An investigation of urban area run off road crashes in Western Australia 2005-2009

RR 10-005

CURTIN-MONASH ACCIDENT RESEARCH CENTRE

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December 2013

CURTIN-MONASH ACCIDENT RESEARCH CENTRE
DOCUMENT RETRIEVAL INFORMATION

Report No.	Project No.	Date	Pages	ISBN
RR 10-005	10-002 RSC	December 2013	67+	N/A

Title

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Abstract

Single vehicle run off road crashes account for around one in ten crashes but are a significant contributor to serious injury. The aims of this investigation were to describe the epidemiology of single vehicle run off road crashes in the urban area and consider a range of safe road and roadside countermeasures and others to reduce the incidence of crashes and injury severity. Two crash types occurring in the Perth metropolitan area 2005-2009 were selected for analysis: vehicles running off the road and crashing into an object or involved in a non-collision (rolling over) (n=12,843), and, vehicles running off the road and colliding with a pedestrian off-carriageway (n=18). Descriptive analyses were undertaken of both datasets and multivariate analysis of the severity of the crash for the larger dataset. For the larger set of crashes the findings were generally consistent with those reported elsewhere and highlight the role of speed, road alignment, and type of collision (hit object or other) as contributors to injury severity. The vast majority of crash sites in this study lacked roadside barriers and audio-tactile edge-lining, which are known to be important and effective countermeasures for run off road crashes. A number of recommendations related to safe road use, safe vehicles, safe speeds, and safe roads and roadsides were provided.

Keywords

Road safety; single vehicle run off road crashes; serious injury; crash countermeasures

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EXECUTIVE SUMMARY

Introduction

Nearly 1.3 million people a year die in road traffic crashes with an additional 20-50 million people sustaining some form of injury (World Health Organization, 2011). A large proportion of crashes, particularly those in non-urban areas and those resulting in serious injury or fatality, are run off road crashes. Accordingly, it is important to be aware of the influencing factors surrounding run off road crashes – both in the urban and non-urban context - when identifying effective countermeasures, including, but not limited to the drivers and vehicles involved, and the speed at which they are travelling, as well as features of the road.

The general aims of this investigation were to describe single vehicle run off road crashes in the urban area and to propose relevant countermeasures to reduce their incidence and injury severity. The specific objectives of this investigation were to:

- Review the research literature to identify key findings related to run off road crashes, particularly those in urban areas, and relevant countermeasures;
- Describe the epidemiology of run off road crashes in the Perth urban area during the period 2005-2009 and the factors associated with the resulting injury severity; and to,
- Provide recommendations for the development of engineering, environmental and other countermeasures to reduce the incidence of and/or injury severity of run off road crashes in urban areas.

Method

A search of relevant databases including Google Scholar, ProQuest, Current Contents, Scopus, Factiva and EconLit was undertaken using 'key words' to identify pertinent international reports, refereed journal articles and conference papers relative to on urban run off road crashes and current roadside barrier engineering initiatives at a local, national and international level. The search was restricted to publications from 1990 onwards. Crash data for the study included police records of all on-road traffic crashes (both police attended/reported and road user reported) occurring during the period 2005-2009 in Western Australia, extracted by Main Roads Western Australia (MRWA) from their Integrated Road Information System (IRIS). Two crash types were selected for analysis. The first and primary crash type involved a single vehicle running off the carriageway and either colliding or not colliding (known as a *non-collision* crash) with an object. The secondary and incidental crash type involved vehicles running off the carriageway and colliding with a pedestrian off the carriageway. Upon extraction, crashes were then linked (using the Straight Line Kilometre information at the site of the crash) with the MRWA road inventory and infrastructure database to identify the location and type of barriers and edge-lining at the crash site.

Crashes occurring in the Perth metropolitan area were considered to be representative of the population of *urban area* crashes. The categorisation of metropolitan area crashes is based on the classification of Western Australia geography using the Accessibility/Remoteness Index of Australia (ARIA) (Department of Health and Aged Care, 2001). For the purposes of this study the local government area of the crash reported in the IRIS database was assigned an ARIA code and then categorised as metropolitan, regional and remote for analysis.

Summary of the review of relevant literature

- Between 1999 and 2008 in Western Australia, single vehicle crashes resulted in an annual average of 109 deaths and 957 persons seriously injured.
- In 2006, single vehicle collisions comprised 65% of all fatal crashes in Western Australia.
- Seventy three percent of fatal metropolitan crashes and 87% of fatal regional crashes were single vehicle crashes in 2008.
- Between 1999 and 2008, a larger proportion of single vehicle crashes occurred in the metropolitan area (57%) of Western Australia, with an 8% increase over the course of this period.
- While 59% of fatal single vehicle crashes occurred in the rural/remote areas, hospitalisation (52%) and other crashes (58%) more commonly occurred in the metropolitan area.
- Urban environments have higher rates of single vehicle serious injury crashes though a single vehicle crash in the non-urban has a higher likelihood of resulting in a serious injury.
- WA evidence shows that non-collision (roll-over crashes) are significantly more likely to result in a serious injury compared with an hit-object single vehicle crash, while research elsewhere indicates that collisions with a fixed roadside object such as poles and trees are more likely to result in a higher level of injury severity compared with other crash types in both the urban and non-urban area.

- In WA, single vehicle crashes occurred predominantly on sealed roads (90%), straight sections of the road (65%), roads that were level (73%) and on dry roads (76%) across all three geographic areas over the past decade.
- Serious injury and fatal single vehicle crashes are more likely to occur on curved sections of the road.
- There remains conflicting evidence as to whether fatal single vehicle run off road crashes are more likely to occur at night time.
- Young urban drivers have a higher crash risk than novice rural drivers.
- Speeding is a common factor in crashes occurring in rural and metropolitan areas for single vehicle crashes and other types.
- Alcohol and non-use of restraints are commonly associated with single vehicle crashes, particularly in the rural area.
- Driver fatigue has been identified as a risk factor for single vehicle crashes in low speed urban environments.
- Countermeasures to reduce run off road crashes identified limited studies on the effectiveness of prevention methods in urban areas.
- The following countermeasures are recommended to reduce the adverse consequences of a run off road crashes:
  - ➢ Making poles and other roadside objects more crashworthy;
  - ➢ Clearing the immediate roadside of any rigid obstacles;
  - ➢ Installing some form of crash barrier to better manage energy transfer in a crash;
  - ➢ Reducing travel speeds and, thus, impact speeds; and
  - ➢ Improving the crashworthiness of vehicles in impacts with trees and poles, embankments, etc. and in rollovers.
- It is clear that a combination of road safety treatments would provide the best results in preventing run off road casualty crashes.
- A Victoria showed that the most successful treatment categories were treatments of the road surface (29.6% crash reduction) and treatments of road and roadside geometry (22.9%).
- The most significant of road surface treatments was found to be shoulder sealing (31.8%) and the most significant treatments of road and roadside geometry were those dealing with horizontal curvature of the road (43.6%).

- A number of studies have also reported on the use of roadside barriers to effectively reduce crash frequency and fatality. It has been found that wire rope barriers significantly reduce fatal and serious crashes, as well as cross-median crashes. In addition wire rope barriers reduce accident and injury costs but the inherent flexibility of wire-rope barriers makes them an unsafe option for vehicle containment in some areas, where it may be necessary to provide a rigid or semi-rigid barrier, and in some cases a barrier that will contain large semi-trailers.
- Semi-rigid barriers deform substantially under impact but deflect less than wire rope barriers. The safety effects of semi-rigid barriers are less conclusive. One study reported that guardrail safety barriers were responsible for 32% of car crash fatalities. Further, small reductions in fatal crashes were observed in one US study, but large reductions in fatal cross-median crashes highlighting the resistance of semi-rigid median barriers to penetration from colliding vehicles onto opposite roadsides.
- Rigid barriers exhibit negligible deflection when impacted by a vehicle, the consequence of which is that the impact severity of a motor vehicle colliding with the barrier is increased. Use of concrete barriers is usually limited to areas where heavy vehicle impacts are likely, or space is limited. Further, small car crashes into a concrete median barrier at 80 km/hour at a 45° angle are not survivable - a factor which needs to be considered when evaluating the most effective and safe barrier types for urban areas.
- Motorcyclists and pedestrians are two examples of vulnerable road users that have particular needs in relation to crash barriers.
- It has been reported that motorcycle users are most susceptible to fatal injury due to collision with a guardrail safety barrier, or wire rope barrier, but the third most likely road user type to result in fatality from impact with a concrete barrier (based on US studies). Speed is a major factor in motorcycle-barrier crashes and although guardrails are more harmful to motorcyclists than other road users, they provide some protection for motorcyclists from colliding with other road-side objects such as trees, which are more likely to result in fatality.
- It remains unclear as to whether redesign of safety barriers would improve motorcycle fatality counts. The Barriacel Motorcycle Crash Attenuating Device (MCAD) is a new development designed by road safety specialists, which offers 360° protection for motorcyclists and cyclists from impacts with roadside barrier posts, which in addition

can be easily fitted to both new and existing barriers. It is yet to be examined for its effectiveness 'in situ'.

- In South Australia, examination of the evidence from several serious accidents at road-side dining areas led to the development of the energy-absorbing bollard which deforms minimally on impact and has passed rigorous crash testing. Importantly, the bollard design allows for pedestrian movement, but additionally offers significant pedestrian protection not usually afforded by the glass panels, brick walls and plantar boxes which often delineate these kinds of areas. Further, energy-absorbing bollards have been shown to significantly reduce impact forces, thereby reducing impact severity compared to rigid road-side objects such as trees and poles, which absorb little energy upon impact.

Summary of the findings of the analysis of single vehicle run off road crashes

Distribution and injury severity

- A total of n=12,843 crashes in the metropolitan area met the single vehicle run off road crash inclusion criteria, accounting for nearly 60% of the occurrence of this type of crash across Western Australia during the study period.
- Approximately 78% of single vehicle run off road crashes in metropolitan Perth resulted in property damage only (major and minor).
- Twice as many serious injury single vehicle run off road crashes occurred in the metropolitan area (n=1528) compared with regional (n=1109) and remote (n=866) Western Australia.
- Single vehicle run off road crashes were more likely to result in death or hospitalisation (serious injury) in remote (23.6%) and regional (19.1%) areas compared with metropolitan Perth (11.9%).

Selected crash and road characteristics

- Just over two-thirds of single vehicle run off road crashes in the metropolitan area occurred on straight (68.1%) *versus* curved (31.9%) sections of road.
- For run off road crashes on straight sections of road 57% occurred when the vehicle veered to the left off the carriageway while 43% were reported to have veered to the right of the carriageway.
- For run off road crashes on curves, near equal proportions of crashes occurred on left-hand (49%) and right-hand (51%) bends.

- Approximately 95.3% of all run off road crashes (straight and curves) resulted in collision with an object. And 96.6% of non-collision crashes resulted in the vehicle overturning.
- 23.3% of non-collision crashes resulting in the death or hospitalisation of one or more vehicle occupants compared with 11.3% of hit object crashes.

Hit object crashes

- Roadside kerbs (23.7%) are the primary (first recorded) object of collision, followed by poles/posts/signs (18.3%), traffic islands (14.9%), trees/shrubs (13.3%) and fences/building walls (10.9%).
- Approximately 82% of motorcycle and moped single vehicle crashes involved a collision with an object.
- Around 7% of riders colliding with an object were killed; in contrast, 1% of hit object crashes for all vehicle types resulted in the death of an occupant.
- Compared with all vehicle hit object crashes, riders were somewhat more likely (n=38 or 11% of all rider hit object crashes) to collide with a barrier or guard rail.

Roadside barriers and edge-lining

- Five percent of vehicles running off road in the metropolitan area collided with a guard rail or barrier.
- For *left off carriageway crashes on straight sections*, left-hand barriers were recorded at 3% of crash sites.
- For *right off carriageway crashes on straight sections*, median barriers and right-hand barriers were respectively recorded at 3.5% and 3.1% of crash sites.
- For *off carriageway crashes on left bend*s, left-hand, median and right-hand barriers were respectively recorded at 2.5%, 1.1% and 2.9% of crash sites.
- For *off carriageway crashes on right bend*s, left-hand, median and right-hand barriers were respectively recorded at 2.4%, 1.1% and 2.7% of crash sites.
- Brifen (wire-rope), Constant Slope Shape Concrete, Double-side Lip Channel and Two-Rail barriers were the most frequently identified barriers at the crash site.
- Edge-lining was recorded for 19% of run off road crash sites. In nine out of ten sites standard edge-lining was recorded, while audio-tactile edge-lining was noted at 17 sites with near equal representation across straight and curve crash sites.

Posted speed zone

- Across all road alignments, 61.3% of single vehicle run off road crashes in metropolitan Perth occurred on roads with posted speed limits up to and including 60km/hour.
- Speed limit and road alignment, and speed limit and crash severity were statistically associated ($p \leq .001$ in both cases).

Time of day, day of week and lighting

- Single vehicle run off road crashes in the metropolitan area were most frequent during the six-hour period of 18:00-23:59 (36.3%) followed by 00:00-05:59 (24.2%).
- Run off road crashes in the metropolitan area were more likely to occur on a Saturday (20%), followed by Sundays (17.4%) and Fridays (17.2%).
- The majority of single vehicle run off road crashes in metropolitan Perth occurred when it was dark and street lights were operational at the location of the crash (46.4%).

Road surface, gradient and condition

- Across straight and curved sections of road the majority of single vehicle run off road crashes in the metropolitan area occurred on sealed roads.
- Just under 75% of single vehicle run off road crashes occurred on a level road. This proportion was higher for crashes occurring on straight sections of road compared with curves.
- Single vehicle run off road crashes were considerably more likely to occur on dry roads, with a slightly higher proportion of crashes on curves compared to straight section of road in the wet.

Road user characteristics

- Around 88% of crash involved road users were designated as drivers of motor cars, trucks, buses and tractors, with a further 3.4% being riders of motorcycle, moped and bicycles.
- Passengers accounted for 9% of crash involved road users,

Driver/ride age, gender and injury type

- A statistically significant relationship between driver/rider status and age was found. The majority of crash involved riders were aged 25-39 years (45.4%) while the majority of crash involved drivers were aged 17-24 years (48.5%).

- Across both groups of road users males accounted for around 75% those involved in a run off road crash in the metropolitan area.
- Compared with drivers, riders involved in a single vehicle run off road crash in metropolitan Perth were more likely to be killed (7.2% *versus* 2.9%) and hospitalised (51.8% *versus* 34.4%).

Driver/rider Blood Alcohol Concentration level

- Approximately 34.4% of drivers and riders recorded a BAC level of ≥0.050gm%, with proportionally more drivers than riders recording higher levels of BAC, e.g., ≥0.101gm%.
- Approximately one-third of driver/rider run off road crashes on straights (34.6%) and curved (33.9%) recorded a BAC level of 0.05gm% and higher.
- Around 55% and 43% of crashes respectively occurring 00:00-05:59 and 18:00-23:59 involved a driver/rider with a BAC of 0.050gm% or higher, with the majority of illegal levels being ≥0.101gm%.

Driver/rider seatbelt/helmet use

- Driver/rider status and use of protection were found to be significantly associated. Riders were around seven times more likely than drivers (14% *versus* 2.1%) not to be using protection at the time of the crash.
- Those who sustained a fatal injury (35.7%) or an injury requiring admission to hospital (7.3%) were considerably more likely to be unbelted at the time of the crash compared with other injury outcomes.
- Non-use of helmets was highest among those admitted to hospital (13%) and those treated without admission (15.1%).

Driver/rider license status

- Approximately 2.6% of drivers/riders involved in a single vehicle run off road crash in the metropolitan area were not validly licensed at the time of the crash.

Passengers

- A total of n=1,206 passengers were recorded by police to have been injured in the n=12,830 single vehicle run off road crashes (excluding n=13 bicycle crashes) in the metropolitan area.
- Just over half (51.7%) of those injured were aged 17-24 years followed by those under 17 years of age (23.9%).

- Around six in ten passengers injured in a single vehicle run off road crash in metropolitan Perth were male.
- Passengers injured in a single vehicle run off road crash in metropolitan Perth were mostly admitted to hospital for treatment (38.7%) or treated without being admitted (38.8%).
- Around one in ten injured passengers was not wearing a seatbelt (or helmet in the case of a pillion passenger) at the time of the crash.
- Passengers who sustained a fatal injury (30%) were considerably more likely to be unprotected at the time of the crash compared with other injury outcomes.

Vehicle characteristics

- Passengers vehicles (94.3%) were the most predominant vehicle type involved in run off road crashes in the metropolitan area, followed by motorcycles/mopeds (3.8%)
- Registration status was analysed for cars, trucks, buses, motorcycles, moped and motorbikes. Nearly all (99.7%) motorised vehicles involved in a run off road crash in metropolitan Perth were registered at the time of the crash.

Multinomial Regression analysis of serious injury, minor injury versus no-injury single vehicle run off road crashes

- Four variables were found to be independently and significantly related to the increased odds of a single vehicle run off road crash resulting in a serious injury and minor injury versus no-injury.
- Crashes occurring on curves compared with straight sections of road were associated with a significantly higher odds of serious injury (OR=1.48) and minor injury (OR=1.31).
- Crashes involving a vehicle roll over/non-collision as opposed to hitting an object had significantly higher odds of a serious injury (OR=1.74) and minor injury (OR=2.01).
- Single vehicle crashes occurring in higher speed zones were significantly associated with increased odds of serious injury (OR=1.53; 70-90km/hour; OR=1.30; 100-110km/hour) and risk of a minor injury (OR=1.31; 70-90km/hour; OR=1.24; 100-110km/hour) compared with crashes occurring in speed zones posted 60km/hour and lower.
- Crashes in the wet were significantly associated with a lower risk of serious injury (OR=0.49) and minor injury (OR=0.74).

Analysis of single vehicle run off road crashes resulting in the collision with a pedestrian off-carriageway

- A total of n=18 crashes involving a vehicle running off the road and colliding with a pedestrian off-carriageway were noted.
- Around a third of the run off road pedestrian off-carriageway crashes resulted in serious injury, with near equal numbers resulting in minor injury or no injury.
- 83.3% of the run off road - pedestrian off-carriageway crashes occurred midblock.
- 77% occurred on a straight section of road and 23% on a curve.
- 57.2% occurred in speed zones 40-50km/hour and 42.8% in speed zones 60-80km/hour.
- 64.7% occurred during daylight 35.3% occurred at night with street lights on.
- 77.7% of crashes occurred on weekdays.
- 50.1% of crashes occurred after 6.00am and before 6.00pm.
- In 88% of crashes the weather/road condition was noted to be dry.
- Passenger vehicles accounted for 66.6% of vehicles running off the road and colliding with a pedestrian off-carriageway. Further, 86% of drivers were male and over one-third of the remaining controllers were aged 18, while 45.5% were 40+ years of age.
- A total of n=21 pedestrians were struck off-carriageway by vehicles running off the road. Three of the n=18 crashes involved the collision with two pedestrians.
- No information on the gender, age and injury was respectively recorded for n=3, n=2 and n=5 involved pedestrians. Where information was available:
    - 61% (n=11) of pedestrians struck were male;
    - 26.3% (n=5) were aged 7 to 16 years;
    - 15.8% (n=3) were aged 17-23 years;
    - 26.3% (n=5) were aged 26-40 years;
    - 31.5% (n=6) aged 48-80 years; and
    - One pedestrian was killed, while 31% (n=5) were hospitalised and 44.3% (n=10) injured and not requiring hospitalisation or medical attention.

