

Traditionally, drivers have resorted to measures such as exposure to cold air while driving, drinking caffeine, loud music to alleviate the effects of fatigue and drowsiness. Elvik and Vaa, 2004 cites studies that indicate there is little evidence that countermeasures such as cold air and increasing the volume of the car radio are beneficial and may in fact distract sleepy drivers (20). Interestingly, response to loud sounds has been identified as a means of assessing drowsiness of the driver, more alert drivers less likely to be annoyed by such sounds. Consuming of caffeine (around 150 mg) was considered to have an effect on sleepiness as was a 30 minute nap. Taken in combination was expected to bring about the greatest effect (66).

More recently in-vehicle technology developments provide additional means of monitoring the driver for signs of fatigue (69) as well as in the prevention of lane departures once a driver is fatigued (70). Recent in-vehicle fatigue monitoring systems allow work and rest limits to be set for long distant commercial drivers designed to prevent driver fatigue, providing management with a mechanism to better control fatigue related issues and. The systems provide alerts to vehicle operators to ensure appropriate rest breaks are being taken, and enables monitoring of compliance. Video monitoring options are also available to

monitor driver for signs of fatigue (69). No evaluations of these systems were available at time of review.

Increasing alertness of the driver can be achieved through physical road warnings. Persaud, 2004 investigated the impact of around 340 km of centreline rumbles strips on two-lane undivided rural roads. After considering regression to the mean and accounting for traffic volumes and other influential factors, results indicated reductions in all-injury crashes of around 14% and 25% in head-on and opposing direction side-swipe injury crashes (71).

Recently, an innovative treatment of blue reflectors introduced 300 m from an informal heavy vehicle rest stop has been introduced in NSW. The aim is to alert heavy vehicle drivers unfamiliar with the route of an upcoming rest stop, in an attempt to address fatigued driving among heavy vehicle drivers. Currently, this treatment has been introduced at 100 sites in NSW. Anecdotal evidence suggests the sites are well received & used by the heavy vehicle industry with no recorded adverse comments. Costs were minimal, typical costs of reflectors were approximately \$5.00 each with 6 reflectors per site (45).

Driver Inattention and Distraction

Few measures to reduce the incidence of driver distraction are reported in the literature. This is partly because distraction can be an *involuntary* shift of attention from “stimuli critical to safe driving to stimuli unrelated to safe driving” (72). In many cases then, minimising the impact if this involuntary shift in attention may be the more effective means of dealing with this detrimental influence on driver performance. Measures of potential success include system-based measures such as comprehensive barrier treatment or reduced speed limits (producing less severe impacts if collision cannot be avoided); or vehicle technology, such as Electronic Stability Control to allow more effective correction if loss of control of vehicle ensues as a result of distraction.

Crooke (2006) suggests further research in to effectiveness of restricting mobile and in-vehicle technology (except in emergencies), to address the issue of distraction. Restricting the standard inclusions of in-vehicle media devices, as well as dynamic billboards, can also be considered, given their potential to distract the driver (49, 50). Reduction in “visual clutter” on the road, i.e., excess of signage and other road furniture that requires driver attention, can reduce overload on driver, minimising distraction as well as fatigue inducing stimuli (73).

Conflict with Animals

Collision with animals appears to be on the rise (53), yet little data are available to fully understand the available countermeasures for addressing this crash type, and their efficacy. This section quotes from literature cited by Elvik and Vaa (20), and Rowden (53) as well as the rural and remote area study the authors completed on animal crashes in Northern Queensland (20, 53).

Available measures quoted in the study to minimise animal-vehicle collisions range from:

Physical measures such as:

- warning signs for drivers,
- fencing the road reserve, and
- under and over passes for animals to bypass crossing the road.

Deterrents such as:

- whistles,
- predator scents, and
- roadside reflectors.

Crash avoidance measures such as:

- in-vehicle infrared thermal imaging,
- encouraging trip planning that avoids night-time driving,
- lower speed limits, and
- driver education.

Given the minimal studies on these measures, their effectiveness in minimising the target crash type is difficult to establish. Available research indicate that some measures show promise particularly the physical measures, and other measures appear to not have a significant long-term impacts on crash incidence (20, 53). Conspicuous temporary warning signs can reduce collisions with animals by between 18 and 50%, though Rowden (53) highlights the effects are likely to diminish over time. Rowden (53), notes the potential for infrared imaging to assist drivers detect, and so avoid, potential collisions with animals. Elvik and Vaa, (20) notes other treatments that were found to have some effectiveness: increased lighting was shown to have some effect on crashes with animals as did fencing which was found to reduce crashes by 12% when controlling for traffic, animal density and speed, or 80% if combined with safe crossing facilities. However, crash migration issues can arise with fencing and en-masse implementation of this can be inhibitive due to costs. While over and underpasses can be useful, these are not effective if not combined with fencing (20).

The predator scent, “Plant Plus”, was tested for impact on deterring animals from the roadside. Studies found it effective in deterring Parma Wallabies but that is also appeared to attract red-necked pademelons to the site. This corroborates with other findings that suggest crashes can increase as a result of the scent. While game mirrors were found to affect some deer, any effects on deer behaviour were found to decrease over time (20).

Lowered speed limits promise to have effect on animal-vehicle crashes, reduction in speed limits of 2 km/h or 10 km/h estimated to reduce such crashes by 15% or 56% respectively (20). Hobday, (74), suggests posting speed limits below 80 km/h to assist in animal-vehicle crashes (74). Lowered speed limits have the added benefit of increasing safety in other areas of safety as well.

A Norwegian study found feeding moose in areas of high risk animal-vehicle collisions, thereby lowering need for the animals to cross road in search of food, reduced crash numbers by half (74).

Road Surface

Van de Kerkhof (1987) states road surface is the most important determinant of driving speed, and can bring about speed reductions of between 14-23%. Interestingly, Duncan (1974) states gradients and curves are the most important determinants of travel speed (75).

On the whole, the rougher the surface the slower the speed up to a threshold beyond which the road surface becomes the safety hazard. Martens reviewed a study by Cooper et al, (1980)

that found speeds go up by about 2.5 km/h after resurfacing. A smooth section of road followed by a rough section can bring about 5 % reduction in speeds (75).

Elvik and Vaa, 2004, presented findings on effects of bringing the standard of road and road surface to design standards through treatments such as resurfacing, road realignment and reconstruction, as well as in some cases the instalment of barriers. This was found to reduce crashes by 20% (20). As the treatments were presented as a group, it is difficult to identify the crash reducing effect of road surfacing alone.

Road Geometry and Road Curvature

As noted by Elvik and Vaa (20), an analysis of factors influencing mean speed for a given speed limit was conducted by Vaa in 1991 and found that speed was strongly related to road alignment. Radius of horizontal curves was shown to affect the speed level, the sharper the curve, the lower the travel speed. In fact, both speed and lateral position is modified by the driver in response to driving through a curve (76). Gradient also impacted average speeds, speeds reducing with increasing grade (77). Consequently, uphill grades were reported to have better safety levels (Matthews and Barnes 1988), crash rate estimated to be around 7% lower on uphill compared with similar downhill stretches (77).

One effective means of addressing crashes on curves is to minimise the presence of curves and the radius of curves (20). As can be expected, the fewer the curves and steep inclines, the fewer the crashes, reductions of between 7-12% were estimated when these features were absent (78). Drivers' speed choice when negotiating a particular curve is a function of the curve radius and the approach speed, where the approach speed is established over the preceding 500 m, and may be predicted by the level of winding of the preceding 500 m of the road (78).