Discussion

Single vehicle run off road crashes in the metropolitan area account for nearly six in ten crashes of this type across Western Australia. Compared with the regional and remote areas of Western Australia, two to 3.5 times as many single vehicle run off road crashes occur in the metropolitan area. When the injury severity of these crashes is considered, this factor is reduced to 1.8 to 2.3 times. This is because crashes of this type in the metropolitan area were considerably less likely to result in death or hospitalisation compared with those occurring in the non-metropolitan areas. A number of factors were noted from the multivariate analysis to be significant risk factors for serious injury and minor injury crashes (versus no injury crashes). It was shown that the odds of the single vehicle crash resulting in a more severe injury increased when the crash occurred in a *higher speed zone* and occurred on a *curve* compared with a straight section of road. Further, when vehicles left the road and their energy and speed was not absorbed or dissipated through hitting an object, but instead rolled over –a *non-collision* -, the risk of injury nearly doubled. One factor, crashing when the road was *wet*, was found to be associated with a lower risk of serious and minor injury. These findings were generally consistent with those reported elsewhere, including other studies in Western Australia.

From a safe systems perspective the study identified a range of factors that should be considered in the development of countermeasures to reduce run off road crashes and their injury. In regard to road users, males, younger age drivers and riders, those affected by alcohol, and unlicensed and unbelted (helmeted) drivers are key target groups for run off road crashes, as they are for many other crash types. Unfortunately, there was no opportunity to address the range of vehicle factors that might have contributed to the occurrence of single vehicle run off road crashes in this study. Other research has provided good evidence to suggest that vehicle technologies such as ABS, traction control, and electronic stability control, lane departure warning systems and others are likely to reduce the incidence of loss of control, run off road crashes. The challenge is to ensure these features are readily available, affordable and that vehicle buyers are incentivised to consider them.

Speeding has long been acknowledged as one of the most significant risk factors for crashing and subsequent injury, particularly in the circumstance of vehicles running off the road in both urban and non-urban environments. Higher travels speeds, whether legal or illegal, are problematic because of their associated risk of losing control of the vehicle and the increased distance travelled during the time taken to react and brake, which subsequently increases the distance and time travelled until stop. This study was not able to investigate the role or excess or inappropriate speeds per se. It was noted that the majority of single vehicle run off road crashes occur in lower speed zones but crashes in higher speed zones are significantly more likely to result in serious injury. Again, these findings are consistent with those reported elsewhere and underscore the need to develop strong initiatives in the area of safe speeds and their enforcement to reduce the incidence of loss of control crashes.

The study identified a number of significant issues in relation to safe roads and roadsides and relevant countermeasures to reduce single vehicle run off road crashes in the metropolitan area. The analysis particularly highlighted the problem of crashes on curves, roll over collisions, and collisions into roadside objects – particularly poles, trees, and fences/building. What is clear from this study is that when vehicles run off the road in the metropolitan area they are considerably more likely to hit an object – other than a barrier - though in most cases will not result in injury. Indeed a very small minority of crash sites were found to be protected by roadside barriers or to have audio-tactile edge-lining installed. Thus, there is still the need to consider initiatives to keep drivers from running off the road and others to reduce the severity of injury should they crash. To this end, road engineers should consider the appropriate use of measures such as:

- the installation of audio-tactile edge-lining;
- the creation of clear zones (where space permits);
- the clearing of potential roadside hazards where possible (or their protection through isolation barriers);
- improving the alignment, delineation and site lines on curves;
- improving the lighting at sites where crashes at night are identified; and,
- the installation or retrofitting of barriers appropriate for the road, environment, speed and traffic use at the site.

Motorcyclists and pedestrians were also considered in this study because of their vulnerable road user status. When motorcyclists collide with an object they are considerably more likely than vehicle occupants to be killed, with poles, trees, and traffic islands being the most common objects to be impacted. The Barriacel Motorcycle Crash Attenuating Device is one countermeasure to show promise in protecting motorcyclists. This study also showed that pedestrians off-carriageway are infrequently collided by vehicles running of the road. One fatality for such a crash was recorded over the study period. Nevertheless, some pedestrian dense areas that have high exposure to vehicles in close proximity, such as outdoor dining areas, may benefit from the installation of the Flexible Bollard system as installed in South Australia.

Recommendations

This study has identified a number of safe road user, safe vehicle, safe speed and safe road and roadside related factors for single vehicle run off road crashes in the metropolitan area. From this a number of recommendations, particularly for safe roads and roadsides, are offered for consideration. Some recommendations are specific to run off road crashes per se, while others are more generally applicable but also expected to impact on the incidence of and injury severity of run off road crashes in the metropolitan area.

Surveillance and reporting

Improve the collection and quality of information in the MRWA IRIS database on run off road crashes

It is recommended that MRWA consider the inclusion of Road Use Movement codes to identify the direction of travel – to the near side or far side – off the carriageway for vehicle crashing on left and right hand curves.

Improve the collection and quality of information in the MRWA IRIS database on guard rails/barriers impacted in a collision

It is recommended that MRWA include an additional field for hit object-barrier crashes in the IRIS database to describe the type of guard rail/barrier impacted.

Safe Road Use

Minimising driver/rider impairment through alcohol

It is recommended that the State review and revise where appropriate existing Blood Alcohol Concentration Level legislation for unrestricted drivers to encourage a lower level of consumption by drivers and potentially reduce impaired driving through alcohol.

Maximising the use of personal protection by vehicle occupants and riders in metropolitan areas

It is recommended that the State consider additional education, enforcement and technology initiatives to promote and increase the use of seat belts by vehicle occupants and helmets by motorcycle/moped riders.

Safer Vehicles

Accelerating the uptake of safer vehicles with technologies to minimise run off road crashes

It is recommended that the State continue to promote community understanding and awareness within the community of technologies and vehicles that are likely to reduce loss of control, run off road crashes. Consideration should also be given to initiatives that financially ‘incentivise’ car buyers to purchase safer vehicles.

Safe Speeds

Reducing vehicle speeds through rezoning to reduce loss of control crashes and injury severity

It is recommended that MRWA work in conjunction with local governments to identify run off road crash ‘black spots' that are appropriate for reduced speed limits to minimise the occurrence of loss of control, run off road crashes.

Reducing local area speeds through strategic enforcement to reduce loss of control crashes and injury severity

It is recommended that metropolitan local governments participate in the Local Government-WA Police Speed Management Enforcement Program. This program provides guidelines to local governments on the surveillance and reporting to police of speeding on local area roads to facilitate strategic enforcement.

Safer Roads and Roadsides

Identifying ‘black spots’ for run off road crashes in local urban areas

It is recommended that MRWA work in conjunction with metropolitan local governments to identify run off road crash ‘black spots'. Spatial mapping of these ‘black spots’ would provide the first-level information required for a program of engineering and environmental countermeasures. Secondly, local area maps could also be used to educate the community of high risk problem roads.

The development of a program of appropriate engineering and environmental countermeasures to reduce run off road crashes and injury severity

Following spatial mapping, it is recommended that road safety audits of the selected sites are subsequently undertaken to make informed decisions on required and relevant ‘best practice’ countermeasure for the site. Local government traffic engineers should work in conjunction with MRWA to determine the most appropriate and cost-effective treatment or suite of treatments. These treatments, in addition to those related to speed management, can include:

- the installation of audio-tactile edge-lining;

- the creation of clear zones (where space permits);
- the clearing of potential roadside hazards where possible (or their protection through isolation barriers);
- improving the alignment, delineation and site lines on curves;
- improving the lighting at sites where crashes at night are identified; and,
- the installation or retrofitting of barriers appropriate for the road, environment, speed and traffic use at the site.

Audit of pedestrian dense areas that have high exposure to potential run off road-pedestrian collision crashes.

It is similarly recommended that local governments 'audit' their high pedestrian, vulnerable road use activity areas to identify locations where the risk of injury to pedestrians 'off-carriageway' is elevated should a vehicle run off the carriageway. In lower speed zones where pedestrian manoeuvrability and streetscape are an issue, local government might consider (subject to cost-benefit calculations) the installation of energy-absorbing bollards such as those proposed by the SA Government.

ACKNOWLEDGEMENTS

The authors would like to acknowledge the Project Advisory Group and Main Roads Western Australia for their assistance with the project, particularly in relation to the supply of relevant data and comments on early draft of the reports..

1. INTRODUCTION

Nearly 1.3 million people a year die in road traffic crashes with an additional 20-50 million people sustaining some form of injury (World Health Organization, 2011). A large proportion of crashes, particularly those in non-urban areas and those resulting in serious injury or fatality, are run off road crashes. In Western Australia, over the 2005-2007 period, 33% of people killed or seriously injured were involved in run off road crashes, 18% of which occurred in the metropolitan area (Office of Road Safety, 2009), accounting for an estimated community cost of 1.8 billion dollars (Curtin-Monash Accident Research Centre, 2011).

Run off road crashes in urban areas often involve fixed objects (such as trees, poles, and posts) and in some instances pedestrians (Haworth, Vulcan, Bowland, & Pronk, 1997; Mackenzie, 2008; Road Safety Council of Western Australia, 2006; Treacy, Jones, & Mansfield, 2002). They are also more likely to occur on curved roads or slopes (Meuleners, 2009).Various countermeasures have been proposed to reduce the likelihood of a vehicle leaving the road. These include roadway treatments such as re-alignment, improving skid resistance, and providing more effective road delineation (Johnston, Corben, Triggs, Candappa, & Lenne, 2006). Still, most run off road crashes end in impact with a roadside object. While improving road conditions may decrease the likelihood of a vehicle leaving the road, the severity and adverse effects of the crash remain. In practice, roadsides could be made more crashworthy through the removal of rigid objects and improved crashworthiness of trees and poles (Johnston et al., 2006). But to stop a vehicle leaving the roadway altogether and impacting with a non-frangible object that may increase the risk of injury it may be more appropriate to consider the implementation of a roadside barrier.

The Safe System approach to dealing with events such as run off road crashes acknowledges that that drivers and riders will make mistakes and that the road network and its infrastructure should be designed and configured to minimise the risk of fatal and serious injury as a consequence (Austroads, 2010). The installation of barriers to improve roads and roadsides and to minimise the risk of injury is one initiative under the safe system response. It is important that this initiative be aware of the factors surrounding run off road crashes, including - but not limited to - the type of road user involved, the speed at which they are travelling and other behavioural factors such as alcohol and use of protection, features of the road and roadside, and the nature of the surrounding area to ensure the installation of the most appropriate countermeasure for the type of traffic and surrounding environment.

1.1 Aims and Objectives

The general aims of this investigation were to describe run off road crashes in the urban area and propose relevant countermeasures to reduce their incidence and injury severity.

The specific objectives of this investigation were to:

- Review the research literature to identify key findings related to run off road crashes, particularly those in urban areas, and relevant countermeasures;
- Describe the epidemiology of run off road crashes in the Perth urban area during the period 2005-2009 and the factors associated with the resulting injury severity; and to,
- Provide recommendations for the development of engineering, environmental and other countermeasures to reduce the incidence of and/or injury severity of run off road crashes in urban areas.

2. METHODS

2.1 Ethics approval

This research was undertaken with the approval of the Human Research Ethics Committee of the School of Public Health, Faculty of Health Sciences, Curtin University.

2.2 Literature search and retrieval

A review of the scientific literature published in Australia and elsewhere was undertaken to:

- identify the range of driver, vehicle, road, and crash variables associated with run off road crashes, particularly those in urban locations; and to,
- describe current and innovative roadside barrier engineering initiatives to counter run off road crashes in urban locations.

A literature search of databases including Google scholar, ProQuest, Current Contents, Scopus, Factiva and EconLit was undertaken using ‘key words’ to retrieve local, national and international publications (books, reports, scientific journal articles, conferences papers) relevant to the topic. Publications prior to 1990 were excluded.

2.3 Western Australian road traffic crashes

Police records of all on-road traffic crashes (both police attended/reported and road user reported) occurring during the period 2005-2009 in Western Australia were extracted by Main Roads Western Australia (MRWA) from their Integrated Road Information System (IRIS). Upon extraction, crashes were then linked (using the Straight Line Kilometre information at the site of the crash) with the MRWA road inventory and infrastructure database to identify the location and type of barriers and edge-lining at relevant crash sites.

2.3.1 Selection of crashes by type and location

Two crash types occurring in the Perth metropolitan area were selected for analysis to address the aims and objectives of the study. The first and primary crash type involved a single vehicle running off the carriageway and either colliding or not colliding (known as a *non-collision* crash) with an object. This crash type is defined in the IRIS dataset by Road Use Movement (RUM) codes identifying the vehicle has having left the road on straight (RUM codes 71-74) and curved (RUM codes 81-84) sections of road. These results of the analysis of these crash types are presented in Chapter 4.

The secondary and incidental crash type involved vehicles running off the carriageway and colliding with a pedestrian off the carriageway. This crash type is defined in the IRIS dataset by Road Use Movement (RUM) code 8 which identifies the pedestrian being struck while on the *footway* and sub-Pedestrian Movement codes 16 (not on carriageway - walking or running) and 24 (off carriageway – stationary). Off-carriageway pedestrian crashes involving a vehicle having run off the carriageway were included because of the high incidence of pedestrians in the urban area and their risk of injury as vulnerable road users. These crashes, expected to be few in number, were analysed separately to the aforementioned crash type and the findings presented in Chapter 5.

In relation to the location of the crash, for pragmatic reasons, crashes occurring in the Perth metropolitan area were considered to be representative of the population of *urban area* crashes. The categorisation of metropolitan area crashes is based on the classification of Western Australia geography using the Accessibility/Remoteness Index of Australia (ARIA) (Department of Health and Aged Care, 2001). ARIA presents five categories of remoteness ranging from Highly Accessible, Accessible, Moderately Accessible, Remote, and Very Remote. These categories can be used to classify Western Australia into areas defined as metropolitan, regional and remote. In general, the metropolitan area of Perth consists of Highly Accessible and Accessible areas, while areas outside of metropolitan Perth with an ARIA index of Accessible and Moderately Accessible are classified as regional Western Australia. Remote and Very Remote areas are classified as remote Western Australia (Marchant, Hill, Caccianiga, & Gant, 2008). For the purposes of this study the local government area of the crash reported in the IRIS database was assigned an ARIA code and then categorised as metropolitan, regional and remote for analysis.

2.3.2 Data management and analysis

Motor vehicle crash data extracted from the IRIS database were imported into SPSS (Version 19) for management and analysis. The pattern of run off road crashes in the metropolitan area of Western Australia was described using descriptive analyses and the factors associated with the severity of injury (no injury, minor injury, serious injury) of the crash modelled using multinomial logistic regression.

3. LITERATURE REVIEW

3.1 Prevalence and characteristics of single vehicle run off road crashes in Western Australia

Single vehicle crashes account for the largest proportion of serious injury and death in Australia (Johnston et al., 2006). Between 1999 and 2008 in Western Australia, single vehicle crashes resulted in an annual average of 109 deaths and 957 persons seriously injured (Meuleners, 2009).

In 2006, single vehicle collisions comprised 65% of all fatal crashes in Western Australia; with a 16% increase in the number of police-reported road crash fatalities compared to the preceding five year average (Marchant et al., 2008). A further increase in total fatality numbers was reported in 2008, with 81% of total fatalities due to single vehicle crashes. Seventy three percent of fatal metropolitan crashes and 87% of fatal regional crashes were single vehicle crashes in 2008 (Road Safety Council of Western Australia, 2009).

Between 1999 and 2008, a larger proportion of single vehicle crashes occurred in the metropolitan area (57%) of Western Australia, with an 8% increase over the course of this period. While 59% of fatal single vehicle crashes occurred in the rural/remote areas, hospitalisation (52%) and other crashes (58%) more commonly occurred in the metropolitan area (Meuleners, 2009).

Single vehicle run off road crashes make up a large proportion of single vehicle crashes, particularly those resulting in serious injury and fatalities. Run off road crashes usually occur when a single vehicle runs off the road possibly colliding with one or several objects (Liu & Subramanian, 2009).

3.2 Factors contributing to single vehicle crashes in relation to regional differences

3.2.1 Characteristics of single vehicle crashes in urban areas

Past research has examined the different characteristics between motor vehicle crashes in urban compared with rural areas (Chen et al., 2009; Zwerling et al., 2005); however limited studies have attempted to identify the different characteristics between single vehicle or run off road crashes occurring in urban and rural environments. Only one study clearly stratified single vehicle crash data by geographic areas (metropolitan, rural, remote) in Western Australia using Police crash records from 1999 to 2008 (Meuleners, 2009), and two Victorian studies analysed serious injury and fatal single vehicle crashes occurring within a 200km radius of Melbourne between 1995 and 1996, and 1996 and 1997 respectively (Haworth & Bowland, 2000; Haworth et al., 1997). One US-based study using country-wide crash data from 1991 to 2007 distinguished between run off road and on-road fatal single vehicle crashes, the latter referring to crashes in which a vehicle remains on the road after the crash (Liu & Subramanian, 2009). However, this study did not entirely distinguish between urban and rural crashes.

While national and international studies have consistently reported a higher fatality risk for motor vehicle and single vehicle crashes specifically in rural compared with urban locations (Donaldson, Cook, Hutchings, & Dean, 2006; Kmet & Macarthur, 2006; Liu & Subramanian, 2009; Zwerling et al., 2005), urban environments have been found to have higher rates of single vehicle crashes, particularly those resulting in serious injury and involving other road users (Meuleners, 2009; Retting, Williams, Preusser, & Weinstein, 1995). For example, collisions with a pedestrian and with an object were reported to be more prevalent in the metropolitan areas of Western Australia than in the rural and remote areas over the past decade. Further, an increase of single vehicle crashes involving an impact with pedestrians was observed in the metropolitan and rural areas by 10% and 12%, respectively, during this period, while they decreased by 7% in the remote areas (Meuleners, 2009). In addition, single vehicle crashes due to hit object collisions increased in the metropolitan and rural areas by 9% and 7%, respectively, over the course of the study period, whereas a decrease by 2% was noted in the remote areas of the state. An increase in 'non-collision' crashes was reported for all three areas; however, it was highest in metropolitan areas increasing by 12%, compared to 5% in rural and 10% in remote areas (Meuleners, 2009).

Studies from around Australia have found that impacts with fixed objects comprised the most frequent single vehicle run off road crash type in all studied areas (Haworth et al., 1997; Mackenzie, 2008; Road Safety Council of Western Australia, 2006; Treacy et al., 2002). In Victoria, impacts with trees were reported to be the more common crash type outside of metropolitan areas whereas collisions with poles or posts were more common in the metropolitan area in Victoria between 1995 and 1996 (Haworth & Bowland, 2000; Haworth et al., 1997), while motor vehicle rollovers were more common outside of the metropolitan area (10% versus 4%) (Haworth et al., 1997). Recent Western Australian data however, found that in all three areas (metropolitan, rural and remote), a single vehicle crash was more likely to result in a serious injury if it involved an impact with a pedestrian or did not involve a collision (e.g., roll-over crash) at all compared to collisions with fixed objects (Meuleners, 2009). The same study also revealed that crashes involving an impact with an animal were less likely to result in a serious injury crash compared to collisions with fixed objects in all three areas. Conversely, a review of the international literature by Kloeden, Mclean, Baldock and Cockington (1999) found that single vehicle run off road and other motor vehicle crashes involving collisions with fixed roadside objects, such as poles and trees, resulted in a higher level of injury severity than other crash types in both urban and rural areas.