Modifying design to minimise curves and inclines however, can be cost prohibitive. Edgelines have been used as a far cheaper means of addressing run-off-road crashes. Edgelines improve safety by visually guiding the driver through a curve and presenting a more defined area for vehicle position (79). Among several other studies, a US study by Tsyganov (80) found up to a 26% reduction in crashes as a result of the installation of edgelines. Also in the US, a New York study found that all crashes on a two-lane winding road reduced by 5% and crashes in to fixed objects were estimated to reduce by 17% through the use of edgelines (78). A driver simulator study found that drivers negotiated a curve by selecting a position on the outside of the lane on approach to the curve, cutting in to the curve, and passing through the middle at curve entry. The curve was exited with vehicle positioned closer to the middle of the lane. Carlsson and Wagner (81) cites other studies that corroborate these findings, such as Van Driel, 2004. More recently, Carlson and Wagner, (81) evaluated the effect of *wider edgelines*, 6 inch lines compared to the standard 4 inch lines. Results indicated a 6 inch wide edgeline was found to reduce casualty crashes by between 15-38%, with BCRs being similar to rumble strips. On the other hand, an increase in speed was also evident when edgeline marking was introduced on road sections that had previously no marking (82). This might be the result of drivers feeling more confident while driving, and resultant risk homeostasis. In response to this finding, County of Wiltshire in the UK removed all line marking akin to the Dutch "Naked Streets" concept and found serious crashes dropped by a third and speed by up to 11 km/h (83).

While this was not evident in the literature, as a suggestion from the authors, where a lane might be made redundant, or lane width reduced consider line marking a flatter curve.

Roadside Characteristics

The landscape through which the driver travels through is also likely to affect driving behaviour. A Swedish study observing participants in a driver simulator presented with three different landscapes (open landscape with no built up area, forested or varied). Open landscapes with little vegetation are more likely to be associated with higher travel speeds (76), similarly, more dense roadside environments were associated with lower travel speeds (84). Open landscapes was also associated with a lateral lane position furthest from the centre of the road while forested landscapes encouraged movement away from the trees and towards the centre of the road. It is interesting to note that similar behaviour is adopted with respect to lane width, the wider the lane, the more the driver will position the vehicle to the outer edge of the road (76). While open roadsides allow greater clear zones and reposition the driver away from the centre line, they also contain minimal reference points and landmarks within the driver's peripheral vision, creating difficulty for the driver to accurately gauge speed (75, 77, 85).

Cut slopes are also associated with higher crash frequencies (86). Flattening a cut slope from a gradient of 30% to 25% reduces the number of injury crashes by around 40% and the number of property-damage-only crashes by around 30%. Flattening from 25% to 17% reduced the number of crashes by a further 20% (20). Driving through cut slopes could potentially be producing a visual tunnel effect, influencing speed choice on driver can affect the accuracy of driver speed perception (87).

Roadsides with the presence of trees, culverts, guardrail have also been associated with higher crash frequencies (86). Similarly, increasing the distance to such roadside hazards, such as increasing the median width or increasing distance from shoulder edge to light pole were both associated with lower run-off-road frequencies. Minimising the number of isolated trees on the roadside, and decreasing the distance between edge of shoulder and guardrail, appear to incorporate a safer roadside design, as study results indicated that the presence of these features were found to increase the frequency of run-off-road crashes can potentially be seen as a consequence of these factors on driver speed perception. Review of design guidance on the relationship between speed environment, curve radius and 85th percentile speed could be beneficial, as research suggests that the current guidance underestimates drivers' speed choices(86).

Sight Distance

Based on the literature review by Elvik and Vaa, (20) it appears that increasing sight distance can have varying effects on safety, depending on the situation. Some studies found there to be no effect (88, 89) while others found it can lead to increased crashes (90). Naturally, crashes are likely to increase without a minimum level of sight distance as well (91). Literature suggests that increasing the sight distance from less than 200 to more than 200 metres (but below 1 km) leads to 23% higher accident rate (lower 95% limit 6% increase, upper 95% limit 43%) but no relationship was found between sight distance and crash rate sight distances over 1 km. Elvik and Vaa (20) suggest that this could be due to sight obstructions being considered hazards, producing lower speeds on approach. A Swedish study found indicates that travel speed is more dependent on the heterogeneity of surrounding areas, and less on the available sight distance.

Night-time Conditions

Increased street lighting is generally expected to reduce night time crashes (20) although studies also indicate that reflectivity and line marking at night can also produce an increase in speed, given the drivers are now less uncertain of the path ahead and more confident in their driving (75). Transverse lines are expected to be more effective in the night as they would be more apparent in the driver's peripheral vision (75). Reduction in speed limits is also expected to reduce travel speed (see section 4.3). Although this still relies on the driver to adhere to the posted speed limits which is not always the case (92).

Driver Age and Gender

Infrastructural measures that address issues relating to age and gender specifically are not common. A safer road environment and Safe System measures that allow for gender or age-related errors to be accommodated are recommended, combined with behavioural programs and targeted campaigns to better align driver behaviour to Safe System compatible behaviour.

4.3 TREATMENTS TO COMBAT DELIBERATE UNSAFE DRIVER BEHAVIOUR

Speed and Speeding

Irrespective of the driver error, treatments that affect the travel speed and eventual impact speed of a vehicle are likely to play a primary role in improving safety. Many studies have examined physical means of reducing vehicle travel speed, while others investigate means of influencing driver choice of travel speed.

A recent review, Road Design Factors and Their Interactions with Speed and Speed limits by Edquist et al. was undertaken on the different aspects of the road environment that influenced driver speed (73). The review focussed on the role of road geometry, driver mental capacity and workload, driver expectations, the presence of other road users, and weather conditions on driver speed. Road geometry includes features such as the road surface, the road width and the road curvature. Typically, the wider the road, the faster the travel speed. Furthermore, road curvature is thought to contribute to speed reduction due to limited sight distance which creates greater uncertainty for the driver about the upcoming road environment.

Several measures have been identified from the literature to effect speed reductions, which are presented below, including reducing the perceived traversable space; use of physical and perceptual countermeasures, reduction of posted speed limits as well as the use of police enforcement. Many of the identified measures below are extracted from findings from Edquist et al. (73), and The Handbook of Road Safety by Elvik and Vaa (20).

1. Reduce Perceived Traversable Space to Reduce Travel Speed

Drivers appear to base speed choice on the perceived driveable space available (73, 75), speeds found to be increasing with increased road width (93). That is, driver speed choice can be influenced by the total width of the cross section of the road which includes number and width of lanes, presence and width of median, as well as presence and width of shoulders. Therefore, a measure of inducing slower speed choice is to reduce the perceived travel space of the road. This is however, not as straightforward. On the one hand, reducing the lane widths to an extent can produce measurable reductions in speed (75), lane widths of 3.4 m for

example generating faster travel speeds than lane widths of 3.0 m (94). Similarly, a Norwegian study on the influence of road characteristics on mean speed of traffic found that speed increases by 1.4 km/h per metre of increased road width at a speed limit of 50 km/h and by 0.6 km/h per metre of increased road width at a speed limit of 80 km/h (20). Another study found reduction in lane width lowered average speeds, and moved the vehicle closer to the centre of the lane while wider road widths increased speeds and moved the vehicle closer to the edge of the traffic lane. Other older studies also found a correlation between lane width and driver speed choice except for one which reported little impact (83).

However, reducing *lane widths* beyond a threshold (approximately the width of a car), does increase likelihood of head-on, run-off-road crashes and side-swipes (75). For this reason, studies have also found that increasing the total width of the road is also recommended by some studies to reduce the number of crashes on roads in rural areas (95). Injury crashes also reduced by around 5% in rural areas when roads narrower than design standards were increased in width to meet standards, and injury crashes reduced by around 8% when road widths were increased within the standards (20). The findings however, do not identify which part of the road width was increased. Increases to shoulder widths, lane widths, median widths can each increase width of road, but each can have a different effect on road safety levels. Traffic volumes can also impact speed reduction. When controlling for traffic volumes and speed, Garber, 2008 did not find any relationship between road width and crashes.⁴⁸ Studies on effects of increases to lane widths found crashes including property damage crashes, were predicted to reduce by around 5% in rural areas; while injury crashes are predicted to increase by 9% (20). This supports the argument that wider lane widths can increase speed (and hence injury consequences) but will reduce likelihood of side-swipes (hence property damage crashes). When considering widening of lanes on curves specifically, crashes can reduce by around 8% (80).

Road width is affected by *median widths* as well. Elvik and Vaa (20) found the presence of medians typically reduce crashes in most situations, though the largest crash reductions were in urban situations. Increasing median width seems to reduce crashes only in rural areas. A significant increase of crashes on roads with wider medians was found in urban areas (20).

Shoulder widths likewise can have an effect on the travel speed choice of the driver, sealing or widening shoulders increasing the perceived travel space of the road, and therefore the mean travel speed. Bakker and van der Horst, 1987, found that the reverse is not always true. A study that reduced shoulder widths on one side of the road (from 1.2 m to 0.3 m) did not necessarily produce a linear reduction in mean travel speeds for traffic in the adjacent direction of travel, but did produce a 4 km/h reduction for the opposing direction of travel. This result could also be affected by the original mean speeds noting that the lane widths were a relatively narrow 2.85 metres, which presumably means recorded speeds were on the lower end of the scale. Ornek, 2007, found crash reduction benefits as the left sealed shoulder increased in width from 0 m to 1 m, peaking at 1 m with tapering benefits for sealed shoulder widths greater than this (96). This is not necessarily supported by the NCHRP report in 2009 that looked at safety performance predictions on multilane rural highways and found increasing benefits with increasing width of sealed shoulder (97).

The key to interpreting these findings is noting the extent to which reductions to road cross section occur. Reducing widths beyond design standards could negate any induced speed reductions by minimising gap between adjacent vehicles and therefore error margin, and potentially increasing driver anxiety in keeping to the lanes. Study results indicate that

increased lane width is favourable in curves, but not always on sections. Travel behaviour in rural roads with higher speed limits can be quite different to urban travel behaviour as well and not all studies made this distinction in relation to the findings.

Reducing perceived traversable area does not need to mean reduction to the physical cross section of the road. Perceptual countermeasures have been used in the past to induce lower travel speeds by suggesting to the driver a higher travel speed than actual (see section 3).

2. Use of Physical Warning Measures to Reduce Travel Speed

On long monotonous routes, drivers may lose track of travel speed and could benefit from a “reminder” of actual travel speed. Physical measures such as rumble strips and edgelines, have been used in the past to provide this reminder as have dynamic variable message signage (VMS). Results on the effect of rumble strips have been somewhat mixed. A systematic analysis of shoulder rumble strips in the US compared miles of edgeline rumble strips with run-off-road fatalities to find a clear relationship between the two, with fatalities steadily decreasing with an increase in rumble strip usage, see Figure 3. Both fatalities and injury crashes are estimated to reduce by around 30% on undivided two-lane rural roads by around 50% on divided multi-lane roads (98). It is noted that the study does not appear to have been controlled for other confounding effects. The US Federal Highways Agency indicated longitudinal rumbles strip edge lines produced speed reductions of around 8 km/h although transverse rumble strips produced speed reductions of less than 2 km/h (99).

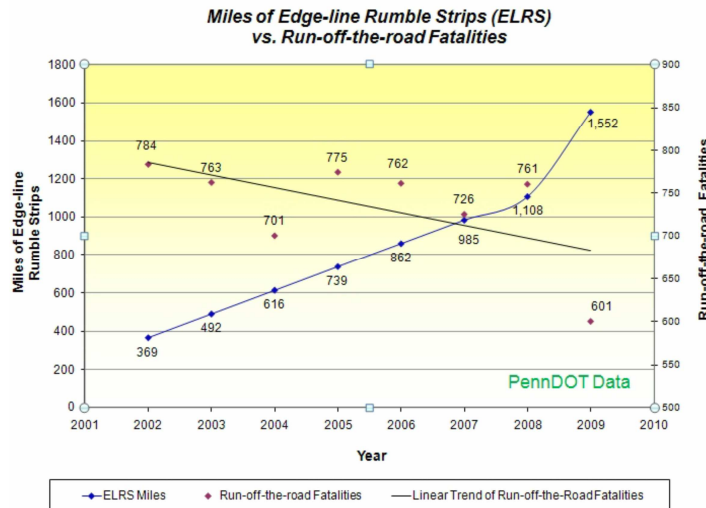


Figure 3 - Relationship established by Wilder on Fatality versus Miles of Edgeline Rumble Strips
Source: Wilder 2011

Other studies have found minimal reductions. One study found a 2 km/h reduction in speed resulting from milled *rumble strips* separating the traffic lane from the median (6). Another a UK-based modified version of rumble strips termed ‘rumble waves’ aimed at reducing noise pollution, was also found to affect speed reductions in the same order of around 1 km/h (100). A study in Sweden by Kronqvist (101) found rumble strips instigated more active braking than any of the other measures but then tended to be followed by immediate increase in speed, resulting in no direct speed reductions.

As discussed earlier, *edgelines* generally have been found to improve safety, though studies on the speed reduction effects of edgelines have not been conclusive, with both increases and decreases in average speed recorded after the installation of edgelines.

Warning signs are used in many forms to alert the driver of the appropriate speed for a section of road. *Static advisory signs* are used on tight curves to indicate an appropriate safe speed to negotiate the curve, and dynamic warning signs are often used alert the driver of travel speeds above the posted speed limit. The effects of these are varied. Advanced warning signs have been found to have crash reduction factors of around 15-30% on rural bends (20, 100). A US report by FHWA quotes a 1968 study that found a reduction of 18% associated with advisory signs (78). On the whole advisory speed signs on curves do not seem to lead to lower speed, but appear to produce fewer crashes. Elvik and Vaa suggesting drivers viewed the signs as a warning for an impending hazard rather than a suggested travel speed (20).

Dynamic signs displaying warning messages to speeding drivers were found to have some speed reducing impacts. A speed feedback sign on three rural main roads, displaying to the driver actual travel speeds were estimated to reduce speeds by around 11 km/h (99). A case study of a rural four-lane divided highway indicated speed activated warning signs produced speed reductions of around 6.5 km/h along a route with 85 percentile speeds of 115 km/h. In a study on countermeasures for rural roads, Oxley, 2004, cites studies that found warning signs an effective means of lowering travel speed: LED warning signs flashed when vehicle headways were too small, or when approach speeds were too high (95). Two case studies of flashing lights to warning signs on two horizontal curves in the US were recorded to reduce 85th percentile speeds by around 1.5 km/h (98).

Repeater speed limit signs – a speed activated speed limit reminder on a major road – found a speed reduction in 85th percentile speeds of around 8 km/h. Road pavement marking of the word “SLOW” appeared to have no real effect (99).

3. Use of Perceptual Countermeasures to Reduce Travel Speed

Road widths and lane widths can also be reduced perceptually through other forms of linemarking. A reduction in speeds was found subsequent to cross hatching on the edge of the road (73). Several forms of line marking designs have also been tested to reduce the perceived width of the lane including herringbone, peripheral and lane width transverse lines. These measures have been found to reduce travel speed (102), sometimes as much as 11 km/h (103).