3.2.2 Road characteristics

Inconsistent findings have been reported concerning the characteristics of road surface, alignment and condition in relation to single vehicle crashes across Australian states. Based on the literature reviewed it appears that environmental factors play a more significant role as an immediate cause preceding a single vehicle crash in urban areas.

Straight, dry and unsealed roads are common characteristics of crashes in rural areas (Kidd & Willett, 2002; Mackenzie, 2008; Treacy et al., 2002). In Western Australia, single vehicle crashes also occurred predominantly on sealed roads (90%), straight sections of the road (65%), roads that were level (73%) and on dry roads (76%) across all three geographic areas over the past decade. However, the risk for a serious injury single vehicle crash in the metropolitan area was found to be 21% higher on the curved part of the road compared to a straight road and 36% higher on the crest of a hill or slope than the level part of the road (Meuleners, 2009). Victorian statistics revealed that one third of fatal single vehicle crashes in both metropolitan and rural areas occurred on curved roads, and a higher relative risk at sites on curves was reported (Haworth et al., 1997). Similarly, Liu and Subramanian (2009) reported that fatal single vehicle run off road crashes in the US between 1991 and 2007 occurred at a higher rate on curved parts of the road and that the odds of experiencing a fatal single vehicle crash were 1.7 times higher on curved than on straight roads. This study, however, did not differentiate between urban and rural areas. In Western Australia, the road surface (sealed or unsealed) was not associated with the risk of serious injury crashes in any of the analysed areas between 1999 and 2008. This disagrees with the findings of previous studies where unsealed roads were associated with higher crash risks for all types of motor vehicle crashes (Kidd & Willett, 2002) and with single vehicle rollover crashes in the Northern Territory (Treacy et al., 2002).

The speed limits of various types of roads have been associated with an increased risk of single vehicle run off road crashes and serious injury crashes (Haworth et al., 1997; Liu & Subramanian, 2009). Although Western Australian statistics show that a larger proportion of crashes occurred on local roads (67%) than on highways between 1999 and 2008 across all three areas of the state, and a higher proportion of crashes were reported for local roads in the metropolitan areas (76%) compared to the rural (58%) and remote areas (53%), there was a significant 40% increased risk for a serious injury single vehicle crash on a highway rather than on a local road in metropolitan areas. Rural roads had a 29% increased risk for a serious injury single vehicle crash on a highway compared to a local road (Meuleners, 2009). In Victoria, half of fatal single vehicle crashes reported between 1996 and 1997 occurred on roads with speed limits of 100 km/h or above; 23% of which occurred on metropolitan roads. Within the metropolitan area specifically, a larger proportion of crashes occurred on highways than on minor roads (Haworth et al., 1997). The differing findings between the two states are likely to be explained by the different types of crashes analysed, i.e. fatal only versus all types of single vehicle crashes.

3.2.3 Temporal characteristics

Previous research has identified that night time driving increases the risk of crashing, particularly on open rather than urban roads in Western Australia (Kidd & Willett, 2002). Daylight was the most common lighting condition for crashes reported in Western Australia between 1999 and 2008 in all areas. However, dark conditions with no street lights present made up a larger proportion of crashes in the rural (23%) and remote (22%) areas than in the metropolitan area (7%). The percentage of crashes that occurred at night was the highest for fatal single vehicle crashes overall (50%). Similarly, fatal single vehicle run off road crashes reported between 1991 and 2007 in the US were more likely to occur at night time (74%) (Liu & Subramanian, 2009), and in South Australia, driving in darkness or low light was found to correlate with increased single vehicle crashes in rural areas (Mackenzie, 2008). Conversely, Meuleners (2009) reported that driving in darkness and at dawn/dusk significantly decreased the risk for a single vehicle serious injury crash in rural Western Australia and found no significant effects of day or night time driving on crash risk in metropolitan areas (Meuleners, 2009).

In the metropolitan and remote areas of Western Australia wet roads significantly decreased the risk for a serious injury single vehicle crash compared to when it was dry (Meuleners, 2009). None of these environmental factors were associated with serious injury crashes in the rural area. The apparent decreased risk of serious injury crashes in wet versus dry road conditions has also been reported in other Australian studies. Kloeden, Ponte and McLean (2001) suggest that this difference may be explained by an increase in low severity skidding crashes in wet conditions, rather than a decrease in high severity crashes in wet conditions.

3.2.4 Driver characteristics

In Western Australia, as for Australia as whole, young drivers (17-24 years) and male drivers are over-represented in road fatality and crash statistics (Armstrong, Smith, Steinhardt, & Haworth, 2008; Baldock, Long, Lindsay, & McLean, 2005; Haworth & Bowland, 2000). The same applies to single vehicle crashes both in metropolitan and rural areas in Western Australia (Meuleners, 2009) and other states (Haworth et al., 1997; Treacy et al., 2002). In addition, Stevenson & Palamara (2001) reported that young urban drivers had a higher crash risk than rural drivers in a Western Australian cohort study of 1,796 novice drivers. Similarly, a recent prospective cohort study of 20,822 drivers aged 17-24 in New South Wales by Chen et al. (2009) found that young urban drivers had an increased crash risk in general although the risk of a single vehicle crash was elevated among rural drivers.

3.2.5 Behavioural risk factors

Speeding and alcohol use are common factors in single vehicle crashes and generally have been associated more frequently with crashes occurring on rural roads (Chen et al., 2009; Haworth et al., 1997; Zwerling et al., 2005). Contrarily, speed was reported to be a contributing factor in 40% of urban compared to 30% of rural fatal crashes occurring in 2000 in Western Australia (Kidd & Willett, 2002). Similar data emerged from Meuleners (2009) study into single vehicle crashes in Western Australia between 1999 and 2009, revealing that speeding was a common factor in fatal crashes in metropolitan areas of Western Australia (40%) and even more so for hospitalisation crashes (61%).

Alcohol use and non-use of restraints are common factors related to single vehicle crashes and motor vehicle crashes in general and have been found to be more commonly associated with rural crashes (Tziotis, Roper, Edmonston, & Sheehan, 2006). While these factors were frequently found among metropolitan crashes in Western Australia as well as in all other areas of the state over the past decade, the number of fatalities and crashes requiring hospitalisation associated with these factors increased with the level of remoteness (Meuleners, 2009).

Similarly to alcohol use and non-use of seat belts, sleep and fatigue related driving has been suggested to occur more often in rural areas, highways and monotonous road environments where speed limits are higher (Baldock et al., 2005; Zwerling et al., 2005). However, Armstrong et al. (2008) found that driver fatigue is also a significant contributing factor for single vehicle crashes in low speed, urban areas of <60 km/h in a retrospective analysis of Queensland Police crash reports from 2000 to 2006. Both alcohol and fatigue affected driving – which are commonly noted at night and early morning - are likely contributors to the higher incidence of run off road crashes during these hours (Transport Canada, 2011).

3.2.6 Preventive measures for single vehicle run off road crashes in urban areas

While it seems that much focus has been directed at the characteristics and prevention of single vehicle run off road crashes occurring in rural areas, little research has studied the differences in risks and effectiveness of prevention measures in urban areas. However, the more complex driving environments of urban roads - which have more entrance points, exit points and intersections per kilometre than a highway in a rural area - provide more opportunities to crash and therefore require equal attention to ensure road safety. Usually higher volumes of traffic on urban roads and greater numbers of pedestrians, cyclists and other vulnerable and sometimes unpredictable road users are further risk factors which may increase the likelihood of a motor vehicle crash in urban areas (Chipman, 1991). Due to the projected continued growth of the Australian population with concentrations of population in the metropolitan areas of each state or territory (Australian Bureau of Statistics, 2008) these road safety concerns are likely to increase further. Increased population and consequently traffic volume in cities will have important implications for road safety in the metropolitan areas of Australia.

The more frequent occurrence of single vehicle crashes particularly those resulting in serious injury in urban compared to rural areas of Western Australia (Meuleners, 2009) also indicates that greater attention needs to be focused on reducing the numbers and severity of crashes in urban environments. While further analysis is required into the causal factors characteristic to urban roads to ensure implementation of appropriate and location specific strategies, recent research has provided a first insight into the geographic differences in crash risk in Western Australia between 1999 and 2008 (Meuleners, 2009). The most common crash types and contributing factors in the metropolitan area of Western Australia can thus be summarised as follows:

- impacts with a pedestrian or a fixed object occurred most frequently,
- non-collision crashes and collisions with pedestrians were more likely to result in a serious injury than collisions with other roadside objects across all areas of WA,
- an increasing trend was observed for all three types of crashes (hit pedestrian, hit object, non-collision),
- an increased crash risk on the curved compared to the straight part of the road,
- an increased crash risk on the crest of a hill or slope compared to the level part of the road,
- a decreased crash risk in wet compared to dry road conditions,
- a higher proportion of crashes occurred on local roads in the metropolitan areas (76%) compared to the rural (58%) and remote areas (53%),
- a higher significant increased risk for a serious injury single vehicle crash on a highway rather than on a local road in metropolitan areas (40%) compared to rural roads (29%),
- young drivers (17-24 years) and male drivers were over-represented in single vehicle fatality and crash statistics both in all areas,
- speed was a contributing factor in 40% of urban areas and in 61% of hospitalisation crashes in metropolitan areas,
- alcohol use and non-use of restraints were common factors related to single vehicle crashes in all areas of Western Australia, however, the number of fatalities and crashes requiring hospitalisation increased with the level of remoteness.

As for rural crashes, it is clear that the causes of single vehicle crashes in urban environments are multiple and it is difficult to identify a single, predominant causal factor. The challenges in identifying and implementing an effective single countermeasure to reduce the incidence of single vehicle crashes in urban areas may explain to some extent the lack of literature in this area.

In line with these findings, it has been argued that a number of countermeasures are necessary to prevent run off road crashes in general (Johnston et al., 2006). A research report by Johnston et al., (2006) developed a set of three core strategies for dealing with run off road crashes in Victoria: (a) targeting immediate behavioural causes for a vehicle to leave the road, (b) reducing the probability of a vehicle leaving the road through improving road conditions and vehicle safety technology, and (c) reducing the consequences of a crash after a vehicle has left the road.

It is apparent that for a large proportion of single vehicle run off road crashes the immediate causes are not unique but common to many other crash types, particularly behavioural factors such as driving under the influence of alcohol or other drugs, speeding, fatigue, inattention etc. Various interventions addressing these issues have been implemented around Australia, e.g. intense random breath testing and intense enforcement of speed limits, and have been shown to be effective in reducing serious injuries and fatalities. In relation to Random Breath Testing, there is good evidence to show that this initiative can have a long term impact on run off road single vehicle crashes at night (e.g., Homel, McKay & Henstridge, 1995.). Given that very high levels of blood alcohol levels and speed are common factors found more frequently in run off road crashes it has been suggested that further intervention is necessary to prevent these crashes (Johnston et al., 2006).

To reduce the likelihood that a vehicle leaves the lane regardless of the immediately preceding driver/vehicle behaviour a number of road treatment and vehicle safety improvement measures have been recommended (Johnston et al., 2006). These road-based measures represent the most common prevention strategies implemented in Victoria to date (Johnston et al., 2006). Specific examples include:

- improving the road alignment (particularly horizontal curvature), especially for individual curves of unexpectedly small radius relative to the preceding road alignment;
- providing sealed shoulders on rural roads;
- routinely repairing pavement “drop off” occurrences where sealed pavements meet unsealed shoulders;

- improving the skid resistance of pavements, particularly on short radius curves and the approaches to high-crash intersections;
- ensuring high quality roadside delineation (post-mounted delineators, chevron signs, raised reflective pavement markings, pavement markings, etc.), with special emphasis on tactile edge lines on rural roads;
- improving vehicle stability; for example recent evidence suggests that Electronic Stability Programs (ESP) are reducing single vehicle crashes by substantial amounts (ESP senses imminent loss of control and intervenes directly); and,
- reducing travel speeds in order to decrease the probability of loss of control.

It has been estimated that a combination of road safety treatments including re-alignment, shoulder sealing, pavement widening, line marking (tactile edgelines) and guideposts, better signage, overtaking lanes and improving safety of the roadside may reduce up to 40% of crashes in rural areas (RAC, n.d.) and also have been suggested to provide the best results in preventing run off road casualty crashes (Johnston et al., 2006).

A study conducted by Corben, Deary, Mullan and Dyte (1997) that sought to assess an accident black spot program that had been implemented to decrease the occurrence of crashes into roadside hazards in Victoria may yield some useful information regarding effectiveness of treatments for single vehicle crashes involving collisions in urban areas. The report considered 254 treatment sites and crash data from 1984-1995, a time period including equal lengths of time before and after the treatments. This data set contained 9,253 crashes: 6,989 crashes before the site treatments and 2,264 after the treatments. Overall, there had been a significant reduction of 8.6 per cent in casualty crash frequency for the treatment sites. This significant drop was mainly centred in the metropolitan area (14.5%) while treatments in rural areas had been less successful, yielding a non-significant casualty crash reduction of 4 per cent. Importantly, the most successful treatment categories were treatments of the road surface (29.6% crash reduction) and treatments of road and roadside geometry (22.9%). The most significant of road surface treatments was found to be shoulder sealing (31.8%) and the most significant treatments of road and roadside geometry were those dealing with horizontal curvature of the road (43.6%) (Corben et al., 1997). With regard to the costs of crashes, Corben et al. (1997) found that the overall reduction in crash costs from the total black spot treatment program was 15.5%. This is double the reduction in the number of crashes, suggesting that the treatments not only reduced the frequency, but also the severity of crashes. Again this reduction was only significant in the metropolitan area (25.4%). The reduction in crash costs for the rural area was 10.3 per cent. The most substantial crash cost savings came for road surface treatments (36.2%). When calculations of cost benefit ratios were made, it was found that the ratio for the entire treatment program was 4.1:1. Again, the metropolitan area proved more amenable to treatments, with the cost benefit ratio being 5.6:1 (Corben et al., 1997).

A number of measures have also been recommended to reduce the adverse consequences of a run off road crash (Johnston et al., 2006), such as:

- making poles and other roadside objects more crashworthy;
- clearing the immediate roadside of any rigid obstacles;
- ensuring all roadside vegetation is crashworthy;
- installing some form of crash barrier to better manage energy transfer in a crash;
- reducing travel speeds and, thus, impact speeds; and
- improving the crashworthiness of vehicles in impacts with trees and poles, embankments, etc. and in rollovers.

Of this list, a number of studies have reported on the use of roadside barriers to effectively reduce crash frequency and fatality. This countermeasure is briefly reviewed in the following sections.

3.3 Road side barriers

3.3.1 Flexible

Wire rope barriers consist of three or four tensioned cables supported by weak posts[1]. Upon impact the cables flex and deflect considerably, thereby decreasing crash severity, and also allowing for vehicle redirection (Department of Infrastructure Energy and Resources, 2007).

A number of studies have investigated the effectiveness of wire rope barriers. Candappa, D'Elia, Corben, & Newstead (2009) analysed crash data at treated and

[1] All jurisdictions in Australia now accept only 4-wire rope barrier installations (B.Snook, personal communication 2013).

untreated sections of road along the same route. Results showed that wire rope barriers significantly reduced serious crashes by up to 87% along an individual route with an overall reduction of 29% across all routes. Larsson, Candappa, and Corben (2003) reported a 45-50% reduction in fatal and serious injury crashes on two lane roads in Sweden, with an overall 90% fatality reduction. In Calgary, Alberta, installation of a tensioned median cable barrier along a 10.75km section of a six-lane divided freeway reduced the number of collisions leading to injury by 28%, with a benefit-cost ratio of 11.1 (Churchill, Barua, Hassan, Imran, & Kenny, 2011).

The prevention of cross-median crashes is particularly important in urban areas where medians may be narrow, and traffic volume high. Installation of cable barrier systems on high traffic, high speed roads in Jefferson County USA prevented up to 157 cross-median encroachments within a 21 month period (Agent & Pigman, 2008). In North Carolina and Washington, cable barriers reduced cross-median crashes by 61.8% and 61% respectively (Hammond & Batiste, 2009; Safety Evaluation Group, n.d.) fatal cross-median crashes by 74.7% (Safety Evaluation Group, n.d.) and fatal and serious injury collisions by 58% (Hammond & Batiste, 2009). Cross-median crash reductions as high as 95% have also been reported (Ray, Silvestri, Conron, & Mongiardini, 2009).

Studies by Grzebieta et al. (n.d.) showed that at a 20° angle 110km/hour speed, wire-rope barriers could cause a small car to roll. Consequently, the barrier was too short, highlighting the need for wire-rope barriers to be of an adequate length and also to be set up in the same way in which they were initially tested and certified (Grzebieta et al., n.d.). Other important characteristics of wire rope barriers highlighted by Nilsson and Prior (2004) include low accident costs and low injury risk both of which make them an attractive countermeasure. It is important to note however, that the flexibility of wire-rope barriers makes them an unsafe option for vehicle containment in some areas, where it may be necessary to provide a rigid or semi-rigid barrier, and in some cases a barrier that will contain large semi-trailers (Department of Infrastructure Energy and Resources, 2007).

The effectiveness and popularity of wire-rope barrier installations is said to be offset by the on-going maintenance required to tension them and repair them in the event of a crash, activities which some road authorities are said not to undertake adequately

(B. Snook, personal communication, 2013). Thus whole of life costs of wire-rope barriers should thus be considered in cost-benefit analyses.

3.3.2 Semi-rigid

Semi-rigid barriers are made up of horizontal steel beams attached to block-outs which are supported on wooden or steel posts (Department of Infrastructure Energy and Resources, 2007). Although they deform substantially under impact, they deflect less than the flexible systems described above. Three semi-rigid systems are commonly used in Australia; the W-Beam, the Thrie-Beam and the modified Thrie-Beam, each of which serves a region specific function. In speed zones up to 110 km/h, the W-Beam system is widely used as a general purpose semi-rigid barrier suitable for passenger vehicle impacts. In locations where the barrier is regularly hit, the Thrie-Beam (which consists of a stronger rail) is used (Department of Infrastructure Energy and Resources, 2007). Main Roads Western Australia's frequent use of the Thrie-beam is not necessarily related to the regularity of impacts but because it is reported to have greater capacity in the event of a collision (B. Snook, personal communication 2013). Where there is a higher than normal likelihood of heavy vehicle impacts, the modified Thrie-Beam system is often implemented as a more resistant barrier than the Thrie-Beam system (Department of Infrastructure Energy and Resources, 2007). In Western Australia, the modified Thrie-beam is said to perform better for small vehicle impacts and is used in preference to the Thrie-beam, except at locations where there is a transition from W-beam to concrete barrier when the Thrie-beam will be installed (B. Snook, personal communication 2103).

An investigation into the effectiveness of W-Beam barriers in North Carolina revealed a 5.3% reduction in fatal crashes, and 81.2% reduction in fatal cross-median crashes (Safety Evaluation Group, n.d.). The addition of a combined W-beam and cable barrier system led to a 100% reduction in fatal cross-median crashes (Safety Evaluation Group, n.d.). Small car W-beam barrier tests involving a car travelling at 110km/hour at a 20° angle resulted in a low deceleration crash in which the vehicle was safely halted (Grzebieta et al., n.d.). At the slower test speed of 80 km/h and increased crash angle of 45°, the vehicle wheel went underneath the barrier and was torn from the vehicle indicating the important consideration of height in W-beam barrier design and implementation. Crash test and simulator investigation of barrier safety performance noted the influence of sloped terrain on barrier under-ride

(Marzougui, Mohan, & Mahadevaiah, 2007). In fact, the Safety Evaluation Group of North Carolina (n.d.) reported that 90% of crashes which involved a breach of the safety barrier were due to under-ride. In urban areas where medians may be narrow, stronger less resistant barriers are required.