Road safety perceptual countermeasures (PCM) use visual cues on the road to trigger a response from the driver. Transverse markings are defined to work in two ways: either they distort the perception of speed by the driver, suggesting to the driver an increased travel speed with a resultant reduction in speed to compensate for this; or they provide additional peripheral cues by which to estimate travel speed, allowing the driver to more accurately gauge speed of travel (83). Three forms of transverse lines were tested in a driving simulator study by Godley (103). Transverse lines across the full length of the traffic lane, peripheral lines on the edges of the lane and a herringbone pattern, which included the peripheral lines but angled at 45 degrees towards or away from the hazard. The measures were found to act as a hazard alert as well as a perceptual speed reduction measure. The driver appeared to choose travel speed based on the treatment up until the point the driver could make a judgement of the appropriate speed based on viewing the hazard itself. Results indicated speed reductions in all cases, immediately and through the treatment. The full transverse lines produced the

greatest reductions of up to 11 km/h. The herringbone and peripheral designs were not found to be as effective as the full transverse lines, the peripheral lines producing between 6 and 9 km/h reductions. Herringbone designs had the effect of flattening the path through the curve. Both even spacing of the lines and gradual reductions in spacing on approach to the hazard were tested, results indicating no obvious influence of the spacing on speed reductions (103). It needs to be noted that transverse lines across the full width of the lane can contribute to lower skid resistance for vehicles, and therefore peripheral lines might be preferred as a treatment option. A Melbourne study evaluated peripheral lines along a winding road, as well as guide posts that varied in height through a curve, height peaking at the apex of the curve. Both designs were intended to reduce travel speeds of motorcyclists along the route. Findings indicated some success, though the longevity of these effects has been questioned (102).

Evaluation results of the introduction of “Converging Chevron Marking Patterns” on rural roads have shown promise. In the early 1990s, Japan introduced such markings to create the impression of narrower lanes and higher travel speeds, with reviews of the study indicating effective speed reductions (104). Encouraged by this, Wisconsin in the US trialled a similar measure where a reduction in 85th percentile speeds of 22 km/h was noted where before treatment speeds were over 110 km/h (16). A statically significant reduction in targeted crashes was also recorded. Introduced on an S-curve on a two-lane roadway with travel speeds of around 60 km/h, evaluations indicated speed reductions of around 6 km/h (99).

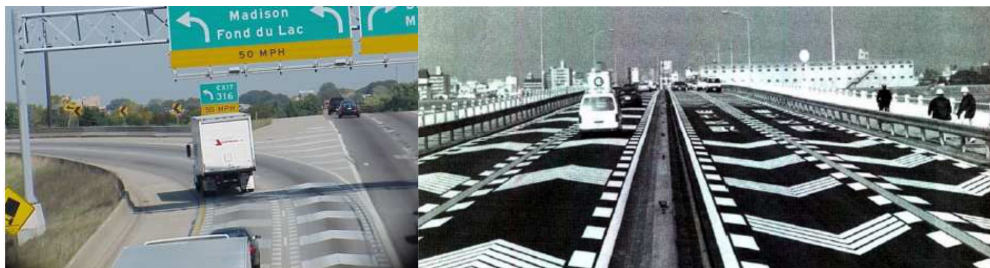


Figure 4 - Converging Chevron Design, Wisconsin (left) and Japan (right)
Source: Drakopoulos and Vergou, 2003 & Rothenberg, 2004

Another PCM tested evaluated by Godley was termed the “Drenthe Province” treatment from The Netherlands. This included 2.25 m lane widths, wide centrelines with alternate sections of gravel and white linemarking and edgeline marking with alternate sections of gravel edgeline and road pavement. This treatment was found to produce speed reductions of around 2 km/h (103). Road surfaces that “squeak” when vehicles travel over a speed limit have also been suggested in the literature with the inclusion of gravel chippings along the centerline. Extending this, similar to rumble strips, surfaces that squeak can also be used to discourage drivers from straying to the outer edges of the lane. Auditory warnings are particularly appropriate in rural areas where noise pollution is less of a concern.

Hatched median strips were also tested and found to effect speed reductions of around 3 km/h. Narrow lanes of less than 3 metres wide lanes also produced speed reductions of around 3 km/h. The combination of the hatched median strips with either gravel edgeline marking or narrow lanes were found to produce speed reductions of around 6 km/h but only on straight stretches (103).

With open roadsides containing minimal reference points or the restriction of peripheral vision, drivers can often have difficulty accurately gauging their speed (77, 85). This is also

experienced in many tunnel environments. A driver simulator study by Manser and Hancock (105) looked at participant speed behaviour when exposed to visual patterns along a tunnel wall. The pattern found to be most associated with reduced speed consisted of vertical black and white stripes that reduced in width as the driver proceeded through the tunnel (Figure 5). The design produced statistically significant speed variations of around 4 km/h, the study noting that though the drivers were instructed to maintain speed through the tunnel, drivers exposed to this particular visual pattern, responded by unconsciously decreasing vehicle speed throughout the tunnel when compared to the control cases (12). The longevity of the design was not examined.

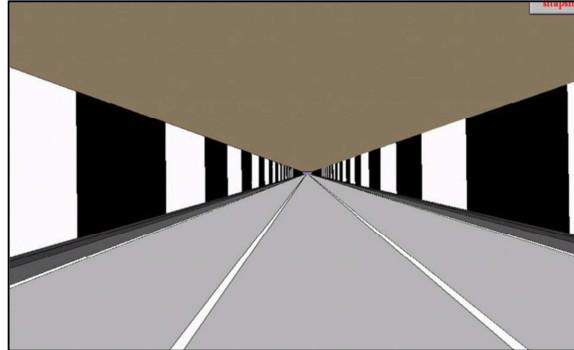


Figure 5 -Graphic of perceptual countermeasure trialled in driving simulator

Source: Manser and Hancock, 2007

Trees on the side of the road for speed perception were not found to produce significant reductions in speed (84) although Martens reported that taller objects on the roadside lead to greater speed reductions, and the absence of trees were found to lead to increase in speed (76). The combination of objects on the side of the road and reduced pavement width was highlighted as an effective countermeasure (75).

Minimising legibility of signage to an extent was also shown to reduce travel speed (106).

4. Use of Speed Limit Reductions to Reduce Travel Speed

It is recognised that the level of driver non-compliance to speed limits is significant. An early survey of WA speed limit compliance found nearly half of the drivers surveyed exceeded the speed limit by 0-9 km/h; 12% exceed the posted speed limit by over 10 km/h. In general, a larger percentage of drivers exceed the posted speed limit in rural areas (107).

However, posted speed limits can also indicate a benchmark for travel speed, at least for the large percentage of drivers that do comply with the speed limits. Furthermore, there is a greater association of high speed crashes in rural areas, road sections with speed limits over 85 km/h more greatly associated with run-off-road crashes, and were less likely to have zero crashes within that road section (108). Speed and posted speed limits therefore do play a critical role in defining the boundaries of safe travel speed (109).

Reducing the posted speed limits is considered an influential means of reducing travel speeds. Retting and Teoh report on changes to speed limits on rural highways and conclude that travel speed can be “curbed or even reversed” when speed limits are lowered (110). Kronqvist (101) looked at several measures of reducing approach speeds at an intersection, including the impact of reducing speed limits. The various measures of the Swedish study included placing a gantry with directional signage; rumble strips on the approach; reduced

speed limits; narrowing of the approach from two lanes to one; and adding trees and fencing on the approach. The study found that the reduced speed limit signs were the most likely to effect speed reductions and recommended that speed limit reduction in conjunction with the rumble strips may produce the necessary braking and eventual speed reductions required for the site (101).

These findings are further supported by a study of variable speed limit signs at 3 rural sites in Finland, which reduced speed limits based on weather and found speed reduction of between 7.5 km/h to 13 km/h (99). The higher the initial speed limits the greater the likely reduction in travel speed, reductions in speed limits of between 10-20 km/h having the impact of reducing travel speed by 1-5 km/h (83).

Infrastructural measures are generally more effective than the lowering of speed limits (111) as the physical measures induce speed reduction as opposed to relying on driver compliance to speed limits. Nonetheless, speed camera programs have been found to be highly effective in crash reduction (112, 113) and reduced speed limits in combination with enforcement programs are considered a highly viable option of reducing mean travel speed.

Interestingly while speed cameras are predicted to effectively reduce all injury crashes through crashes by up to 17% (20), the effect is more applicable in urban areas than rural (114). This could be due to increased exposure to vulnerable road users in urban areas, as well as the plethora of kerbside objects in close proximity to the traffic lanes, increasing likelihood of collision, and thereby reaping greater benefits from enforced speed limits. Covert speed camera programs are generally found to be more effective than overt ones, though a combination in the same area was the most effective (115, 116).

A prominent police presence has been shown to have a positive influence on driver behaviour. Comparing speed limit sign, radar enforcement and marked police car, only police car produced had significant effect on speed. Speed behaviour was found to be modified by enforcement only if driver is made aware of speed violation and if there is a clear possibility of punishment. Repeated enforcement at on location can effect speed reductions over a time period (time halo effect) but is unlikely to produce a speed reductive effect in surrounding sites (distance halo effect) (75).

During a publicised double demerit period in WA, evaluations found injury crashes where speed was a factor were reduced by 40% reduction, and fatal crashes were halved (117).

Non-Seatbelt Use

No infrastructural measures were noted in reviewed literature to address this unsafe behaviour of non-seatbelt wearing, and preventing the crash or minimising the crash impact forces appear to be the most effective means of addressing this driver behaviour. Infrastructural measures to minimise the likelihood of a collision occurrence and consequence are addressed elsewhere in the report and have not been duplicated here. Nonetheless, findings on the effectiveness of the more common means of addressing seatbelt wearing propensity have been briefly identified below. An in-depth study on non-seatbelt use in Australia and steps to address this was completed by Oxley et al in 2009 “*Non-wearing of adult seatbelts in Australia: where to next?*” (58). Much of the below section and references are sourced from this report.

Typical means of addressing this concern has been through enforcement and increased penalties, driver education, and media campaigns, penalties comprising both a fine and demerit points for most infringements. Anecdotal information suggests there has been a reduction in cautions issued for seatbelt offences during the period 2007 and 2008. See Oxley et al 2009 for current penalty structure in WA.

Enforcement of seatbelt usage in rural and remote WA is particularly challenging given the vast distances as well as the high incidence of non-wearing amongst Indigenous populations (58).

Several initiatives have been taken by the WA government and road agencies to increase the incidence of seatbelt use (see Oxley et al. (58) for details). Among these, compulsory seatbelt legislation combined with enforcement continues to be the main influence on seatbelt wearing levels, the overwhelming majority of evidence has clearly shown that the introduction of compulsory use legislation has been responsible for increase in the rates of seatbelt use and significant reductions in road fatality and injury rates(118, 119). For example, wearing rates escalated from 28% to 83% in two years in State of Alberta, Canada, when wearing a seatbelt while travelling was made compulsory, dropped to 45% during a period of voluntary usage, and increased back to 88% when usage was once again deemed compulsory (119). Another study by Gundy, (120) on effects of a combined enforcement and publicity campaign, conducted in Friesland, The Netherlands (1984), found an improvement in wearing rates of about 25 % for both inside and outside built-up areas (20). Publicity and educational campaigns on their own have been found to have minimal effect on increased seatbelt usage but are expected to have major road safety benefits when combined with legislation and enforcement (58). In-vehicle seatbelt reminder systems have been found to be effective in increasing seatbelt usage of between 5%-10% (121, 122).

Alcohol

Few infrastructural measures apart from comprehensive roadside barriers are available to mitigate the influence of alcohol on road crashes. Enforcement measures such as the Double Demerit initiatives conducted by WA have found to reduce the higher level of fatal crashes involving speed and alcohol that have been observed over holiday periods. Enforcement of various kinds including “blitzes” have been found to have some effect on crash reduction (20). Again, preventing the crash or minimising the crash impact forces appear to be the most effective means of addressing this driver behaviour.

5. TAXONOMY

The matched lists of driver errors and road design features were summarised and compounded into a taxonomy. Based on the project focus and discussions through the development of the taxonomy, potential crash cause, related driver error and road design features are incorporated in to a circular taxonomy, with possible countermeasures presented for each category. Moving out radially:

1. The taxonomy core highlights four crash cause categories;
2. The next layer identifies within these categories behaviour that commonly leads to errors;
3. The next layer identifies road design features that are likely to have elicited the error;
4. The next two narrow layers are default recommendations of countermeasures that assures Safe System Alignment of design;
5. The outer layers provide alternative, less effective countermeasures that can be trialled to address the issue of rural road crashes.

The means of utilising the taxonomy is presented in Flow Chart 1. Essentially, once the area of concern is identified (speed, impairment etc), the driver error can be selected, leading to the identification of the road design inadequacy. This then leads to several countermeasures that can be implemented or trialled.

Flow Chart 1: Suggested Process for Taxonomy to be used:



6. COUNTERMEASURES IN RELATION TO WA RURAL CRASHES

The main focus of this study was to address the percentage of crashes involving vehicles running off the road and colliding with roadside objects or overturning in WA. While other crash types exist, addressing these crash scenarios will target the dominant crash type responsible for the majority of serious casualty rural road crashes in WA.

It can be said that single-vehicle run-off-road crashes are generally the result of poor choice of travel speed (e.g., not driving to conditions or exceeding the posted speed limit), driver impairment (e.g., fatigue, drowsiness, alcohol, distraction), or inadequate driver response to external factors (conflict with animals, weather-related factors, poor road surface).

However, in keeping with Safe System philosophy of engineering road design to create road networks *forgiving* of driver error, it is more apt to define the crash scenarios in terms of poor or inadequate, road design factors. That is:

- Poor choice of speed within the posted speed limit - road layout designed such that higher speeds are encouraged and permitted; inadequate signage provided to warn driver of impending hazard which would require lower speeds, road not designed to include forgiving barriers to prevent serious injury resulting from vehicles running off the road;
- Travelling over the posted speed limit - road layout designed such that higher speeds are encouraged and permitted; inadequate enforcement of speed limits, (keeping in mind that literature indicates driver speed behaviour is unlikely to change unless the posted speed limit appears credible to the driver and supported by the road design, or there is a tangible possibility of being caught by the police for travelling over the speed limit); road not designed to include forgiving barriers to prevent serious injury resulting from vehicles running off the road vehicles running off the road;
- Driver impairment - road not designed to include forgiving barriers to prevent serious injury resulting from vehicles running off the road; inadequate enforcement of driver “fitness to drive”;
- External factors - road not designed to include forgiving barriers to prevent serious injury resulting from vehicles running off the road; designs constructed over key animal crossing paths; poor road surface.

In the context of rural and remote road networks in WA, the relatively minor volumes of traffic particularly in remote WA make it difficult to justify costly realignments of roads, and flattening of curves and grades. Below is listed a small number of recommendations of measures believed to be worthy of further investigation. The standard treatments such as CAMs and warning signs have not been identified here as it is believed these would be utilised as necessary in current practice.

Studies indicate lane widths, presence of sealed shoulders and the number of lanes can all influence driver speed choice.