3.3.3 Rigid

Rigid safety barriers vary in structure depending on their purpose and exhibit negligible deflection when impacted by a vehicle, the consequence of which is that the impact severity of a motor vehicle colliding with the barrier is increased (Department of Infrastructure Energy and Resources, 2007). Rigid barriers are reported to be least preferred due to their hazardous potential (Grzebieta, Zou, & Jiang, 2005) and are somewhat limited to areas where high speed, heavy vehicle impacts are likely. Although costs for (single vehicle) median barrier crashes are around 20% that of multi-vehicle cross-median crashes (Chitturi, Ooms, Bill, & Noyce, 2011), and less severe (Chitturi et al., 2011; Hu & Donnell, 2010), it has been found that concrete barriers redirect vehicles more often (63.8%) than cable barriers (16.0%) (Hammond & Batiste, 2009), where a vehicle is more likely to stay in the median after impacting the barrier.

Use of concrete barriers is usually limited to areas where heavy vehicle impacts are likely, or space is limited (Department of Infrastructure Energy and Resources, 2007). Small car crashes into a concrete median barrier at 80 km/hour at a 45° angle are not survivable (Grzebieta, Zou, Jiang, & Carey, n.d.), a factor which needs to be considered when evaluating the most effective and safe barrier types for urban areas.

3.4 Vulnerable road user groups and barriers

3.4.1 Motorcyclists

Motorcyclists are vulnerable road user group that have particular needs in relation to the installation of effective and safe road barriers. A 2007 study by Gabler (2007) barrier crashes in the USA found that motorcycle users compared with vehicle occupants were 81.1 times more likely to be fatally injured when colliding with a guardrail barrier and were the third most likely road user type to be killed from impact with a concrete barrier. Daniello and Gabler (2011a) also later reported on the effect of barrier type on injury severity for motorcycle-barrier crashes in three US states. Analysis of 951 crashes over a 6 year period found that 40.1% of W-beam crashes were fatal or caused severe injury. A similar figure (40.3%) was reported for motorcycle-cable barrier collisions (Daniello & Gabler, 2011a). However, a small number of cable barrier collisions were included in the analysis, which may have influenced the results somewhat. W-beam barriers were also involved in just under 60% of n=77 fatal motorcycle crashes involving barriers occurring between 2001-2006 across Australia and New Zealand examined by Jama, Grzebieta, Friswell and McIntosh (2011).

Though the findings of the latter study are limited by the failure to the reference them against barrier crashes that were non-fatal, there was some evidence to suggest that rider factors contributed to the occurrence of the crash in the first instance. Jama et al. (2011) noted that speed and a combination of speed and alcohol, particularly on curves, were critical contributing factors. These factors suggest that fatalities may be decreased by appropriate intervention and modification to limit such behavioural risk factors. Jama et al. (2011) consider that it is unclear whether the redesign of safety barriers would improve motorcycle fatality counts as guardrails are typically more harmful to motorcyclists than other road users. But, they nevertheless provide some protection for motorcyclists from colliding with other road-side objects - such as trees which are more likely to result in fatality – and were noted to be the most frequent roadside hazard protected by barriers in the Jama et al. (2011) investigation.

Recent innovations in barrier technologies show some promise in relation to reducing the risk of injury for crashing motorcyclists. The Barriacel Motorcycle Crash Attenuating Device (MCAD) is a new development designed by road safety specialists which offers 360° protection for motorcyclists and cyclists from impacts with roadside barrier posts. The energy absorbing product can be easily fitted to both new and existing barriers (Highway Engineering Australia, 2011). At this stage however, research is yet to be undertaken of the performance of Barriacel MCAD 'in situ'.

3.4.2 Pedestrians

The use of barriers in pedestrian-dense urban areas to protect them from vehicles travelling off-carriageway is a significant challenge for a number of reasons. While the barrier is required to have the necessary properties to limit the vehicle's travel off-carriageway, it similarly should not cause undue deflection of the vehicle back onto the roadway or into vulnerable road users such as pedestrians off-carriageway. Nor should it present as an impediment to pedestrian manoeuvrability. In South

Australia, examination of the evidence from several serious accidents at road-side dining areas led to the development of the energy-absorbing bollard (SA Health, 2012). Regularly placed energy-absorbing bollards deform minimally on impact and can be placed around dense pedestrian areas such as café strips, bus stops, etc. This form of urban crash barrier has reportedly passed rigorous crash testing and will stop a 1200kg motor vehicle travelling at 60 km/h or a 1600kg motor vehicle travelling at 50 km/h (Government of South Australia, 2000). Importantly, the bollard barrier design allows for pedestrian movement, but additionally offers significant pedestrian protection not usually afforded by the glass panels, brick walls and plantar boxes which often delineate these kinds of areas (South Australian Department of Human Services, 2000). Further, energy-absorbing bollards have been shown to significantly reduce impact forces, thereby reducing impact severity compared to rigid road-side objects such as trees and poles, which absorb little energy upon impact (Zivkovic, 2000).

3.5 Conclusion

It is difficult to provide an assessment of the unique risk factors for single vehicle crashes in urban areas based on the available literature due to the fact that most research has focussed on single vehicle crashes in rural areas as this crash type is the predominates serious injury crashes in non-urban areas. Also a number of different definitions have been used in the literature to describe single vehicle crashes adding to the difficulty in making accurate comparisons.

To date, only one study has examined the different characteristics of single vehicle crashes by geographic location in Western Australia including all types of single vehicle crashes (Meuleners, 2009). Two Victorian studies made some distinctions between metropolitan and other study areas in a radius of 200km outside the metropolitan area. These studies however, did not specifically aim to measure differences in crash characteristics relating to geographic areas. The majority of available studies focus on characteristics of single vehicle crashes in rural areas only or do not clearly distinguish between different geographic locations (Baldock et al., 2005; Mackenzie, 2008; Ornek & Drakopoulos, 2007; Treacy et al., 2002). Only one US-based study has examined the specific characteristics of single vehicle run off road crashes (Liu & Subramanian, 2009). However, and similar to other research (Haworth et al., 1997), these study findings are limited in their ability to obtain a comprehensive description of the problem as they are not representative of all police reported crashes but focused on fatal crashes only.

It has been shown across many studies that flexible wire rope barriers are effective in reducing cross-median crashes and decreasing crash severity (particularly wire-rope barriers). Similarly, cross-median crashes are significantly reduced by semi-rigid and concrete barriers although the effects on fatalities are less clear. Vulnerable road users such as motorcyclists are at risk of fatal injury when colliding with all barrier types. However, the protection provided from rigid road-side objects by safety barriers is advantageous for both motorcyclists and motor vehicles.

Similarly, pedestrians are particularly vulnerable in the urban environment. Energy-absorbing bollards, which aid in pedestrian protection from errant vehicles, are particularly suited to the urban environment due to reportedly minimal deflection and the ability to stop motor vehicles travelling at 50-60 km/h which is the typical speed limit for urban areas.

Accordingly, countermeasures to reduce run off road crashes in the Perth urban area should account for all road-users, travel speeds and pedestrian activity to be effective in reducing the incidence and injury severity of these crashes.

4. ANALYSIS OF SINGLE VEHICLE RUN OFF ROAD CRASHES IN METROPOLITAN PERTH 2005-2009

A total of 161,625 crashes were recorded by WA Police to have occurred in the metropolitan Perth area during the period 2005-2009. Applying the criteria for the identification of a single vehicle run off road crash (RUM codes 71-74 and 81-84) involving drivers and riders in this location resulted in the selection of 12,843 crashes of interest or 7.9% of all metropolitan area crashes and 58% of single vehicle run off road crashes across Western Australia. In the regional and remote locations of Western Australia these crash types account for around a quarter to one-third of all crashes.

Table 4.1 RUM code 71-74 and 81-84 and all other RUM code crashes; by location, Western Australia, 2005-2009

	Location							
	Metropolitan		Regional		Remote		All Areas	
	n	%	n	%	n	%	n	%
RUM Codes 71-74 and 81-84 crashes	12,843	7.9	5,809	24.5	3,663	33.3	22,315	11.4
All other RUM crashes	148,782	92.1	17,827	75.5	7,327	66.7	173,936	88.6
All	161,625	100.0	23,636	100.0	10,990	100.0	196,251	100.0

N=25 missing location

When crashes of this type are considered by crash severity, they are proportionally more likely to result in death or hospitalisation (serious injury) in the remote (23.6%) and regional (19.1%) areas of Western Australia compared with metropolitan Perth (11.9%). In absolute terms however, many more fatal and serious injury single vehicle run off road crashes occur in the metropolitan area (n=1,528) compared with regional (n=1,109) and remote (n=866) Western Australia. These numbers affirm the need to address crashes of this type in the metropolitan area with some priority.

In the following sections the findings of the analysis of the dataset of n=12,843 single vehicle run off road crashes in the metropolitan area (excluding those crashes with a pedestrian off-carriageway which are described in Chapter 5) will be presented in relation to selected crash, road, vehicle and road user characteristics. The results from the descriptive analyses will be presented first, followed by the results of the multivariate analysis of the data to determine the factors that best explain the variation in injury outcomes associated with these crashes.

4.1 Selected crash and road characteristics

Descriptive findings for the crash characteristics of severity; nature; road user movement; road alignment and section; time of day; lighting; day of week, and weather are reported in the following sections.

4.1.1 Severity

Approximately 78% of single vehicle run off road crashes in metropolitan Perth resulted in property damage only (major and minor). A further 12% of crashes resulted in the police reported death or hospitalisation of an involved road user, while the remainder of crashes involved medical attention only.

Table 4.2 Severity of single vehicle run off road crashes occurring in metropolitan Perth; 2005-2009

Crash Severity	n	%
Fatal	132	1.0
Hospitalisation	1396	10.9
Total Serious Injury Crashes	*1528*	*11.9*
Medical treatment only	1330	10.4
Property Damage Only (Major)	7816	60.9
Property Damage Only (Minor)	2169	16.9
Total	12843	100.0

4.1.2 Road Use Movement

As the dataset was restricted to single vehicle run off road crashes, the analysis of road use movement patterns was restricted to those leaving the road on straight (RUM Codes 71-74) and curved (RUM Code 81-84) sections of road. Just over two-thirds of single vehicle run off road crashes in the metropolitan area occurred on straight (68.1%) *versus* curved (31.9%) sections of road. For run off road crashes on straight sections of road 57% occurred when the vehicle veered to the left off the carriageway while 43% were reported to have veered to the right of the carriageway (thus crossing the centre line). For run off road crashes on curves, near equal proportions of crashes occurred on left-hand (49%) and right-hand (51%) bends.

Table 4.2 also shows that approximately 95.3% of all run off road crashes (straight and curves) resulted in the collision with an object. The vast majority (96.6%) of the n=610 non-collision crashes resulted in the vehicle overturning.

Table 4.3 Road Use Movement of single vehicle run off road crashes occurring in metropolitan Perth; 2005-2009

Road Use Movement	n	%
Off Straight-Non-Collision		
• Left of carriageway	211	1.6
• Right of carriageway	139	1.1
Off Straight-Hit Object		
• Left of carriageway into object/vehicle	4982	38.8
• Right of carriageway into object/vehicle	3420	26.6
Off Curve-Non-Collision		
• Left bend	108	0.8
• Right bend	152	1.2
Off Curve-Hit Object		
• Left bend into object/vehicle	1897	14.8
• Right bend into object/vehicle	1934	15.1
Total	12843	100.0

Cross tabulation of run off road crash type by crash severity (Table 4.4) showed that the majority of both non-collision and hit object crashes resulted in property damage only, with 23.3% of non-collision crashes resulting in the death or hospitalisation of one or more vehicle occupants compared with 11.3% of hit object crashes. However, the absolute greater number of fatal and serious injury 'hit object' crashes defines this single vehicle crash type as a significant road safety problem.

Table 4.4 Crash severity of non-collision and hit object single vehicle run off road crashes occurring in metropolitan Perth; 2005-2009

	Run off Road Crash Type					
	Non-Collision		Hit Object		All	
Crash Severity	n	%	n	%	n	%
Fatal	5	0.8	127	1.0	132	1.0
Hospitalisation	137	22.5	1259	10.3	1396	10.9
Medical Treatment	116	19.0	1214	9.9	1330	10.4
PDO Major	303	49.7	7513	61.4	7816	60.9
PDO Minor	49	4.7	2120	17.3	2169	16.9
Total	610	100	12233	100	12843	100

Chi Square: X^2=180.87 df=7; $p \leq .001$

4.1.3 Hit Object Crashes

All vehicle types

For single vehicle hit object crashes up to three objects, in order of collision, are recorded by WA Police (see Table 4.5). No information was provided for the object(s) of collision for n=55 (0.4%) hit object crashes occurring during the study period. Police reports indicate that the majority of hit object crashes (55.3%) in the metropolitan area involved the collision with one object only, with 32.5% and 12.2% respectively colliding with two and (at least) three objects.

Roadside kerbs (23.7%) are the primary (first recorded) object of collision, followed by poles/posts/signs (18.3%), traffic islands (14.9%), trees/shrubs (13.3%) and fences/building walls (10.9%). Of the n=2,881 initial collisions with a kerb, 80% of vehicles reportedly collided with a second object, the most frequent being a power pole (19%); fence/building wall (18.8%); trees/shrub (18%), and other pole, post or sign (16.3%). Only 2% of collisions initially with a kerb subsequently involved the vehicle colliding with a guard rail/barrier. Trees/shrubs, other poles, posts and signs, power poles, and fences and building walls were the most frequent second and third objects impacted and recorded irrespective of the object of first collision.

Table 4.5 Object types by order of collision for hit object single vehicle run off road crashes in metropolitan Perth; 2005-2009

	Order of Collision					
	1st Object		2nd Object		3rd Object	
Object Type	n	%	n	%	n	%
Power Pole	1248	10.2	837	15.4	173	11.6
Other pole, post and sign	986	8.1	1150	21.2	260	17.5
Guard Rail/Barrier	495	4.1	93	1.7	16	1.1
Tree/Shrub	1622	13.3	1318	24.2	407	27.4
Traffic Island	1811	14.9	131	2.4	29	2.0
Kerb	2881	23.7	236	4.3	38	2.6
Fence; Building wall	1330	10.9	830	15.3	293	19.7
Embankment	281	2.3	138	2.5	29	2.0
Vehicle parked off carriageway	710	5.8	266	4.9	101	6.8
All other objects	814	6.7	451	8.1	139	9.4
Total	12178	100	5450	100	1485	100

n=55 missing Object Type

Motorcycles and mopeds

Because of the comparative lack of protection afforded to motorcycle and moped riders in the event of a collision, hit object crashes were separately analysed for this group of road users to identify objects of concern. Approximately 82% (n=352) of motorcycle and moped single vehicle crashes involved the collision with an object. Around 7% of riders colliding with an object were killed, compared with 1% of hit object crashes involving all vehicle types (as shown in Table 4.6). No riders involved in a non-collision crash during the study period were killed.

No information on the object(s) of collision was available for n=79 (18.5%) of riders involved in a hit object crash. Approximately 64% (n=222) collided with one object only, 28% (n=97) with two objects, and 8% (n=30) with at least three objects. As shown in Table 4.6 riders were most likely to initially collide with the kerb (33.2%) followed by a traffic island (28.9%). Poles, posts and signs; trees/shrubs, and fence/building walls were the most frequent second and third objects of collisions for riders. Compared with all vehicle hit object crashes, riders were somewhat more likely (n=38 or 11% of all rider hit object crashes) to collide with a barrier or guard rail.

Table 4.6 Object types by order of collision for hit object single vehicle run off road crashes involving motorcycles and mopeds in metropolitan Perth; 2005-2009

	Order of Collision					
	1st Object		2nd Object		3rd Object	
Object Type	n	%	n	%	n	%
Power Pole	14	4.0	11	8.7	1	3.3
Other pole, post and sign	28	8.1	32	25.1	6	20.1
Guard Rail	8	2.3	30	2.4	0	0.0
Tree/Shrub	33	9.5	21	16.5	5	16.7
Traffic Island	101	28.9	9	7.1	1	3.3
Kerb	116	33.2	13	10.2	0	0.0
Fence; Building wall	11	3.2	17	13.5	7	23.3
Embankment	5	1.4	5	3.9	1	3.3
Vehicle parked off carriageway	8	2.3	5	3.9	2	6.7
All other objects	25	7.1	11	8.7	7	23.3
Total	349	100.0	127	100.0	30	100.0

n=79 missing Object Type

4.1.4 Roadside barriers

Overall, guard rails/ barriers were infrequently impacted by vehicles running off the road in the metropolitan area. A total of n=604 (5%) vehicles running off road in the metropolitan area collided with a guard rail or barrier. In nearly all cases (n=495 or 82%) the guard rail or barrier was reported to be the first object impacted.

The presence and type of barriers at crash locations was analysed by retrieving the road inventory infrastructure information at the Straight Line Kilometre (SLK) location of the crash. To improve the sensitivity of this analysis it was necessary to analyse crashes by the various sub-types detailed in Table 4.3.

Left of carriageway run off road crashes (hit object and non-collision) on straight roads

For crashes where vehicles went *left* off the carriageway on a straight section of road (RUM Code 71 non-collision; RUM Code 72 hit object), left-hand roadside barrier information was retrieved for 3% (n=155/5,238) of crashes. As shown in Table 4.7, Brifen (wire-rope) barriers and Constant Slope Shape Concrete barriers were the most common installation at the left-hand side of the site of the hit object crash. In all instances police reported that the vehicle had collided (either as a first, second or third object) with a 'barrier'. Whilst the definition of a non-collision crash is the absence of impact with an object or another vehicle, the road inventory infrastructure information at (or around) n=13 non-collision crash sites indicates that barriers were installed at the time the inventory data was retrieved.

Table 4.7 Barrier type along left-hand side of crash site for left off carriageway on straight crashes in metropolitan Perth, 2005-2009

Barrier along the LHS of crash site	Left off Carriageway on Straight					
	Hit Object		Non-Collision		All	
	n	%	n	%	n	%
Brifen (wire rope)	62	43.7	5	38.5	67	43.2
Flexfence (wire rope)	1	0.7	0	0.0	1	0.6
Double-sided Lip Channel	1	0.7	0	0.0	1	0.6
W-Beam	11	7.7	1	7.7	12	7.7
Two Rail	12	8.5	0	0.0	0	0.0
Three Rail	4	2.8	1	7.7	5	3.2
Thrie Beam	2	1.4	1	7.7	3	1.9
Tric Block Concrete	1	0.7	0	0.0	1	0.6
Constant Slope Shape Concrete	43	30.3	5	38.5	48	30.9
Type F Shape Concrete	5	3.5	0	0.0	5	3.2
Total	142	100.0	13	100.0	155	100.0

n=5,038 no information on barrier along left-hand side of crash site

Right of carriageway run off road crashes (hit object and non-collision) on straight roads

For crashes where vehicles went *right* off the carriageway on a straight section of road (RUM Code 73 non-collision; RUM Code 74 hit object), information on the location of barriers along the median (Table 4.8) and right-hand side of the road (Table 4.9) at the location of the crash was identified. Of the n=3,559 crash locations, approximately 3.5% (n=124/3,559) and 3.1% (n=111/3,559) were respectively covered by median and right-hand road side barriers. Given the movement of the vehicle to the right of the carriageway it is reasonable to assume it would necessarily collide with a median barrier first if one existed at the location.