- Review lane widths with design standards on subject routes to ensure the lane widths are not unnecessarily wider than required;

- Where lanes are wider than design standards, consider perceptual measures to visually reduce perceived width. Consider in particular:
 - Sections of full or peripheral transverse lines repeated intermittently using non-slip paint;
 - Sections of converging chevrons using non-slip paint;
 - Consider narrowing the lanes through edgeline marking while retaining wide shoulders.
- Given the often minimal volumes along remote and some regional routes, consider reducing the number of lanes to the minimum required;
- Where a traffic lane is to be made redundant, consider as options:
 - relinemarking the section of road to include a wide central median (see section);
 - raised edgeline markings;
 - using the now redundant lane to incorporate a 2+1 flexible barrier trial.
 - as a suggestion from the authors, where a lane might be made redundant, or lane width reduced consider linemarking a flatter curve.
- Consider programs of dynamic speed alert signs combined with enforcement to lower travel speeds.
- Consider a trial of high frangible guideposts combined with reduced pavement width to perceptually reduce travel speed
- Consider speed limit reductions in conjunction with the rumble strips at gateways to towns to produce the necessary braking and eventual speed reductions required
- Consider a trial of blue markers introduced 300 m before a rest stop to highlight to truck drivers of the upcoming rest stops

As can be seen through the literature, one road feature can have both beneficial and adverse effects on safety concurrently, for example, increasing lane width can reduce potential of side-swipes while increasing likelihood of higher speeds. The astute road designer will need to optimise the feature to optimise overall safety while not compromising another aspect of safety.

7. REFERENCES

1. Council. AT. National Road Safety Strategy, 2011-2020: Australian Transport Bureau; 2011.
2. Pyta V, Tziotis M. Heavy vehicle crashes in rural and remote Australia and New Zealand. Australasian College of Road Safety Conference, 2011, Melbourne, Victoria, Australia; 2011-09; Pearce, ACT, Australia: Australasian College of Road Safety (ACRS); 2011.
3. Zwerling C, Peek-Asa C, Whitten PS, Choi SW, Sprince NL, Jones MP. Fatal motor vehicle crashes in rural and urban areas: decomposing rates into contributing factors. *Injury Prevention*. 2005;11(1):p. 24-8.
4. Australian Population and Migration Research Centre. Accessibility and Remoteness Index of Australia: The University of Adelaide; 2006. Available from: <http://www.adelaide.edu.au/apmrc/research/projects/category/aria.html>.
5. Siskind V, Steinhardt D, Sheehan M, O'Connor T, Hanks H. Risk factors for fatal crashes in rural Australia. *Accident Analysis & Prevention*. 2011;43(3):1082-8.
6. Anund A, Kecklund G, Vadeby A, Hjalmdahl M, Åkerstedt T. The alerting effect of hitting a rumble strip—A simulator study with sleepy drivers. *Accident Analysis & Prevention*. 2008;40(6):1970-6.
7. Davis GA, Pei J, Morris P. Identification of causal factors and potential countermeasures for fatal rural crashes. Minnesota: Minnesota Department of Transportation, 2005.
8. Rakauskas ME, Ward NJ, Gerberich SG. Identification of differences between rural and urban safety cultures. *Accident Analysis & Prevention*. 2009;41(5):931-7.
9. Mackenzie J. Characteristics of high injury severity crashes on 80-110 kmh rural roads in South Australia. Australasian Road Safety Research Policing Education Conference, 2008, Adelaide, South Australia.
10. Hanna CL, Hasselberg M, Laflamme L, Moller J. Road traffic crash circumstances and consequences among young unlicensed drivers: A Swedish cohort study on socioeconomic disparities. *BMC Public Health*. 2010;10(1).
11. Clapham K, Senserrick T, Ivers R, Lyford M, Stevenson M. Understanding the extent and impact of Indigenous road trauma. *Injury*. 2008;39, Supplement 5(0):S19-S23.
12. Marchant R, Hill D, Caccianiga R, Grant P. Reported road crashes in Western Australia 2006. Perth, Western Australia: Road Safety Council of Western Australia, 2008.
13. Clark DE, Cushing BM. Rural and urban traffic fatalities, vehicle miles, and population density. *Accident Analysis & Prevention*. 2004;36(6):967-72.
14. Muelleman R, Wadman M, Tran T, Ullrich F, Anderson J. Rural motor vehicle crash risk of death is higher after controlling for injury severity. *Journal of Trauma-Injury Infection & Critical Care*. 2007;62(1):221-6.
15. Donaldson AE, Cook LJ, Hutchings CB, Dean JM. Crossing county lines: The impact of crash location and driver's residence on motor vehicle crash fatality. *Accident Analysis & Prevention*. 2006;38(4):723-7.
16. Doecke S, Kloeden C, McLean A. Casualty crash reductions from reducing various levels of speeding. Monograph. Adelaide, South Australia, Australia: University of Adelaide. Centre for Automotive Safety Research (CASR), 2011 2011-02. Report No.: 9781921645136 1449-2237.
17. Kloeden C, McLean A. Rural speed and crash risk. Road Safety Research, Policing and Education Conference, 2001, Melbourne, Victoria, Australia.

18. Retting R, Teoh E. Traffic speeds on interstates and freeways 10 years after repeal of national maximum speed limit. *Traffic Injury Prevention*. 2008 2008-04;9(2):119-24.
19. Baldock M, Kloeden C, McLean A. In-depth research into rural road crashes. Monograph. Adelaide, South Australia, Australia: University of Adelaide. Centre for Automotive Safety Research (CASR), 2008 2008-12. Report No.: 9781920947583 1449-2237.
20. Elvik R, Vaa T. *The Handbook of Road Safety Measures*. Oxford: Elsevier Science; 2004.
21. Perera L, Dissanayake S. Contributing factors to older-driver injury severity in rural and urban areas. *Journal of the Transportation Research Forum*. 2010;49(1):5-22. PubMed PMID: 01165599.
22. Ratnayake I, editor *Identification of factors related to urban and rural highway crashes* 2004.
23. Chen HY, Ivers RQ, Martiniuk ALC, Boufous S, Senserrick T, Woodward M, et al. Risk and type of crash among young drivers by rurality of residence: Findings from the DRIVE Study. *Accident Analysis & Prevention*. 2009;41(4):676-82. PubMed PMID: 01137454.
24. Edmonston C, Sheehan M, Siskind V. "It's just the way it is out here ...": the role of 'remoteness' and 'context' in understanding and preventing rural road trauma. *Australasian Road Safety Research Policing Education Conference, 2009, Sydney, New South Wales, Australia; 2009-11; Sydney, New South Wales, Australia: Roads and Traffic Authority (RTA); 2009.*
25. Symmons M, Haworth N, Johnston I. *Rural road safety: overview of crash statistics*. Monograph. Clayton, Victoria, Australia: Monash University Accident Research Centre (MUARC), 2004 2004-03. Report No.: 0732617227.
26. Digges K, Malliaris AC. *Crashworthiness safety features in rollover crashes*. SAE International. 1998.
27. Massie DL, Campbell KL, Williams AF. Traffic accident involvement rates by driver age and gender. *Accident Analysis & Prevention*. 1995;27(1):73-87.
28. Thompson J, Baldock M, Mathias J, Wundersitz L. Older drivers in rural and urban areas: comparisons of crash, serious injury, and fatality rates. *Australasian Road Safety Research Policing Education Conference, 2010, Canberra, ACT, Australia; 2010-09; Kingston, ACT, Australia: Conference Logistics; 2010.*
29. Corcoran S, James EL, Ellis JM. Do elderly Victorians in rural areas have access to public transport? *Road and Transport Research*. 2005;14(1).
30. Li G, Braver ER, Chen L-H. Fragility versus excessive crash involvement as determinants of high death rates per vehicle-mile of travel among older drivers. *Accident Analysis & Prevention*. 2003;35(2):227-35.
31. Tziotis M, Mabbott N, Edmonston C, Sheehan M, Dwyer J, Ap R. *Road safety in rural and remote areas of Australia*. Sydney: Austroads; 2005. 154 p.
32. Moller J. The spatial distribution of injury deaths in Australia: urban, rural and remote areas? *Aust Inj Prev Bull*. 1994;8(8):8.
33. Pack AI, Pack AM, Rodgman E, Cucchiara A, Dinges DF, Schwab CW. Characteristics of crashes attributed to the driver having fallen asleep. *Accident Analysis & Prevention*. 1995;27(6):769-75.
34. Roberts P, Taylor S, Sidebottom A. *Observational study for motor vehicle restraint use in Western Australia*. Perth: ARRB Consulting. 2006.
35. Legge M, Martin K. *Serious injury analysis of regional and remote crashes in Western Australia 2006-2010*. 2013.

36. Rice TM, Peek-Asa C, Kraus JF. Nighttime driving, passenger transport, and injury crash rates of young drivers. *Injury Prevention*. 2003;9(3):245-50.
37. Sheehan M, Siskind V, Turner R, Veitch C. Rural and remote road safety research project: major recommendations. Monograph. Carseldine, Queensland, Australia: Queensland University of Technology. Centre for Accident Research and Road Safety (CARRS-Q), 2008 2008-07. Report No.: 9780975159668.
38. Smart D, Sanson A, Vassallo S. In the driver's seat: Understanding young adults' driving behaviour: Australian Institute of Family Studies; 2005.
39. Otmani S, Pebayle T, Roge J, Muzet A. Effect of driving duration and partial sleep deprivation on subsequent alertness and performance of car drivers. *Physiology & Behavior*. 2005;84(5):715-24.
40. Phipps-nelson J, Redman JR, Rajaratnam SM. Temporal profile of prolonged, night-time driving performance: breaks from driving temporarily reduce time-on-task fatigue but not sleepiness. *Journal of Sleep Research*. 2011;20(3):404-15.
41. Ting P-H, Hwang J-R, Doong J-L, Jeng M-C. Driver fatigue and highway driving: A simulator study. *Physiology & Behavior*. 2008;94(3):448-53.
42. Mabbott NA, Hartley LR. Patterns of stimulant drug use on Western Australian heavy transport routes. *Transportation Research Part F: Traffic Psychology and Behaviour*. 1999;2(2):115-30.
43. Hartley L. Fatigue in the Western Australian transport industry: The principle and comparative findings: Institute for Research in Safety & Transport; 1996.
44. Matthews G. Towards a transactional ergonomics for driver stress and fatigue. 3. 2002;2(195-211).
45. Cleaver MA, Simpson J, De Roos MP, Hendry LA, Peden SM. Blue reflectors: an inexpensive and effective way of managing fatigue of drivers of heavy vehicles. Australasian Road Safety Research Policing Education Conference, 2009, Sydney, NSW, Australia. 2009.
46. Arnold PK, Hartley LR, Corry A, Hochstadt D, Penna F, Feyer AM. Hours of work, and perceptions of fatigue among truck drivers. *Accident Analysis & Prevention*. 1997;29(4):471-7.
47. Research and Education Program of Kingston FaLAPH. Driver distraction: A review of the literature, and Driver Distraction and cell phone use: A policy paper. Kingston: 2007.
48. Gårder P. Segment characteristics and severity of head-on crashes on two-lane rural highways in Maine. *Accident; Analysis and Prevention*. 2006;38(4):652-61.
49. Regan M, Young K. Driver distraction: A review of the literature and recommendations for countermeasure development. Road Safety Conference; 24-26th September; Sydney, Australia, 2003.
50. Young KL, Lenné MG. Driver engagement in distracting activities and the strategies used to minimise risk. *Safety Science*. 2010;48(3):326-32.
51. Strayer DL, Drews FA, Crouch DJ. A comparison of the cell phone driver and the drunk driver. *Human factors: The journal of the human factors and ergonomics society*. 2006;48(2):381-91.
52. Horberry T, Anderson J, Regan MA, Triggs TJ, Brown J. Driver distraction: the effects of concurrent in-vehicle tasks, road environment complexity and age on driving performance. *Accident Analysis & Prevention*. 2006;38(1):185-91.
53. Rowden P, Steinhardt D, Sheehan M. Road crashes involving animals in Australia. *Accident Analysis & Prevention*. 2008;40(6):1865-71. PubMed PMID: 01117822.
54. Dissanayake S, Ratnayake I. Identification of factors leading to high severity of crashes in rural areas. *Journal of the Transportation Research Forum*. 2006;45(2):87-101.

55. Anderson D. Rural crash rates: method or madness. Rural Road Safety Seminar, 1995, Wodonga, Victoria, Australia; 1995-04; Canberra, ACT, Australia: National Road Trauma Advisory Council; 1995.
56. Chen HY, Senserrick T, Martiniuk ALC, Ivers RQ, Boufous S, Chang HY, et al. Fatal crash trends for Australian young drivers 1997-2007: geographic and socioeconomic differentials. *Journal of Safety Research*. 2010;41(2):123-8.
57. McDermott FT, Cordner SM, Cooper DJ, Winship VC. Management deficiencies and death preventability of road traffic fatalities before and after a new trauma care system in Victoria, Australia. *The Journal of Trauma*. 2007;63(2):331-8.
58. Oxley J, Langford J, Palamara P, Muir C, Koppel S, Bohensky M, et al. Non-wearing of adult seat belts in Australia: where to next? 2009.
59. WA Office of Road Safety. Increasing restraint use: Directions document 2006-2008. Perth, Western Australia: Department of the Premier and Cabinet, Government of Western Australia., 2007.
60. Beck L, Shults R, Mack K, Ryan G. Associations between socio-demographics and safety belt use in states with and without primary enforcement laws. *American Journal of Public Health*. 2007;97:1619-24.
61. Boyle J, Lampkin C. 2007 Motor Vehicle Occupant Safety Survey: Volume 2 seat belt report. Washington DC: NHTSA, 2008.
62. Lenné MG, Triggs TJ, Redman JR. Interactive effects of sleep deprivation, time of day, and driving experience on a driving task. *Sleep: Journal of Sleep Research & Sleep Medicine*. 1998;21(1):38-44.
63. Miller PG, Coomber K, Staiger P, Zinkiewicz L, Toumbourou JW. Review of rural and regional alcohol research in Australia. *Australian Journal of Rural Health*. 2010;18(3):110-7.
64. Czech S, Shakeshaft AP, Byrnes JM, Doran CM. Comparing the cost of alcohol-related traffic crashes in rural and urban environments. *Accident Analysis & Prevention*. 2010;42(4):1195-8.
65. Corben B, Candappa N, Van Nes N, Logan D, Peiris S. Intersection safety study: meeting Victoria's intersection challenge: task 5: generation of intersection designs within the safe system context. 2010.
66. Horne J, Reyner L. Sleep related vehicle accidents. *BMJ*. 1995;310(6979):565-7.
67. King GF. Evaluation of safety roadside rest areas. 1989.
68. Phipps-Nelson J, Redman JR, Rajaratnam SMW. Temporal profile of prolonged, night-time driving performance: breaks from driving temporarily reduce time-on-task fatigue but not sleepiness. *Journal Of Sleep Research*. 2011;20(3):404-15. PubMed PMID: 21129055.
69. Technology. S. Fatigue Management Technology. In: Candappa N, editor. 2013.
70. May JF, Baldwin CL. Driver fatigue: The importance of identifying causal factors of fatigue when considering detection and countermeasure technologies. *Transportation Research Part F: Traffic Psychology and Behaviour*. 2009;12(3):218-24.
71. Persaud BN, Retting RA, Lyon CA. Crash reduction following installation of centerline rumble strips on rural two-lane roads. *Accident Analysis & Prevention*. 2004;36(6):1073-9.
72. Streff F, Spradlin H. Driver distraction, aggression, and fatigue: a synthesis of the literature and guidelines for Michigan planning. *Ann Arbor*. 2000;1001:48109.
73. Edquist J, Rudin-Brown C, Lenné MG. Road design factors and their interaction with speed and speed limits. Monash University Accident Research Centre, 2009.
74. Hobday AJ. Nighttime driver detection distances for Tasmanian fauna: informing speed limits to reduce roadkill. *Wildlife Research*. 2010;37(4):265-72.