Table 4.8 Barrier type along median of crash site for right off carriageway on straight crashes in metropolitan Perth, 2005-2009

Barrier along the median of the crash site	Right off Carriageway on Straight					
	Hit Object		Non-Collision		All	
	n	%	n	%	n	%
Brifen (wire rope)	16	13.3	0	0.0	16	12.9
Flexfence (wire rope)	0	0.0	0	0.0	0	0.0
Double-sided Lip Channel	87	72.5	2	50.0	89	71.8
W-Beam	2	1.7	0	0.0	2	1.6
Two Rail	0	0.0	0	0.0	0	0.0
Three Rail	0	0.0	1	25.0	1	0.8
Thrie Beam	0	0.0	0	0.0	0	0.0
Tric Block Concrete	12	10	1	25.0	13	10.5
Constant Slope Shape Concrete	2	1.7	0	0.0	2	1.6
Type F Shape Concrete	1	0.8	0	0.0	1	0.8
Total	120	100.0	4	100.0	124	100.0

n=3,435 no information on barrier along median at crash site

Table 4.9 Barrier type along right-hand side of crash site for right off carriageway on straight crashes in metropolitan Perth, 2005-2009

Barrier along right-hand side of the crash site	Right off Carriageway on Straight					
	Hit Object		Non-Collision		All	
	n	%	n	%	n	%
Brifen (wire rope)	46	42.2	2	100.0	48	43.2
Flexfence (wire rope)	1	0.9	0	0.0	1	0.9
Double-sided Lip Channel	3	2.8	0	0.0	3	2.7
W-Beam	10	9.2	0	0.0	10	9.0
Two Rail	11	10.1	0	0.0	11	9.9
Three Rail	4	3.7	0	0.0	4	3.6
Thrie Beam	2	1.8	0	0.0	2	1.8
Tric Block Concrete	0	0.0	0	0.0	0	0.0
Constant Slope Shape Concrete	29	26.6	0	0.0	29	26.1
Type F Shape Concrete	3	2.8	0	0.0	3	2.7
Total	109	100.0	2	100	111	100.0

n=5,038 no information on barrier along right-hand side of crash site

Run off road crashes (hit object and non-collision) on left-hand curve

Crashes on curves can be categorised as occurring on left-hand or right-hand bends. Unfortunately however, the crash data does not provide additional information to determine whether the vehicle ran off the road to the *left* or *right* of the carriageway on the bend. Information on the location of barriers at left-hand curve run off road crash sites (RUM Code 83 non-collision; RUM Code 84 hit-object) is presented in Tables 4.10 and 4.11. Of the n=2005 run off road crashes occurring on left-hand curves:

- Left-hand side barrier information was recorded for 2.5% (n=50/2005) of crash sites.
- Median barrier information was recorded for 1.1% (n=23/2005) of crash sites.
- Right-hand side barrier information was recorded for 2.9% (n=58/2005) of crash sites.

Table 4.10 Barrier type along left, median and right-hand side of crash site for left bend off carriageway in metropolitan Perth, 2005-2009

Barrier Type	Off carriageway –Left bend					
	Left-hand side of crash site		Median		Right-hand side of crash site	
	n	%	n	%	n	%
Brifen (wire rope)	8	16.0	5	21.7	18	31.0
Flexfence (wire rope)	2	4.0	0	0.0	0	0.0
Double-sided Lip Channel	1	2.0	10	43.5	3	5.2
W-Beam	8	16.0	3	13.0	10	17.2
Two Rail	14	28.0	0	0.0	12	20.7
Three Rail	1	2.0	0	0.0	4	6.9
Thrie Beam	2	4.0	0	0.0	3	5.2
Tric Block Concrete	1	2.0	1	4.3	1	1.7
Constant Slope Shape Concrete	11	22.0	0	0.0	5	8.6
Type F Shape Concrete	2	4.0	4	17.4	2	3.4
Total	50	100.0	23	100.0	58	100.0

n=1,955 no information on barrier along left-hand side of crash site; n=1,982 no information on barrier along media of crash site; n=1,946 no information on barrier along right-hand side of crash site

Brifen wire-rope barriers, two-rail barriers, W-Beam, and Constant Slope Concrete barriers were the most common barrier types at all three points (left, median, right) of the crash site. Double sided Lip Channel barriers were most common at the median.

Run off road crashes (hit object and non-collision) on right-hand curve

Information on the location of barriers at right-hand curve run off road crash sites (RUM Code 81 non-collision; RUM Code 82 hit-object) is presented in Tables 4.10. Of the n=2086 run off road crashes occurring on right-hand curves:

- Left-hand side barrier information was recorded for 2.4% (n=51/2086) of crash sites.
- Median barrier information was recorded for 1.1% (n=23/2086) of crash sites.
- Right-hand side barrier information was recorded for 2.7% (n=56/2005) of crash sites.

Table 4.11 Barrier type along left, median and right-hand side of crash site for right bend off carriageway in metropolitan Perth, 2005-2009

Barrier Type	Off carriageway –Right bend					
	Left-hand side of crash site		Median		Right-hand side of crash site	
	n	%	n	%	n	%
Brifen (wire rope)	12	23.5	5	21.7	17	30.4
Flexfence (wire rope)	1	2.0	0	0.0	0	0.0
Double-sided Lip Channel	1	2.0	12	52.2	1	1.8
W-Beam	10	19.6	1	4.3	7	12.5
Two Rail	7	13.7	0	0.0	6	10.7
Three Rail	4	7.8	0	0.0	6	10.7
Thrie Beam	1	2.0	0	0.0	1	1.8
Tric Block Concrete	0	0.0	1	4.3	0	0.0
Constant Slope Shape Concrete	12	23.5	1	4.3	12	21.4
Type F Shape Concrete	3	5.8	3	13.0	6	10.7
Total	51	100.0	23	99.9	56	100.0

n=5,038 no information on barrier along left-hand side of crash site

Similar to crashes on left-hand curves, the most common barrier types across all three points of the crash were Brifen (wire rope) barriers, W-Beam barriers, and Constant Slope Concrete barriers. Double sided Lip Channel barriers were most common at the median, as they were for crashes on left-hand curves.

4.1.5 Edge-lining

Information on edge-lining at the location of the crash was retrieved from the MRWA road inventory infrastructure database. Two forms of edge-lining were noted for n=2,255 (19%) run off road crash sites by road alignment. In more than nine out of ten sites standard edge-lining was recorded. Audio-tactile edge-lining was noted in n=17 sites with near equal representation across straight and curve crash sites.

Table 4.12 Type of edge-line at the location of single vehicle run off road crashes occurring in metropolitan Perth; 2005-2009

Edge-line type	Road Alignment					
	Straight		Curve		All	
	n	%	n	%	n	%
Audio-tactile	10	0.7	7	0.8	17	0.7
Standard	1388	99.3	850	99.2	2238	99.3
Total	1398	100.0	857	100.0	2255	100.0

4.1.6 Road Section

Nearly eight in ten run off road crashes in the Perth metropolitan area occurred midblock (Table 4.13).

Table 4.13 Road section for single vehicle run off road crashes occurring in metropolitan Perth; 2005-2009

Road Section							
Midblock		Intersection		Other		Total	
n	%	n	%	n	%	n	%
10208	79.5	2539	19.8	96	0.7	12843	100.0

4.1.7 Posted Speed Zone

The posted speed limit of the location of the single vehicle run off road crash by road alignment (straight *versus* curved) is presented for 72.5% of target crashes (Table 4.14). Across all road alignments, just under two-thirds (61.3%) of single vehicle run off road crashes in metropolitan Perth occurred on roads with posted speed limits up to and including 60km. A further 27.1% occurred on roads with a posted speed between 70km/hour and 90km/hour and 11.7% on roads with a posted speed of 100km/hour to 110km/hour.

Table 4.14 Posted speed limit for single vehicle run off road crashes in metropolitan Perth, by road alignment; 2005-2009

	Road Alignment					
	Straight		Curve		All	
Speed Zone	n	%	n	%	n	%
Up to 40km/hour	48	0.8	57	1.9	105	1.1
50km/hour	2106	33.8	1150	37.4	3256	35.0
60km/hour	1640	26.3	701	22.8	2341	25.2
70km/hour	822	13.2	370	12.0	1192	12.8
80km/hour	622	10.0	419	13.6	104	11.2
90km/hour	180	2.9	108	3.5	288	3.1
100km/hour	722	11.6	167	5.4	889	9.6
110km/hour	93	1.5	100	3.3	193	2.1
Total	6233	100.0	3072	100.0	9305	100.0

n=3538 missing Posted Speed Limit. Chi Square: X^2=180.87 df=7; $p \leq .001$

Speed limit and road alignment of the location of the crash were found to be statistically associated. Proportionally more run off road crashes occurred at posted speed limits between 100km/hour and 110km/hour on straight sections of road (14.5%) compared with curved sections of road (8.9%).

Speed limit was also found to be statistically associated with crash severity (X^2=280.36 df=28; $p \leq .001$). Around 22.3% of single vehicle run off road fatal crashes occurred in speed zones posted at 90km/hour or higher, compared with 17.9% of crashes resulting in hospitalisation and 19.6% resulting in medical treatment only. Around nine in ten property damage only single vehicle run off road crashes occurred in speed zones up to 80km/hour.

4.1.8 Time of day

Single vehicle run off road crashes in the metropolitan area were most frequent during the six-hour period of 18:00-23:59 (36.3%) followed by 00:00-05:59 (24.2%). An association between time of day of crash and road alignment was computed, with a higher than expected number of run off road crashes occurring 18:00-23:59 on curves and a higher than expected number of run off road crashes occurring 06:00-17:59 on straight sections of road.

Table 4.15 Time of day of single vehicle run off road crashes in metropolitan Perth, by road alignment; 2005-2009

	Road Alignment					
	Straight		Curve		All	
Time	n	%	n	%	n	%
00:00-05:59	2067	24.3	963	23.9	3030	24.2
06:00-11:59	1500	17.6	604	15.0	2104	16.8
12:00-17:59	1968	23.1	879	21.8	2847	22.7
18:00-23:59	2974	35.0	1581	39.3	4555	36.3
Total	8509	100.0	4027	100.0	12536	100.0

n=307 missing Time of Day. Chi Square: X^2=27.42 df=3; $p \leq .001$

4.1.9 Lighting

The majority of single vehicle run off road crashes in metropolitan Perth occurred when it was dark and street lights were operational at the location of the crash (46.4%). Further to this, an additional 38.7% of crashes occurred during daylight hours. Around 9% of crashes occurred when it was dark and the location was unlit (no lights or available lights not on). Lighting conditions and road alignment of crash location were found to be associated: a substantially higher than expected number of crashes occurred on curves when it was dark and no lighting existed at the location (12.2% versus 5.7% for straight).

Table 4.16 Light conditions of single vehicle run off road crashes in metropolitan Perth, by road alignment; 2005-2009

	Road Alignment					
	Straight		Curve		All	
Light Conditions	n	%	n	%	n	%
Daylight	3247	39.9	1418	36.2	4665	38.7
Dawn or Dusk	478	5.9	230	5.9	708	5.9
Dark-lights on	3858	47.4	1743	44.5	5601	46.4
Dark-lights off	94	1.2	49	1.3	143	1.2
Dark-no lights	466	5.7	479	12.2	945	7.8
Total	8143	100.0	3919	100.0	12062	100.0

n=781 missing Lighting. Chi Square: X^2=156.99 df=4; $p \leq .001$

4.1.10 Day of week

Run off road crashes in the metropolitan area were more likely to occur on a Saturday (20%), followed by Sundays (17.4%) and Fridays (17.2%). This pattern was reasonably consistent across straight and curve sections of road.

Table 4.17 Day of week for single vehicle run off road crashes in metropolitan Perth, by road alignment, 2005-2009

	Road Alignment					
	Straight		Curve		All	
Day of Week	n	%	n	%	n	%
Monday	972	11.1	419	10.2	1391	10.8
Tuesday	871	10.0	461	11.3	1332	10.4
Wednesday	995	11.4	435	10.6	1430	11.1
Thursday	1166	13.3	509	12.4	1675	13.0
Friday	1531	17.5	678	16.6	2209	17.2
Saturday	1738	19.9	828	20.2	2566	20.0
Sunday	1479	16.9	761	18.6	2240	17.4
Total	8752	100.0	4091	100.0	12843	100.0

Chi Square: X^2=15.80 df=6; $p \leq .05$

4.1.11 Road surface

Across straight and curved sections of road the majority of single vehicle run off road crashes in the metropolitan area occurred on sealed as opposed to unsealed roads with a marginal increase in the likelihood of a crash on unsealed roads on curves.

Table 4.18 Road surface for single vehicle run off road crashes in metropolitan Perth, by road alignment, 2005-2009

	Road Alignment					
	Straight		Curve		All	
Time	n	%	n	%	n	%
Sealed	8380	99.1	3965	98.3	12345	98.8
Unsealed	78	0.9	68	1.7	146	1.2
Total	8458	100.0	4033	100.0	12491	100.0

n=352 missing Surface

4.1.12 Road gradient

Slightly less than three-quarters of single vehicle run off road crashes occurred on a level road. However, this proportion was higher for crashes occurring on straight sections of road compared with curves. Also, single vehicle crashes on slopes more commonly occurred on curves compared with straight sections of road.

Table 4.19 Road grade for single vehicle run off road crashes in metropolitan Perth, by road alignment, 2005-2009

	Road Alignment					
	Straight		Curve		All	
Road Grade	n	%	n	%	n	%
Level	6083	77.9	2339	61.4	8422	72.5
Crest of Hill	187	2.4	146	3.8	333	2.9
Slope	1541	19.7	1324	34.8	2865	24.7
Total	7811	100.0	3809	100.0	11620	100.0

n=1223 missing Road Grade Chi Square: X^2=348.95 df=2; p ≤ .001

4.1.13 Road condition

Single vehicle run off road crashes were considerably more likely to occur on dry rather than wet roads, with a slightly higher proportion of crashes on curves compared to straight section of road in the wet. These findings are likely to be influenced by the higher number of dry rather than wet weather days in the Perth metropolitan area.

Table 4.20 Condition of road for single vehicle run off road crashes in metropolitan Perth; by road alignment, 2005-2009

	Road Alignment					
	Straight		Curve		All	
Roads Surface	n	%	n	%	n	%
Wet	2370	28.8	1223	30.8	3593	29.4
Dry	5864	71.2	2754	69.2	8618	70.6
Total	8234	100.0	3977	100.0	12211	100.0

n=632 missing Surface Chi Square: X^2=5.00 df=1; p ≤ .05

4.2 Road user characteristics

A total of 14,049 road users (n=12843 drivers/riders and n=1206 passengers) were involved in the 12,843 single vehicle run off road crashes during the study period. Table 4.21 shows the distribution of road users by vehicle types. Around 88% of crash involved road users were designated as drivers of motor cars, trucks, buses and tractors, with a further 3.4% being riders of motorcycle, moped and bicycles. Passengers accounted for 9% of crash involved road users, with most being passengers in motorcars, trucks and buses. In relation to passengers, it must be noted that this figure does not necessarily represent all passengers in the vehicle (or riding pillion) at the time of the crash, but only those that were noted to be injured. The details of uninjured passengers were otherwise not recorded by police during the study period.

Table 4.21 Road users by vehicle type involved in single vehicle run off road crashes in metropolitan Perth, 2005-2009

Road User Group	n	%
Drivers of motor cars, trucks, buses, tractors	11396	87.6
Riders of motorcycles, motor scooters, bicycles	441	3.4
Passengers in motor cars, trucks, buses	1140	8.8
Passengers on motorcycles, mopeds	28	0.2
Total	13005	100.0

n=38 missing vehicle type for passengers; n=1006 missing vehicle type for drivers and riders.

4.2.1 Drivers and riders

Age

A statistically significant relationship between driver/rider status and age was found. The majority of crash involved riders were aged 25-39 years (45.4%) while the majority of crash involved drivers were aged 17-24 years (48.5%).

Table 4.22 Age of drivers and riders involved in a single vehicle run off road crash in metropolitan Perth, 2005-2009

	Road User					
	Drivers		Riders		All	
Age Group	n	%	n	%	n	%
Under 17 years	116	1.2	15	3.6	131	1.3
17-24 years	4827	48.5	109	26.3	4936	47.6
25-39 years	3088	31.0	188	45.4	3276	31.6
40-59 years	1544	15.5	89	21.5	1633	15.7
60+ years	385	3.9	13	3.1	398	3.8
Total	9960	100.0	414	100.0	10374	100.0

n=1463 missing Age. Chi Square: X^2=95.70 df=4; $p \leq .001$

Gender

Across both groups of road users males accounted for around three-quarters of those involved in a run off road crash in the metropolitan area. A statistically significant relationship was computed between driver/riders status and age. Compared with drivers (males 75.1% *versus* females 24.9%), riders were considerably more likely to be male (94.2%) than female (5.8%).

Table 4.23 Gender of drivers and riders involved in a single vehicle run off road crash in metropolitan Perth, 2005-2009

	Road User					
	Drivers		Riders		All	
Gender	n	%	n	%	n	%
Male	7888	75.1	408	94.2	8296	75.8
Female	2619	24.9	25	5.8	2644	24.2
Total	10507	100.0	433	100.0	10940	100.0

n=897 missing Gender. Chi Square: X^2=83.23 df=1; $p \leq .001$

Injury

Injury information was available for 82% of crashing riders and 26% of crashing drivers. The very high proportion of drivers (and lower proportion of riders) without injury information may be the result of missing information and/or that the driver/rider was uninjured in the crash (which is not specifically recorded in the police report). As shown in Table 4.24, a statistically significant relationship between driver/rider status and injury outcomes was computed. Compared with drivers, riders involved in a single vehicle run off road crash in metropolitan Perth were more likely to be killed (7.2% *versus* 2.9%) and hospitalised (51.8% *versus* 34.4%).

Table 4.24 Injury outcome for drivers and riders involved in a single vehicle run off road crash in metropolitan Perth, 2005-2009

	Road User					
	Drivers		Riders		All	
Injury	n	%	n	%	n	%
Fatal	86	2.9	26	7.2	112	3.3
Admission to Hospital	1029	34.4	187	51.8	1216	36.3
Treatment - no admission	1103	36.9	107	29.6	1210	36.1
Injured – no treatment	774	25.9	41	11.4	815	24.3
Total	2992	100.0	361	100.0	3353	100.0

n=8484 missing Injury. Chi Square: X^2=77.55 df=3; $p \leq .001$

Blood Alcohol Concentration Level

Blood alcohol concentration (BAC) level information was available for 42.6% of crashing drivers of cars, trucks, buses and tractors and 55.6% of crashing riders (excluding bicycle riders). A statistically significant relationship was computed between driver/rider status and BAC level. A greater proportion of crashing riders (around seven in ten) compared with drivers (around six in ten) recorded a zero BAC level. Across both groups, approximately 34.4% of drivers and riders recorded a

BAC level of ≥0.050gm%, with proportionally more drivers than riders recording higher levels of BAC, e.g., ≥0.101gm%.