75. Martens M, Compte S, Kaptein NA. The effects of road design on speed behaviour: a literature review. 1997.
76. Antonson H, Mårdh S, Wiklund M, Blomqvist G. Effect of surrounding landscape on driving behaviour: A driving simulator study. *Journal of Environmental Psychology*. 2009;29(4):493-502.
77. Carmody J. Design issues related to road tunnels. University of Minnesota, Center for Transportation Studies, 1997.
78. Administration. FH. Low cost treatments for horizontal curve safety. US Department of Transport, 2006.
79. Coutton-Jean C, Mestre DR, Goulon C, Bootsma RJ. The role of edge lines in curve driving. *Transportation Research Part F: Traffic Psychology and Behaviour*. 2009;12(6):483-93.
80. Tsyganov A, Machemehl R, Warrenchuk N, Wang Y. Before-after comparison of edgeline effects on rural two-lane highways. Monograph. Austin, Texas, USA: University of Texas at Austin.
81. Carlson P, Wagner J. An Evaluation of the Effectiveness of Wider Edge Line Pavement Markings. 2012.
82. Davidse R, Van Driel C, Goldenbeld C. The effect of altered road markings on speed and lateral position. SWOV, Institute for Road Safety Research. 2004.
83. Daniel J, Chien S, Liu R. Effectiveness of Certain Design Solutions on Reducing Vehicle Speeds. New Jersey Department of Transportation, 2005.
84. Aarts L, Brandenburg S, van Nes N, editors. The influence of environmental factors on speed choice. *Integrated and Sustainable Transportation System (FISTS)*, 2011.
85. Candappa N, Corben B, Fotheringham N, editors. Targetting the true cause of a crash. Saferoads: Victorian Local Government Road Safety Conference, Melbourne, Victoria, Australia. 2006.
86. Turner B. Engineering based approaches to reducing rural speed. Austroads; 2009.
87. Lauckner M, Brandenburg S. Influence of basic environmental characteristics on driving speed.
88. Fitzpatrick K, Fambro DB, Stoddard AM. Safety effects of limited stopping sight distance on crest vertical curves. *Transportation Research Record: Journal of the Transportation Research Board*. 2000;1701(1):17-24.
89. Corben BF, Deery H, Mullan N, Dyte D. The general effectiveness of countermeasures for crashes into fixed roadside objects: Monash University; 1997.
90. McBean P. The influence of road geometry at a sample of accident sites. 1982 0266-7045.
91. Austroads. Guide to road design part 3: Geometric design. Sydney, Australia: Austroads, 2010.
92. Sun D. Study of the Effectiveness of Nighttime and Truck Speed Limits. *Traffic and Transportation Studies*. 2010:977-89.
93. Lewis-Evans B, Charlton SG. Explicit and implicit processes in behavioural adaptation to road width. *Accident Analysis & Prevention*. 2006;38(3):610-7.
94. Vey AH, Ferreri M. Effect of lane width on traffic operation. *Traffic Engineering*. 1968;38(11).
95. Oxley J, Corben B, Koppel S, Fildes B, Jacques N, Symmons M, et al. Cost-effective infrastructure measures on rural roads. Monograph. Clayton, Victoria, Australia: Monash University. Accident Research Centre (MUARC), 2004 2004-04. Report No.: 0732617278.
96. Ornek ME, Drakopoulos A, editors. Analysis of Run-Off-Road Crashes in Relation to Roadway Features and Driver Behavior 2007.

97. Torbic DJ. Guidance for the design and application of shoulder and centerline rumble strips: Transportation Research Board; 2009.
98. Wilder R. Shoulder rumble strips on secondary highways a systematic crash analysis. New York State: NYSOT Design and the office of modal safety and security, 2011.
99. FHWA. Engineering countermeasures for reducing speeds: A desktop reference of potential effectiveness. 2009.
100. Turner B. Engineering based approaches to reducing rural speed. Australasian Road Safety Research Policing Education Conference, 2009, Sydney, New South Wales, Australia; 2009-11; Sydney, New South Wales, Australia: Roads and Traffic Authority (RTA); 2009.
101. Kronqvist L. Drivers' speed and attention in alternative designs of an intersection: Linköping. 2005.
102. Fildes B, Jarvis J. Perceptual countermeasures: Literature review. 1994.
103. Godley S, Fildes B, Triggs T, Brown L. Perceptual countermeasures: experimental research. 1999.
104. Rothenberg H, Benavente M, Swift J. Report on Passive Speed Control Devices. Massachusetts Traffic Safety Research Program, MassSAFE. 2004.
105. Manser M, Hancock P. Influence of approach angle on estimates of time-to-contact. *Ecological Psychology*. 1996;8(1):71-99.
106. Liu B-S. Association of intersection approach speed with driver characteristics, vehicle type and traffic conditions comparing urban and suburban areas. *Accident Analysis & Prevention*. 2007;39(2):216-23.
107. Radalj T, Kidd B, editors. Driver speed compliance in Western Australia. Road Safety Research, Policing and Education Conference, 2000, Brisbane, Queensland, Australia.
108. Lee J, Mannering F. Impact of roadside features on the frequency and severity of run-off-roadway accidents: an empirical analysis. *Accident Analysis & Prevention*. 2002;34(2):149-61.
109. Archer J, Fotheringham N, Symmons M, Corben B. The impact of lowered speed limits in urban/metropolitan areas. 2008.
110. Retting RA, Teoh ER. Traffic speeds on interstates and freeways 10 years after repeal of national maximum speed limit. *Traffic injury prevention*. 2008;9(2):119-24.
111. Hirst W, Mountain L, Maher M. Are speed enforcement cameras more effective than other speed management measures?: An evaluation of the relationship between speed and accident reductions. *Accident Analysis & Prevention*. 2005;37(4):731-41.
112. Allsop R. The effectiveness of speed cameras: a review of evidence. 2010.
113. Pilkington P, Kinra S. Effectiveness of speed cameras in preventing road traffic collisions and related casualties: systematic review. *BMJ*. 2005;330(7487):331-4.
114. Belin M-Å, Tillgren P, Vedung E, Cameron M, Tingvall C. Speed cameras in Sweden and Victoria, Australia—A case study. *Accident Analysis & Prevention*. 2010;42(6):2165-70.
115. Diamantopoulou K, Skalova M, Dyte D, Cameron M. Crash risks of high risk road user groups in Melbourne and rural Victoria during 1994. Road Safety Research and Enforcement Conference, 1996, Coogee Beach, New South Wales, Australia; 1996; New South Wales, Australia: Roads and Traffic Authority (RTA); 1996.
116. Keall M, Frith W. Adjusting for car occupant injury liability in relation to age, speed limit, and gender-specific driver crash involvement risk. *Traffic Injury Prevention*. 2004;5(4):336-42.
117. Safety. OoR. Evaluation of the 2002-2003 trial period of the double demerits enforcement campaign and supporting media campaign in Western Australia. Perth, Australia: TNS, 2006.
118. Loeb PD. The effectiveness of seat-belt legislation in reducing injury rates in Texas. *The American Economic Review*. 1995;85(2):81-4.

119. Grant B. Canadian seat belt wearing rates, promotion programs, and future directions. 1991.
120. Gundy CM. The effectiveness of a combination of police enforcement and public information for improving seat belt use. In: Bruin JRMd, editor. Road User Behaviour: Theory and Research. Van Gorcum, Assen. The Netherlands 1988.
121. Williams AF, Wells JK, Farmer CM. Effectiveness of Ford's belt reminder system in increasing seat belt use. *Injury Prevention*. 2002;8(4):293-6.
122. Krafft M, Kullgren A, Lie A, Tingvall C. The use of seat belts in cars with smart seat belt reminders—results of an observational study. *Traffic Injury Prevention*. 2006;7(2):125-9.