Table 4.25 Blood Alcohol Concentration Level of drivers and riders* involved in a single vehicle run off road crash in metropolitan Perth, 2005-2009

	Road User					
	Drivers		Riders		All	
BAC Level	n	%	n	%	n	%
Zero	2866	58.9	168	70.7	3034	59.5
0.001-0.019gm%	74	1.5	5	2.1	79	1.5
0.020-0.049gm%	220	4.5	15	6.3	235	4.6
0.050-0.079gm%	324	6.7	9	3.8	333	6.5
0.080-0.100gm%	275	5.7	10	4.2	285	5.6
≥0.101gm%	1105	22.7	31	13.0	1136	22.3
Total	4864	100.0	238	100.0	5102	100.0

*excludes n=13 bicycle riders. n=7728 missing BACL. Chi Square: X^2=20.55 df=5; p ≤ .01

Cross tabulation of driver/rider BAC levels by road alignment at the crash site did not reveal a significant relationship between the two. Approximately one-third of driver/rider run off road crashes on straights (34.6%) and curved (33.9%) recorded a BAC level of 0.05gm% and higher.

Table 4.26 Blood Alcohol Concentration Level of drivers/riders* involved in a single vehicle run off road crash in metropolitan Perth; by road alignment 2005-2009

	Road Alignment					
	Straight		Curve		All	
BAC Level	n	%	n	%	n	%
Zero	1999	59.5	1035	59.5	3034	59.5
0.001-0.019gm%	46	1.4	33	1.9	79	1.5
0.020-0.049gm%	152	4.5	83	4.8	235	4.6
0.050-0.079gm%	220	6.5	113	6.5	333	6.5
0.080-0.100gm%	186	5.5	99	5.7	285	5.6
≥0.101gm%	759	22.6	377	21.7	1136	22.3
Total	3362	100.0	1740	100.0	5102	100.0

*excludes n=13 bicycle riders. n=7728 missing BACL. Chi Square: X^2=2.70 df=5; NS.

The distribution of the BAC levels of crashing drivers/riders by time of day is presented in Table 4.27. This relationship was found to be statistically significant. Single vehicle run off road crashes in the metropolitan area occurring between 06:00 and 17:59 00 were considerably more likely to involve drivers/riders with a zero

BAC level compared with evening and late night/early morning crashes. In contrast, 55.5% and 43% of crashes respectively occurring 00:00-05:59 and 18:00-23:59 involved a driver/rider with a BAC of 0.050gm% or higher, with the majority of illegal levels being ≥0.101gm%.

Table 4.27 Blood Alcohol Concentration Level of drivers/riders* involved in a single vehicle run off road crash in metropolitan Perth; by time of day 2005-2009

	Time of Day							
	00:00-05:59		06:00-11:59		12:00-17:59		18:00-23:59	
BAC Level	n	%	n	%	n	%	n	%
Zero	425	35.4	703	84.7	957	81.9	915	49.6
0.001-0.019gm%	24	2.0	8	1.0	13	1.1	33	1.8
0.020-0.049gm%	85	7.1	21	2.5	26	2.2	102	5.5
0.050-0.079gm%	129	10.7	19	2.3	37	3.2	144	7.8
0.080-0.100gm%	112	9.3	20	2.4	18	1.5	131	7.1
≥0.101gm%	427	35.5	59	7.1	118	10.1	519	28.1
Total	1202	100.0	830	100.0	1169	100.0	1844	100.0

*excludes n=13 bicycle riders. n=7728 missing BACL Chi Square: X^2=836.19 df=15; $p \leq .001$

Seatbelt/helmet use

Around 97% of drivers and riders involved in single vehicle run off road crashes in the metropolitan area were recorded as using a seatbelt or helmet at the time of the crash. Driver/rider status and use of protection were found to be significantly associated. Riders were around seven times more likely than drivers (14% *versus* 2.1%) not to be using protection at the time of the crash.

Table 4.28 Use of seatbelt/helmet by drivers and riders involved in a single vehicle run off road crash in metropolitan Perth, 2005-2009

	Road User					
	Drivers		Riders		All	
Seatbelt/Helmet Use	n	%	n	%	n	%
Worn	7818	97.9	302	86.0	8120	97.4
Not worn	169	2.1	49	14.0	218	2.6
Total	7987	100.0	351	100.0	8338	100.0

n=3499 missing Seatbelt/helmet use. Chi Square: X^2=185.24 df=1; $p \leq .001$

Cross tabulation of the use of protection (seat belt) by injury for drivers only showed that those who sustained a fatal injury (35.7%) or an injury requiring admission to hospital (7.3%) were considerably more likely to be unbelted at the time of the crash compared with other injury outcomes.

Table 4.29 Seat belt use by drivers involved in single vehicle run off road crashes in metropolitan Perth; by injury outcome, 2005-2009

	Injury							
	Fatal		Admission to hospital		Treatment no admission		Injured no treatment	
Seat belt/helmet use	n	%	n	%	n	%	n	%
Worn	45	64.3	750	92.7	936	96.8	660	97.5
Not worn	25	35.7	59	7.3	31	3.2	17	2.5
Total	70	100.0	809	100.0	967	100.0	677	100.0

n=8873 missing Chi Square: X^2=156.22 df=3; $p \leq .001$

The same analysis for riders (including bicyclists) showed that non-use of helmets was highest among those admitted to hospital (13%) and those treated without admission (15.1%). Helmet use and injury were found not to be significantly associated.

Table 4.30 Helmet use by riders involved in single vehicle run off road crashes in metropolitan Perth; by injury outcome, 2005-2009

	Injury							
	Fatal		Admission to hospital		Treatment no admission		Injured no treatment	
Seat belt/helmet use	n	%	n	%	n	%	n	%
Worn	21	91.3	140	87.0	79	84.9	33	94.3
Not worn	2	8.7	21	13.0	14	15.1	2	5.7
Total	23	100.0	161	100.0	93	100.0	35	100.0

n=129 missing Chi Square: X^2=2.37 df=3; NS.

Licence status

Approximately 2.6% of drivers/riders involved in a single vehicle run off road crash in the metropolitan area were not validly licensed at the time of the crash. Licence status and driver/rider status were found to be significantly associated, with a greater proportion of crashing motorcycle/moped riders than drivers being unlicensed: 15.9% *versus* 9.1%.

Table 4.31 Licence status of drivers and riders* involved in a single vehicle run off road crash in metropolitan Perth, 2005-2009

	Road User					
	Drivers		Riders		All	
Licence Status	n	%	n	%	n	%
Valid licence	8419	90.9	311	84.1	8730	97.4
No valid licence	845	9.1	59	15.9	904	2.6
Total	9264	100.0	370	100.0	9634	100.0

*excludes n=13 bicycle riders. n=2190 missing Licensing Status. Chi Square: X^2=19.48 df=1; $p \leq .001$

4.2.2 Passengers

A total of n=1,206 passengers were recorded by police to have been injured in the n=12,830 single vehicle run off road crashes (excluding n=13 bicycle crashes) in the metropolitan area.

Age

Age was missing for 17.6% of passengers injured in a single vehicle run off road crash in the metropolitan area. Just over half (51.7%) of those injured were aged 17-24 years followed by those under 17 years of age (23.9%)

Table 4.32 Age of passengers involved in single vehicle run off road crashes in metropolitan Perth; 2005-2009

Age Group	n	%
Under 17 years	228	23.9
17-24 years	513	51.7
25-39 years	169	17.0
490-59 years	52	5.2
60+ years	31	3.1
Total	993	100.0

n=213 missing Age

Gender

Gender was missing for approximately 53% of injured passengers. Of the remaining, around six in ten injured in a single vehicle run off road crash in metropolitan Perth were male.

Table 4.33 Age of passengers involved in single vehicle run off road crashes in metropolitan Perth; 2005-2009

Gender	n	%
Male	347	61.7
Female	215	38.3
Total	562	100.0

n=644 missing Gender

Injury

Passengers injured in a single vehicle run off road crash in metropolitan Perth were mostly admitted to hospital for treatment (38.7%) or treated without being admitted (38.8%). Approximately 2% were killed.

Table 4.34 Injury outcomes for passengers involved in single vehicle run off road crashes in metropolitan Perth; 2005-2009

Injury	n	%
Fatal	25	2.1
Admission to Hospital	458	38.7
Treatment - no admission	459	38.8
Injured – no treatment	242	20.4
Total	1184	100.0

n=22 missing Age

Seat belt use

Records show that around one in ten injured passengers was not wearing a seatbelt (or helmet in the case of a pillion passenger) at the time of the crash. This figure was nearly five times that found for drivers (2.1%) but less than that recorded for riders (14%).

Table 4.35 Seat belt/helmet use by passengers involved in single vehicle run off road crashes in metropolitan Perth; 2005-2009

Seat belt/helmet use	n	%
Worn	871	902
Not worn	95	9.8
Total	966	100.0

n=240 missing Seat belt/helmet use

Cross tabulation of use of seat belt or helmet by injury severity revealed that the two were significantly associated: the higher the frequency of non-use, the more the severe the injury outcome. For example, passengers who sustained a fatal injury (30%) were considerably more likely to be unprotected at the time of the crash compared with other injury outcomes.

Table 4.36 Seat belt/helmet use by passengers involved in single vehicle run off road crashes in metropolitan Perth; by injury outcome, 2005-2009

	Injury							
	Fatal		Admission to hospital		Treatment no admission		Injured no treatment	
Seat belt/helmet use	n	%	n	%	n	%	n	%
Worn	14	70.0	299	86.9	347	91.8	192	93.7
Not worn	6	30.0	45	13.1	31	9.2	13	6.3
Total	20	100.0	344	100.0	378	100.0	205	100.0

n=59 missing Chi Square: $X^2=16.87$ df=3; $p \leq .01$

4.3 Vehicle characteristics

Police crash records contain very little information to describe the characteristics of vehicles involved in run off road crashes in the metropolitan area. The most useful and complete information relates to the vehicle type and registration status. Other vehicle information, such as age of manufacture and number of cylinders, are mostly incomplete in police crash records and therefore of limited use.

4.3.1 Vehicle type

As to be expected, passengers vehicles (94.3%) were the most predominant vehicle type involved in run off road crashes in the metropolitan area, followed by motorcycles/mopeds (3.8%). When analysed in relation to the road alignment of the crash site, motorcycles/mopeds accounted for a higher proportion of crashes on curves compared with straight sections of road.

Table 4.37 Vehicle types involved in single vehicle run off road crashes in metropolitan Perth; by road alignment, 2005-2009

Vehicle Type	Road Alignment					
	Straight		Curve		All	
	n	%	n	%	n	%
Passenger car	6328	95.5	4026	92.4	10354	94.3
Motorcycle/moped	147	2.2	268	6.2	415	3.8
Truck	131	2.0	57	1.3	188	1.7
Bicycle	10	0.2	1	0.0	11	0.1
Bus	9	0.1	2	0.0	11	0.1
Other	2	0.0	2	0.0	4	0.0
Total	6627	100.0	4356	100.0	12211	100.0

n=1860 missing. Chi Square: X^2=123.7 df=5; $p \leq .05$

4.3.2 Vehicle registration status

Registration status was analysed for cars, trucks, buses, motorcycles, moped and motorbikes. Nearly all (99.7%) motorised vehicles involved in a run off road crash in metropolitan Perth were registered at the time of the crash.

Table 4.38 Registration status of motorised vehicles involved in single vehicle run off road crashes in metropolitan Perth; 2005-2009

Registration status	n	%
Registered	11313	99.7
Unregistered	31	0.3
Total	11344	100.0

n=493 missing Registration Status

4.4 Multivariate analysis of single vehicle run off road crashes by crash severity

Multinomial logistic regression was used to model the crash severity (no injury; minor injury; serious injury) of run off road crashes using a range of crash, road and driver/rider factors. For this analysis run off road crashes that did not result in injury (‘no injury’) were selected as the ‘reference’ level.

The following variables were entered into the model on a single step and were progressively removed if found to be non-significant. This process continued until significance was achieved for the final model and the goodness of fit statistic.

- Road Alignment (straight *versus* curve)
- Nature of Crash (hit object *versus* non-collision/roll over)
- Road Section (midblock *versus* intersection *versus* other)
- Road Condition (dry *versus* wet)
- Grade (flat *versus* crest of hill *versus* slope)
- Speed Zone of crash location (up to 60km/hour *versus* 70-90km/hour *versus* 100-110km/hour)
- Time of Day of crash (6.00am-5.59pm *versus* 6.00pm-11.59pm *versus* midnight-5.59am)
- Day of Week of crash (Monday-Thursday *versus* Friday-Sunday)
- Driver Blood Alcohol Concentration Level (Zero *versus* 0.001-0.049gm% *versus* ≥ 0.05gm%)

After adjusting for driver/rider age and sex, the final model showed four variables to be significantly and independently associated with increased odds of a single vehicle run off road crash in the metropolitan area resulting in serious injury (killed or hospitalised) and minor injury (injury requiring medical treatment but not admission or no treatment) compared with the outcome of no injury (see Table 4.39).

Crashes occurring on curves compared with straight sections of road were associated with a significantly higher odds of serious injury (OR=1.48) and minor injury (OR=1.31). Similarly, crashes involving a vehicle roll over/non-collision as opposed to hitting an object had significantly higher odds of a serious injury (OR=1.74) and minor injury (OR=2.01). Single vehicle crashes occurring in higher speed zones were significantly associated with increased odds of serious injury (OR=1.53; 70-90km/hour; OR=1.30; 100-110km/hour) and risk of a minor injury (OR=1.31; 70-90km/hour; OR=1.24; 100-110km/hour) compared with crashes occurring in speed zones posted 60km/hour and lower. One road factor was found to be protective against the single vehicle run off road crash resulting in serious and minor injury: compared with crashes occurring on dry roads, crashes in the wet were significantly associated with a lower risk of serious injury (OR=0.49) and minor injury (OR=0.74).

Table 4.39 Multinomial logistic regression of the crash severity of single vehicle run off road crashes in metropolitan Perth, 2005-2009

	Injury Outcome					
	Serious Injury			Minor Injury		
	OR	95%CI	Sig.	OR	95%CI	Sig.
Road Alignment						
-Straight^	1.0	-	-	1.0	-	-
-Curve	1.48	1.30-1.69	0.000	1.31	1.13-1.51	0.000
Nature of Crash						
-Hit Object^	1.0	-	-	1.0	-	-
-Roll over/non collision	1.74	1.34-.2.25	0.000	2.01	1.53-2.67	0.000
Road Condition						
-Dry^	1.0	-	-	1.0	-	-
-Wet	0.49	0.42-0.57	0.000	0.74	0.63-0.86	0.000
Posted Speed Zone						
-up to 60km/hour^	1.0	-	-	1.0	-	-
-70-90km/hour	1.53	1.32-1.76	0.000	1.31	1.12-1.53	0.001
-100-110km/hour	1.30	1.07-1.59	0.000	1.24	1.01-1.54	0.037

missing n=5110 of n=12843 crashes. 'No Injury' crashes are the reference category ^reference value for variable. Adjusted for driver/rider sex and age. -2 Log Likelihood=1181.47, χ^2=307.69, df=20, p<0.001; Goodness of Fit χ^2=404.45, df=344, p<0.05

5. ANALYSIS OF SINGLE VEHICLE RUN OFF ROAD CRASHES IN METROPOLITAN PERTH RESULTING IN THE COLLISION WITH A PEDESTRIAN OFF-CARRIAGEWAY 2005-2009

For the study period 2005-2009 a total of 18 crashes were identified that involved a vehicle running off the road and colliding with a pedestrian located off the carriageway. These crashes were identified by selecting RUM code 8 crashes and the further selection of crashes involving Pedestrian Movement codes 16 and 24 (off carriageway events). Because of the small number of crashes the analysis was restricted to a basic description of selected crash, road, vehicle and road user characteristics and is mostly reported in text rather than table form.

5.1 Selected crash and road characteristics

Around a third (n=6) of the run off road pedestrian off-carriageway crashes resulted in serious injury, with near equal numbers resulting in minor injury or no injury.

Table 5.1 Severity of run off road-pedestrian off-carriageway crashes occurring in metropolitan Perth; 2005-2009

Crash Severity	n	%
Fatal	1	5.6
Hospitalisation	5	27.8
Medical treatment only	5	27.8
Property Damage Only (Major)	1	5.6
Property Damage Only (Minor)	6	33.3
Total	18	100.0

Fifteen (83.3%) run off road-pedestrian off carriageway crashes occurred midblock. The alignment of the road (curved *versus* straight) was unrecorded in five crashes. Of the remaining 13, n=10 (77%) occurred on a straight section of road and n=3 (23%) on a curve.

The speed limit at the location of the crash was not recorded for n=4 crashes. Of the remaining, n=8 (57.2) occurred in speed zones 40-50km/hour and n=6 (42.8) in speed zones 60-80km/hour. The light condition at the time of the crash was unrecorded for one crash. Of the remaining, n=11 (64.7%) occurred during daylight and n=6 (35.3%) occurred at night with street lights on. Fourteen (77.7%) crashes occurred on weekdays and n=4 (22.3%) on weekend days. Six (33.3%) crashes occurred between 6.00pm and midnight; n=3 (16.6%) after midnight and before 6.00am, and the remainder (50.1%) after 6.00am and before 6.00pm. In 88% of crashes the weather/road condition was noted to be dry. The investigation of the Main Roads WA road inventory infrastructure database failed to identify the location of a roadside barrier at any of the n=18 vehicle run off road-hit pedestrian off-carriageway crash sites.

A review of the street and local government area of the crash sites did not show any particular pattern in relation to the occurrence of crashes at noted high pedestrian or shopping/dining areas. The only exception was the identification of two crashes on Beaufort Street, Perth, and one other on Aberdeen Street, Perth – both of which are noted inner city entertainment and shopping areas. Otherwise the crashes occurred on residential streets and roads in outer suburbs.

5.2 Selected vehicle characteristics

Passenger vehicles accounted for 66.6% (n=12) of vehicles running off the road and colliding with a pedestrian off-carriageway. Other vehicle types to collide with a pedestrian off-carriageway included two motorcycles and two trucks, a bus, and one bicycle.

5.3 Selected road user characteristics

5.3.1 Drivers

No information on driver sex was recorded for n=4 vehicle controllers. Of the remaining, 86% (n=12) were male and 14% (n=2) female. In relation to age, no information was available for n=7 controllers. Over one-third (n=4) of the remaining controllers were aged 18, while 45.5% (n=5) were 40+ years of age. No information on Blood Alcohol Concentration (BAC) level was recorded for n=13 vehicle controllers. The remaining n=5 vehicle controllers recorded zero BAC levels.

No injury information was recorded for n=17 of the vehicle controllers, most likely because they were uninjured in the collision. The remaining vehicle controller – a bicyclist – required medical attention but not in hospital.

5.3.2 Pedestrians

A total of n=21 pedestrians were struck off-carriageway by vehicles running off the road. Three of the n=18 crashes involved the collision with two pedestrians. No information on the gender, age and injury was respectively recorded for n=3, n=2 and n=5 involved pedestrians. Where information was available:

- 61% (n=11) of pedestrians struck were male;

- 26.3% (n=5) were aged 7 to 16 years;
- 15.8% (n=3) were aged 17-23 years;
- 26.3% (n=5) were aged 26-40 years;
- 31.5% (n=6) aged 48-80 years; and,
- one pedestrian was killed, while 31% (n=5) were hospitalised and 44.3% (n=10) injured and not requiring hospitalisation or medical attention.

6. DISCUSSION AND RECOMMENDATIONS

6.1 Introduction

The aims of this investigation were to describe the pattern of run off road crashes in the urban area and to identify relevant initiatives to reduce such crashes and resulting injury. Using police reported data on crashes occurring in the Perth metropolitan area for the period 2005-2009, two relevant crash types were identified for analysis: n=12,438 vehicles running off the road and colliding with an object or involved in a non-collision (i.e., roll-over crashes) (the main dataset), and, n=18 vehicles running off the road and colliding with a pedestrian located off the carriageway.

In the following sections the findings from the analyses of the main data set of crashes will be discussed. Relevant recommendations will be made in line with the prevailing Safe Systems approach to road safety and the review of initiatives to counter run off road crashes. Little discussion of run off road pedestrian crashes will be provided because of the very small number of these crashes run.

6.2 Run off road crashes in the metropolitan area and injury severity

Single vehicle run off road crashes in the metropolitan area account for nearly six in ten crashes of this type across Western Australia. Compared with the regional and remote areas of Western Australia, two to 3.5 times as many single vehicle run off road crashes occur in the metropolitan area. However, when the injury severity of these crashes is considered, this factor is reduced to 1.8 to 2.3 times. This is because crashes of this type in the metropolitan area were less likely to result in death or hospitalisation compared with those occurring in the non-metropolitan areas: 11.9% versus 19.1% (regional) and 23.6% (remote).

These descriptive findings are consistent with those reported by Palamara, Kaura & Fraser (2013) describing the relatively higher risk of serious injury when crashing (*all types*) in the regional and remote areas of Western Australia compared with the metropolitan area. In that study, the odds of a serious injury crash in the regional and remote area, compared with the metropolitan area, was found to be significantly related to a number of crash and road factors, including single vehicle crashes, unsealed road surfaces, crashes on curved sections of road, and crashes in higher speed zones. Male gender, higher BAC levels, and unlicensed driving (remote area only) were also found to be significant risk factors. After adjusting for driver/rider age and gender, a number of the above factors were also noted from the multivariate analysis undertaken in this study to be significant risk factors for serious injury and minor injury crashes (versus no injury) single vehicle crashes. For example, the odds of the single vehicle crash resulting in a more severe injury increased when the crash occurred in a higher speed zone and occurred on a curve. The multivariate analysis also showed that when vehicles left the road and their energy and speed was not absorbed or dissipated through hitting an object, but instead rolled over, the risk of injury nearly doubled.

These findings are generally consistent with those reported by Meuleners (2009). Whilst the latter finding suggests that colliding with an object is preferable to rolling over, some objects of collision are clearly more effective in managing crash forces and dissipating energy than others. Hit object run off road crashes are nevertheless a major priority due to their greater absolute number in comparison with non-collision crashes.

These issues will be elaborated on in the sections below on safe road use, safe vehicles, safe speeds, and safe roads and roadsides.

6.3 Safe Road Use and Users

Managing and improving where necessary the behaviour of road users is a key element of the Safe System approach and a cornerstone of the State's road safety strategy. The description of road user behaviours and characteristics and their association with the risk of a single vehicle run off road crash in the metropolitan area and resulting injury was limited in this study to factors such as gender, age, alcohol, licence status, and the use of protection against injury. Younger age (17-25 years) drivers of motor cars and slightly older age (25-39 years) riders of motorcycles/mopeds were more likely than other age groups to be involved in single vehicle run off road crashes. These findings are reasonably consistent with other reports citing these ages as having a higher risk of involvement in fatal and serious injury crashes and single vehicle crashes (e.g., Armstrong et al., 2008; Baldock et al., 2005; Haworth & Bowland, 2000).

Variation in the gender of drivers involved in single vehicle crashes was also noted. In this study males accounted for around 76% of drivers/riders involved in a single vehicle crash, though this proportion was substantially higher for motorcycle/moped riders (94%) because of their greater use of this form of transport. The observed difference in the involvement of male and female drivers/riders is reasonably consistent with other studies citing a higher crash involvement generally among males, particularly for serious injury crashes (e.g., Henley & Harrison, 2009; Marchant et al., 2008).

Why younger age drivers/riders and males are more likely to be involved in single vehicle crashes in the metropolitan area is a matter for speculation and is perhaps related to their greater disposition to drive in a manner which places them at greater risk for crash involvement more generally. These behaviours include speeding and others such as drink-driving and unlicensed driving. Males and younger age drivers/riders are well known for their disposition to speeding; male gender has also been identified as a significant risk factor for unlicensed driving and drink-driving serious injury crashes in the metropolitan area (Palamara et al., 2013).

Alcohol has long been recognised as a significant risk factor for crashing, and in particular single vehicle crashes (Elvik, Hoye, Vaa & Sorensen, 2009). The impact of alcohol on the risk of running off the road and crashing is not altogether surprising in light of how alcohol affects driving skill. Alcohol is a central nervous system depressant and thus slows information processing and reaction time, impairs a driver's ability to undertake multiple tasks, and can lead to drowsiness/sleepiness (Institute of Alcohol Studies, nd). Alcohol also increases over-confidence and can lead to greater risk taking such as speeding (Australian Drug Foundation, 2012) and potentially the loss of vehicle control. This study similarly found that alcohol was associated with the occurrence of single vehicle crashes, but not in the discrimination of the injury associated with the crash. Around four in ten crashing drivers/riders recorded a positive BAC level (i.e., above zero), which is substantially higher than the 11% noted by Palamara et al. (2013) in their investigation of killed and serious injury crashes of all types in the same period in metropolitan Perth. The same comparison in relation to an illegal BAC (0.05gm% and higher) indicated that drivers involved in a single vehicle run off road crash in this study were substantially more likely to be impaired: 34.3% *versus* 8.5%. Interestingly however, drivers/riders with an illegal level of BAC were no more likely to run off the road on a curve compared with a straight but were more likely to be impaired by alcohol when crashing between midnight and 5:59am compared with other times of day. These findings suggest that driver impairment due to alcohol is even more significant when drivers are required to adjust their behaviour to position their vehicle and adjust their speed to safely negotiate curves and bends.

There is some evidence to suggest that unlicensed drivers have a higher risk of crash involvement than validly licensed drivers (Plunkett, 2009) perhaps because of a lack of driving skill or an associated disposition to engage in other risk taking behaviour related to crashing. Indeed Palamara et al. (2013) observed that unlicensed drivers involved in a fatal and serious injury crash had five times the risk of licensed drivers to be driving with a positive level of BAC. In this study around 9% of drivers and 16% of riders were found not to hold a valid licence, which is slightly higher than the 6% observed for drivers/riders involved in a serious injury crash in the metropolitan area over the same period reported by Palamara et al. (2013). Once again, the reasons for the noted involvement of unlicensed drivers/riders in crashes investigated in this study is open to speculation but could be related to an associated pattern of other risk taking behaviours such as drink-driving or even speeding which increases the risk of a single vehicle run off road crash.

Further to the above identified risk factors for crashing, this study also showed, like many others (see Oxley et al., 2009 for a review), that the risk of injury once involved in a crash can be exacerbated by the failure to wear a seat belt or use a helmet. While the vast majority of crashing drivers were noted to be belted, crashing riders of motorcycles, mopeds, and bicycles were seven time more likely to not use a helmet, while passengers were nearly five times more likely to be unprotected. The risk of injury associated with this lack of protection was evident from the findings that road users who sustained serious injuries were also more likely to have higher incidence of non-use of protection. This finding is highly consistent with those reported by Palamara et al. (2013) in their investigation of the association between protection and injury among road users involved in a serious injury crash in the metropolitan area over the same period.

While engineering and other environmental countermeasures are the main focus of this study, there is good reason to nevertheless consider and counter the range of behavioural ‘pre-crash’ and ‘crash factors’ that might otherwise increase the risk of a run off road crash in the metropolitan area resulting in injury. These are important issues under the Safe Systems approach. This study, like others, has provided some evidence to show that alcohol is associated with a single vehicle crash. Similarly, there is very strong evidence elsewhere and in this study that personal protection such as seat-belts can reduce the incidence and severity of injury. These findings provide additional motivation of the need to reduce the consumption and availability of alcohol in the community in general and more specifically to limit the prevalence of alcohol affected drivers and riders. Secondly, the findings highlight the need to maximise the use of seat-belts and the like as a primary means of protection against injury in the event of a crash. Western Australia must maintain an active community education and police enforcement programs for seat belt and helmet use. As Johnston et al. (2006) succinctly noted, behavioural measures to reduce run off road crashes are a necessary but insufficient measure. Hence, the need to address other features of the safe system such as those detailed below.

6.4 Safe Vehicles

Increasing the availability and uptake of safer vehicles is a key cornerstone of the Safe System approach to road safety. Advances in vehicle manufacturing and technology continue to improve both the active and passive safety features of vehicles to reduce the risk of crashing and injury to occupants in the event of a crash. Like the previous local investigation of killed and serious injury crashes conducted by Palamara et al. (2013), this study was similarly unable to investigate the array of vehicle factors associated with a vehicle running off the road or the risk of injury. For example, there was no information for crashing vehicles of the availability of active crash avoidance features such as Anti-lock Braking Systems, Electronic Stability Control and Traction Control to reduce the incidence of crashing. Recent reviews of safer vehicle technologies have highlighted the increasing evidence of their impact on single vehicle, loss of control, run off road crashes. For example, Langford (2009) reported that technologies such as intelligent speed adaptation, lane departure warning, and fatigue monitoring systems will likely reduce single vehicle run off road crashes by an estimated 10.8% to 4.3% depending on the crash type. Kahane and Dang (2009) also reported that a combination of features such as anti-lock braking and electronic stability control will prevent a large proportion of both fatal and non-fatal crashes, particularly in relation to single vehicle crashes.

Safer vehicles, like safer road user countermeasures, are an important initiative but also just one part of the Safe System approach to reducing the incidence of crashes and injury. What is particularly problematic in relation to safer vehicles is the ready availability and affordability of these technologies and the speed at which they are taken up by consumers. Fortunately the overall safety of the vehicle fleet continues to increase with vehicles manufactured 2003-2007 around three times safer than those built some 10-20 years earlier (Langford, 2009). Nevertheless, effort is still required to promote the uptake of vehicles with features that will specifically reduce the risk of run off road crashes – the crash type responsible for a high proportion of serious injuries (Johnston et al., 2006) - both in the metropolitan area and elsewhere.

6.5 Safe Speeds

Speeding has long been acknowledged as one of the most significant risk factors for crashing and subsequent injury (see Aarts & van Schagan, 2006), particularly in the circumstance of vehicles running off the road in both urban and non-urban environments (Zwerling et al., 2005; Meuleners, 2009). Higher travels speeds, whether legal or illegal, are problematic because of their associated risk of losing control of the vehicle and the increased distance travelled during the time taken to react and brake, which subsequently increases the distance and time travelled until stop (Kloeden et al., 2001). Consequently, initiatives to reduce travel speeds through speed rezoning, traffic management, and enforced compliance with existing limits is fundamental to the Safe System framework and should be considered in conjunction with other environment and engineering based measures to reduce the incidence of run off road crashes in the metropolitan area and elsewhere.

In this study nearly six in ten single vehicle run off road crashes occurred in speed zones posted between 40km/hour and 60km/hour, which is comparable with the 61% of fatal and serious injury crashes of all types recorded in the same speed zones reported by Palamara et al. (2013). These findings do not of themselves indicate that speed was a contributing factor to the vehicle having run off the road since it is not known whether drivers/riders were travelling in excess of the speed limit or travelling too fast for the prevailing conditions and subsequently lost control of the vehicle. However, other findings from this study showed that when vehicles were (presumably) travelling at higher speeds in zones posted 70-90km/hour and 100-110km/hour, the single vehicle crash was considerably more likely to result in more severe injury. This is not to suggest that the bulk of attention should be on these zones to the exclusion of lower speed zones. As Holman (2011) has reported, speeding in 60km/hour in Western Australia is a significant contributor to the problem of serious injury crashes.

Safe speed countermeasures have the potential to influence road user behaviour and crash and injury outcomes – whether for single vehicle crashes or others. Even a 5% reduction in average vehicle travel speeds could hypothetically lead to a 10% reduction in all injury crashes and a 20% reduction in fatal crashes (Nilsson, 2004). In the first instance then it is reasonable to consider the appropriateness of speed limits across the urban network to determine what benefit might be achieved through the selective implementation of lower speed limits in areas where run off road crashes are more likely to occur and/or where the consequences of running off the road are likely to be severe. Second to this, it is reasonable to consider how vehicle speeds could be slowed in urban areas through selective engineering efforts and strategic enforcement.

Local government and WA Police are two of the most important stakeholders in relation to lowering vehicle speeds on urban roads. Local government in Western Australia is responsible for around 88% of the total Western Australian road network, the majority of which is in the metropolitan or urban area with lower speed zones (Palamara, Jones, Hildebrand & Langford, 2010). In this study nearly three-quarters of roads on which single vehicle run off road crashes occurred were owned/managed by local government. Recent research has identified that Western Australia local government – particularly those in the metropolitan area - is generally concerned with the management and lowering of local area speeds through engineering initiatives (such as the installation of roundabouts, tactile surface treatments, speed humps/cushions, kerb extensions) and submissions to Main Roads Western Australia for lowered speed zones (Palamara et al., 2010). Most recently, the Western Australian Local Government Association accepted the recommendation proposed by Palamara (2011) for the sector to undertake a more strategic approach to measuring vehicle travel speeds in their localities and to supply timely information on problem area speeding to police to facilitate targeted camera and non-camera based enforcement. WA Police have endorsed this program and hope to utilise the 'intelligence' in the course of the implementation of the recently approved comprehensive and targeted program of strategic automated speed enforcement (see Palamara et al., 2010 and Palamara, 2011). It would seem the initiatives of both local government and WA Police have the potential to reduce vehicle travel speeds in the metropolitan area and consequently reduce the incidence and injury severity of run off road crashes in these areas that might otherwise be related to excess and inappropriate speeds for the prevailing road, traffic and weather conditions.

6.6 Safe Roads and Road Sides

The above discussion has highlighted the application of safer road user behaviour, safer vehicles, and safer speeds initiatives in relation to the findings of this study. These areas are undoubtedly complemented by initiatives in the area of safer roads and roadsides, the final cornerstone of the Safe System framework. Initiatives in this area for single vehicle run off road crashes include those which reduce the likelihood of the vehicle running off the carriageway in the first instance, and secondly, reducing the severity and consequences of the crash once the vehicle has left the carriageway (Johnston et al., 2006).

Widening and sealing the shoulders of roads are important factors to counter run off road crashes in non-urban areas (Johnston et al., 2006) but are less applicable in the urban environment where roads are typically sealed kerb to kerb. Other road issues such as correcting alignments, improved curve delineation, and appropriate pavement markings are relevant to the urban area just as they are in the non-urban area in relation to run off road crashes.

In relation to road alignment, this study found that around two-thirds of run off road crashes occurred on straight sections of road and one-third on curves. It is not known whether this distribution is consistent with the total kilometres of straight and curve sections of road across the metropolitan network[2]. Curves were however, considered to be more ‘hazardous’ from an injury point of view. Run off road crashes on curves were found to be related to a significantly higher level of injury severity: 50% greater odds of a serious injury and 30% greater odds of a minor injury even, after adjusting for the speed zone of the crash. This finding is generally consistent with the increased risk of a serious injury versus non-serious injury for single vehicle crashes in the Perth metropolitan area reported by Meuleners (2009) using data for the period 1999-2008.

The higher risk of a serious injury associated with a single vehicle crash on a curve versus straight was noted to be independent of the nature of crash (hit-object *versus*

[2] Though Main Roads Western Australia holds road geometry information that could be investigated to calculate the proportion of straight and curve roads across the network, there is no agreement on the criteria for a ‘curve’ to facilitate this analysis (A. Radalj, Main Roads Western Australia, personal communication December 2013).

non-collision), which itself had a significant independent effect on the severity of injury. Compared with hit-object crashes, non-collision crashes (which were predominantly roll-over crashes) significantly increased the risk of serious injury and minor injury versus no injury. Again, this is consistent with the finding reported by Meuleners (2009) of an increased risk of a single vehicle non-collision crash in the metropolitan area resulting in serious injury. While crashes on curves and non-collision crashes are less common scenarios for single vehicle run off road crashes compared with crashes occurring on straights and into objects, they nevertheless represent a greater injury risk. In absolute terms however, crashes on straights and into objects predominate and still account for the greater proportion of serious injuries associated with run off road crashes. As Elvik et al. (2009) noted, road alignment affects a number of vehicle performance and driver behaviour factors, such as speed, friction demand, driver expectations and attention and margin of error. In general, narrow roads with a smaller radius are most hazardous and associated with high crash rates (Elvik et al., 2009). Improving the alignment and visibility conditions can reduce the hazard and consequently the risk of crashing. Similarly, initiatives such as installing guard rails on curves, speed and curve advisory signs, and background directional markers have been identified to reduce crashes in curves (Elvik et al., 2009). Identifying curved sections of roads with a high incidence of crashes should be a priority to consider appropriate treatments.

Pavement markings to improve curve delineation and to alert drivers (through audio-tactile edge-lining) when they approach the edge of the carriageway are considered to be promising initiatives to reduce run off road crashes (Johnston et al., 2006). The extent to which audio-tactile edge marking is used across metropolitan Perth was not investigated by this study. What was determined however, is that edge-lining was noted for around one in five single vehicle run off road crash sites, with less than 1% of those sites marked by audio-tactile lining. There is perhaps a need to identify those sites – curved and straight - where audio-tactile edge-lining might be applicable.

Without doubt hit-object single vehicle run off road crashes have the highest priority because of the very high proportion (95%) of single vehicle crashes they were found to account for in this study. As noted in the literature review, the nature of the object vehicles collide with once leaving the carriageway can influence the likelihood and severity of injury. This study undertook a reasonably detailed investigation of the nature of the objects involved in the collision, the sequence of objects hit, and the existence and type of barrier at the location of the crash. With respect to the latter, this information was retrieved from MRWA and relates to information and detail available at the time the data was retrieved, which may differ to that at the time the crash occurred (between 2005-2009). Like other investigations of run off road crashes, this study identified that roadside objects such as utility poles (18% of hit object crashes), trees/shrubs (27% of hit object crashes), and fences/building walls (20% of hit object crashes) were major roadside hazards. While kerbs featured in 26% of hit-object crashes, these crashes are less likely to result in significant injury and damage. At any rate, most vehicles (eight in ten) colliding with a kerb in this study proceeded to collide with a subsequent object.

Thus, there is good reason to consider how best to protect drivers and riders from colliding with objects that do not form part of the road infrastructure intended to stop vehicles from travelling further off the carriageway and to reduce injury severity. Roadside barriers are expected to fulfil this function but fewer than 5% of single vehicle run off road crashes in the metropolitan area were found to involve a collision with a guard rail/barrier. This proportion was found to be double (11%) for motorcycles/moped riders who were most likely (around a third of crashes) to collide with a traffic island than any other single object apart from the kerb.

Though information on the type of barrier at the location of the crash (to the left, the median and the right hand side) was retrieved from MRWA's infrastructure database, it could not always be determined if the vehicle collided with the identified barrier because the direction of travel of the vehicle off the carriageway was unknown in some cases. There was more certainty around this for crashing vehicles which ran off a straight section of road (because of the stated direction of travel – left or right - off the carriageway in the crash database), unlike crashes on curves where only the left or right hand bend of the curve is noted for the crash and not whether the vehicle moved off the carriageway on the near or far side of the bend. MRWA should seek to add this information to their IRIS database of crashes to extend the understanding of vehicle movements for run off crashes on curves. Furthermore, they should extend the information in the police reported crash dataset on 'guard rail/barrier' hit object crashes to include the *type of barrier* rather than rely on the retrieval of this information from other systems when required.

Only a very small percentage (between 1.1% and 3.5%) of single vehicle crash sites were found to have a barrier installed either to the left, at the median or the right-hand side of the crash site. Overall, run off road single vehicle crashes in the metropolitan areas where barriers were installed occurred were most likely to be straight rather than curved sections of road. The predominant barrier types on the left and right hand-side of the site were Brifen wire-rope barriers, Constant Slope Shape Concrete barriers, and Two-Rail barriers. Median barriers were predominantly Double-sided Lip Channel (commonly found on urban freeway roads such as the Mitchell Freeway). Because of the small number of crash sites identified with barriers and uncertainty of knowing what barrier was impacted when a crash occurred on the curve (because of the direction of travel of the vehicle), it was not possible to reliably investigate the relationship between barrier type and injury severity.

What is clearer however is that the majority of run off road crashes in the metropolitan area did not involve collision with a barrier that might otherwise have reduced the severity of impact and injury. This finding highlights the need to consider an increase in the number of barriers across the metropolitan area in locations deemed to have a higher risk of a run off road crash and where other roadsides hazards exist (that cannot be removed) that are likely to contribute to more severe injury if impacted. It is acknowledged however, that it is difficult to retrofit barriers in urban areas because of the physical constraints, access requirements, and associated costs (B. Snook, personal communication, 2013).

Notwithstanding the preceding comment, the type of barrier must be suitable for the location and traffic environment. For example, flexible wire-rope barriers are known to be highly effective in reducing injury severity (Candappa et al., 2009) but they are particularly unsuitable in environments where their flexibility is likely to intrude into spaces frequented by vulnerable road users (e.g., shared-use paths; footpaths). Notwithstanding the variability in the type or barrier or guard rail that might be installed, the evidence overall is that installing guard rails along the roadside can reduce fatal and other injury crashes between 44% and 47% (Elvik et al., 2009). In relation to the installation of median barriers, studies of the effectiveness of concrete, steel and wire rope barriers installed on multi-lane roads indicate that steel and wire rope significantly reduce injury crashes (between 29% and 35%) while concrete does not (Elvik et al., 2009). Elvik et al.'s (2009) conclusions are admittedly based on studies over many decades, during which time vehicle technologies and crash worthiness have substantially changed.

There is good reason to also consider the unique needs of both motorcyclists who might collide with a barrier and pedestrians who needed to be protected by barriers from vehicles which may travel off the carriageway in pedestrian dense areas. As discussed in the literature review, collisions with some barrier types by motorcyclists are associated with an increased risk of injury while other researchers such as Daniello and Gabler (2011b) appear to suggest it is preferable to crash into a guardrail than no barrier at all. The review also noted that the Barriacel Motorcycle Crash Attenuating Device is a promising initiative in providing protection to motorcyclists who might otherwise collide with a barrier.

Though this study identified a relatively small number of run off road instances involving the collision with a pedestrian off-carriageway, it is still reasonable to consider how best to protect pedestrians in shopping, business and entertainment precincts and the like. The Flexible Bollard barrier initiative promoted by the South Australian Health Department (2012) to protect patrons dinning 'al fresco' showed promising results in relation to its energy absorbing properties; its capabilities in containing vehicles of considerable mass, and minimal impact on the streetscape and interference with the manoeuvrability of pedestrians. These bollards show promise as an innovative barrier solution in locations where pedestrians move about in close proximity to vehicles without interfering with the mobility. Bearing in mind the fact this study identified a very small number of crashes (one of which was fatal) where vehicles ran off the carriageway and collided with a pedestrian off-carriageway, there is still reason to consider where and how such bollards could be used in conjunction with other measures such as traffic calming and speed rezoning across pedestrian dense areas in close proximity to the road.

6.7 Recommendations

This study has identified a number of safe road user, safe vehicle, safe speed and safe road and roadside related factors for single vehicle run off road crashes in the metropolitan area. From this a number of recommendations, particularly for safe roads and roadsides, are offered for consideration. Some recommendations are specific to run off road crashes per se, while others are more generally applicable but also expected to impact on the incidence of and injury severity of run off road crashes in the metropolitan area.

6.7.1 Surveillance and reporting

Improve the collection and quality of information in the MRWA IRIS database on run off road crashes

It is recommended that MRWA consider the inclusion or revision of Road Use Movement codes to identify the direction of travel – to the near side or far side – off the carriageway for vehicle crashing on left and right hand curves.

Improve the collection and quality of information in the MRWA IRIS database on guard rails/barriers impacted in a collision

It is recommended that MRWA include an additional field for hit object-barrier crashes in the IRIS database to describe the type of guard rail/barrier impacted.

6.7.2 Safe Road Use

Minimising driver/rider impairment through alcohol

It is recommended that the State review and revise where appropriate existing Blood Alcohol Concentration Level legislation for unrestricted drivers to encourage a lower level of consumption by drivers and potentially reduce impaired driving through alcohol.

Maximising the use of personal protection by vehicle occupants and riders in metropolitan areas

It is recommended that the State consider additional education, enforcement and technology initiatives to promote and increase the use of seat belts by vehicle occupants and helmets by motorcycle/moped riders

6.7.3 Safer Vehicles

Accelerating the uptake of safer vehicles with technologies to minimise run off road crashes

It is recommended that the State continue to promote understanding and awareness within the community of technologies and vehicles that are likely to reduce loss of control, run off road crashes. Consideration should also be given to initiatives that financially 'incentivise' car buyers to purchase safer vehicles.

6.7.4 Safe Speeds

Reducing vehicle speeds through rezoning to reduce loss of control crashes and injury severity

It is recommended that MRWA work in conjunction with local governments to identify run off road crash ‘black spots' that are appropriate for reduced speed limits to minimise the occurrence of loss of control, run off road crashes.

Reducing local area speeds through strategic enforcement to reduce loss of control crashes and injury severity

It is recommended that metropolitan local governments participate in the Local Government-WA Police Speed Management Enforcement Program. This program provides guidelines to local governments on the surveillance and reporting to police of speeding on local area roads to facilitate strategic enforcement.

6.7.5 Safer Roads and Roadsides

Identifying ‘black spots’ for run off road crashes in local urban areas

It is recommended that MRWA work in conjunction with metropolitan local governments to identify run off road crash ‘black spots'. Spatial mapping of these ‘black spots’ would provide the first-level information required for a program of engineering and environmental countermeasures. Secondly, local area maps could also be used to educate the community of high risk problem roads.

The development of a program of appropriate engineering and environmental countermeasures to reduce run off road crashes and injury severity

Following spatial mapping, it is recommended that road safety audits of the selected sites are subsequently undertaken to make informed decisions on required and relevant ‘best practice’ countermeasure for the site. Local government traffic engineers should work in conjunction with MRWA to determine the most appropriate and cost-effective treatment or suite of treatments. These treatments, in addition to those related to speed management, can include:

- the installation of audio-tactile edge-lining;
- the creation of clear zones (where space permits);
- the clearing of potential roadside hazards where possible (or their protection through isolation barriers);
- improving the alignment, delineation and site lines on curves;
- improving the lighting at sites where crashes at night are identified; and,
- the installation or retrofitting of barriers appropriate for the road, environment, speed and traffic use at the site.

Audit of pedestrian dense areas that have high exposure to potential run off road-pedestrian collision crashes.

It is similarly recommended that local governments 'audit' their high pedestrian, vulnerable road use activity areas to identify locations where the risk of injury to pedestrians 'off-carriageway' is elevated should a vehicle run off the carriageway. In lower speed zones where pedestrian manoeuvrability and streetscape are an issue, local government might consider (subject to cost-benefit calculations) the installation of energy-absorbing bollards such as those proposed by the SA Government.

7. REFERENCES

Agent, K. R., & Pigman, J. G. (2008). *Evaluation of median barrier safety issues* (Report No. KTC-08-14/SPR329-06-IF). Kentucky Transportation Center.

Armstrong, K. A., Smith, S. S., Steinhardt, D. A., & Haworth, N. L. (2008). *Fatigue crashes happen in urban areas too: Characteristics of crashes in low speed urban areas.* Paper presented at the In 2008 Australiasian Road Safety Research, Policing and Education Conference, Adelaide, SA.

Aarts, L. & van Schagen, I. (2006). Driving speed and the risk of road crashes: A review. *Accident Analysis and Prevention*, *38*, 215-224.

Australian Bureau of Statistics. (2008). *Australian Social Trends* (Catalogue No. 4102.0). Canberra, ACT: Author.

Australian Drug Foundation (2012). How does alcohol affect driving? Retrieved from http://www.druginfo.adf.org.au/topics/how-does-alcohol-affect-driving.

Austroads (2010). *Guide to road design. Part 6: Roadside design, safety and barriers*. Sydney. Austroads.

Baldock, M. R. J., Long, A. D., Lindsay, V. L., & McLean, A. J. (2005). *Rear end crashes* (Report No. CASR018). Adelaide, SA: Centre for Automotive Safety Research.

Candappa, N., D'Elia, A., Corben, B., & Newstead, S. (2009). *Wire rope barrier effectiveness on Victorian roads*. Melbourne, Victoria: Monash University Accident Research Centre.

Chen, H. Y., Ivers, R. Q., Martiniuk, A. L., Boufous, S., Senserrick, T., Woodward, M., et al. (2009). Risk and type of crash among young drivers by rurality of residence: Findings from the DRIVE Study. *Accident Analysis and Prevention, 41*, 676-682.

Chipman, M. (1991). *The role of exposure in comparisons of crash risk among different drivers and driving environments.* Paper presented at the Association for the Advancement of Automotive Medicine (AAAM) 35th Conference, Baltimore, Maryland.

Chitturi, M. V., Ooms, A. W., Bill, A. R., & Noyce, D. A. (2011). Injury outcomes and costs for cross-median and median barrier crashes. *Journal of Safety Research, 42*, 87-92.

Churchill, T., Barua, U., Hassan, M., Imran, M., & Kenny, B. (2011). *Evaluation of safety and operational performance of high tension median cable barrier on deerfoot trail, Calgary, Alberta*. Paper presented at the Annual Conference of the Transportation Association of Canada, Edmonton, Alberta.

Corben, B., Deary, H., Mullan, N., & Dyte, D. (1997). *The general effectiveness of countermeasures for crashes into fixed roadside objects* (Report No. 111). Monash University Accident Research Centre.

Curtin-Monash Accident Research Centre. (2011). *Flexible Road Safety Barriers: Fact Sheet No. 8*.

Daniello, A., & Gabler, H. C. (2011a). Effect of barrier type on injury severity in motorcyle-to-barrier collisions in North Carolina, Texas, and New Jersey. *Transportation Research Record: Journal of the Transportation Research Board, 2262*, 144-151.

Daniello, A., & Gabler, H. C. (2011b). Fatality risk in motorcycle collisions with roadside objects in the United States. *Accident Analysis and Prevention, 43*, 1167-1170.

Department of Health and Aged Care. (2001). *Measuring remoteness: Accessibility/Remoteness Index of Australia (ARIA)*. Canberra, ACT. Retrieved from www.health.wa.gov.au/publicat.htm

Department of Infrastructure Energy and Resources. (2007). *Road safety barriers design guide: Part A.*

Donaldson, A. E., Cook, L. J., Hutchings, C. B., & Dean, J. M. (2006). Crossing county lines: The impact of crash location and driver's residence on motor vehicle crash fatality. *Accident Analysis and Prevention, 38*, 723-727.

Elvik, R., Vaa, T., Hoye, A., Erke, A., & Sorensen, M. (2009). *The handbook of road safety measures.* (2^{nd} ed.)., Amsterdam, Holland: Emerald Group Publishing.

Gabler, H. C. (2007). *The risk of fatality in motorcycle crashes with roadside barriers* (Paper No. 07-0574).

Government of South Australia. (2000). *Roadside dining protection: A guideline for local government authorities in South Australia*. Adelaide, SA: Author.

Grzebieta, R. H., Zou, R., & Jiang, T. (2005). *Road safety barriers: present and future developments*. Paper presented at the Victorian Roads Conference, Melbourne, Victoria.

Grzebieta, R. H., Zou, R., Jiang, T., & Carey, A. (n.d.). *Roadside hazard and barrier crashworthiness issues confronting vehicle and barrier manufactures and government regulators*.

Hammond, P., & Batiste, J. R. (2009). *Cable median barrier reassessment and recommendations update*. Washington, US.

Haworth, N., & Bowland, L. (2000). *Serious injury single vehicle crashesL 1995-1997* (Report No. 122). Monash University Accident Research Centre.

Haworth, N., Vulcan, P., Bowland, L., & Pronk, N. (1997). *Fatal single vehicle crashes study: Summary report 1995-1997* (Report No. 122). Monash University Accident Research Centre.

Henley, G., & Harrison, J. E. (2009). *Serious injury due to land transport accidents, Australia 2006-07* (Injury Research and Statistics Series No. 53, AIHW Catalogue No. INJCAT 129). Canberra, ACT: Australian Institute of Health and Welfare.

Highway Engineering Australia. (2011). The best of both worlds [online]. *Highway Engineering Australia, 43*, 12-15.

Holman, D. (2011). *Attributable fraction analysis of illegal speeding and road crashes*. Unpublished report to the Road Safety Council of Western Australia. Perth, Western Australia.

Homel, R., McKay, P. & Henstridge, J. (1995). *The impact on accidents of Random Breath Testing in New South Wales: 1982-1992.* In proceeding of the 13th International Conference on Alcohol, Drugs and Traffic Safety (T95). Adelaide, South Australia, August 1995.

Hu, W., & Donnell, E. T. (2010). Median barrier crash severity: Some new insights. *Accident Analysis and Prevention, 42*, 1697-1704.

Institute of Alcohol Studies (n.d). *Driving and driving*. Retrieved from http://www.ias.org.uk/resources/factsheets/drink_driving.pdf

Jama, H. H., Grzebieta, R. H., Friswell, R., & McIntosh, A. S. (2011). Characteristics of fatal motorcycle crashes into roadside safety barriers in Australia and New Zealand. *Accident Analysis and Prevention, 43*, 652-660.

Johnston, I., Corben, B., Triggs, T., Candappa, N., & Lenne, M. (2006). *Reducing serious injury and death from run off road crashes in Victoria – turning knowledge into action.*

Kahane, C. & Dang, J. (2009). *The long term effect of ABS in passenger cars and LTVs*. Washington, USA: National Highway Traffic Safety Administration. Report No. DOT HS 811-182

Kidd, B., & Willett, P. (2002). *Crash patterns in Western Australia.* Paper presented at the Proceedings of the 2001 Road Safety Research, Policing & Education Conference, Adelaide, SA.

Kloeden, C., Ponte, G., & McLean, A. (2001). *Travelling speed and the risk of crash involvement on rural roads* (Report No. CR204). Canberra.

Kloeden, C. N., Mclean, A. J., Baldock, M. R. J., & Cockington, A. J. T. (1999). *Severe and fatal car crashes due to roadside hazards: A report to the Motor Accident Comission*. Adelaide, SA: Government of South Australia.

Kmet, L., & Macarthur, C. (2006). Urban–rural differences in motor vehicle crash fatality and hospitalization rates among children and youth. *Accident Analysis and Prevention, 38*, 122-127.

Langford, J. (2009). *Safer Vehicles: Fact Sheet #4*. Perth, Western Australia: Curtin-Monash Accident Research Centre.

Larsson, M., Candappa, N., & Corben, B. (2003). *Flexible barrier systems along high-speed roads: A lifesaving opportunity*. Melbourne, Victoria: Monash University Accident Research Centre.

Liu, C., & Subramanian, R. (2009). *Factors related to fatal single-vehicle run off road crashes* (Report No. DOT HS 811 232). Washington, DC: N. H. S. Administration.

Mackenzie, J. R. R. (2008). *Characteristics of high injury severity crashes on 80-110 km/h rural roads in South Australia*. Paper presented at the Australasian Road Safety Research, Policing and Education Conference, Adelaide, SA. http://casr.adelaide.edu.au/publications/list/?id=1037

Marchant, R., Hill, D. L., Caccianiga, R. A., & Gant, P. D. (2008). *Reported road crashes in Western Australia 2006*. Retrieved from http://www.ors.wa.gov.au/Documents/Statistics/statistics-annualcrashstats-2006.aspx

Marzougui, D., Mohan, P., & Mahadevaiah, U. (2007). *Performance evaluation of low-tension, three-strand cable median barriers on sloped terrains*. VA.

Meuleners, L. (2009). *The epidemiology of single vehicle crashes, 1998-2008*. Report to Main Roads Western Australia.

Nilsson, K., & Prior, N. (2004). *Wire rope safety barriers and the Pacific Highway Program: RTA reseasrch and investigations*. Paper presented at the Road Safety Research, Policing and Education Conference, Perth, Western Australia.

Office of Road Safety. (2009). *Towards Zero Road Safety Strategy* (ORS 339-07-08).

Ornek, E., & Drakopoulos, A. (2007). *Analysis of run off road crhases in relation to roadway feature and driver behavior.* Paper presented at the 2007 Mid-Continent Transportation Research Symposium, Ames, IA.

Oxley, J., Langford , J., Palamara, P., Muir, C., Koppel, S., Bohensky, M., & Williamson, A. (2009). *Non-wearing of adult seat belts in Australia: Where to next?* Austroads Report No. AP–R346/09.

Palamara, P.; Jones, J.; Hildebrand, J. & Lanford, J. (2010). *Local government enhanced speed enforcement management project: Phase One report*. Perth, Western Australia: Curtin-Monash Accident Research Centre, RR 10-001.

Palamara, P. (2011). *Local government enhanced speed enforcement management project: Final report*. Perth, Western Australia: Curtin-Monash Accident Research Centre, RR 10-002.

Palamara, P., Kaura, K., & Fraser, M. (2013). *An investigation of serious injury motor vehicle crashes across metropolitan, regional and rural Western Australia* (RR 09-001). Perth, WA.

Plunkett, A. (2009). *An examination of the licensing status of drivers involved in fatal road crashes in Western Australia*. Paper presented at the Australasian College of Road Safety Annual Conference, Perth, WA.

RAC. (n.d.). *Regional roads rescue submission*. Retrieved from http://rac.com.au/Community/~/media/Files/PDFs_09/Regional_Road_Rescue_Submission.ashx

Ray, M., Silvestri, C., Conron, C., & Mongiardini, M. (2009). Experience with cable median barriers in the United States: Design standards, policies, and performance. *Journal of Transportation Engineering, 135*, 711-720.

Retting, R. A., Williams, A. W., Preusser, D. F., & Weinstein, H. B. (1995). Classifying urban crashes for countermeasure development. *Accident Analysis and Prevention, 27*, 283-294.

Road Safety Council of Western Australia. (2006). *Analysis of Road Crash Statistics, 1995 to 2004*. Retrieved from http://www.officeofroadsafety.wa.gov.au/documents/state2_summaries.pdf

Road Safety Council of Western Australia. (2009). *Annual crash statistics: WA road fatalities summary 2008*. Retrieved from http://www.officeofroadsafety.wa.gov.au/index.cfm?event=researchAnnualCrashStats

SA Health. (2012, 1/11/2012). *About the Urban Crash Barrier project.* Retrieved from http://www.sahealth.sa.gov.au/wps/wcm/connect/public+content/sa+health+internet/protecting+public+health/urban+crash+barriers/about+the+urban+crash+barrier+project

Safety Evaluation Group. (n.d.). *Median barriers in North Carolina - Long term evaluation*.

South Australian Department of Human Services. (2000). *Proposed Standard: Crash-barrier systems for pedestrian protection*. Adelaide, SA: SA Department of Health.

Stevenson, M. R., & Palamara, P. (2001). Behavioural factors as predictors of motor vehicle crashes: Differentials between young urban and rural drivers. *Australian and New Zealand Journal of Public Health, 25*, 245-249.

Snook, B. (2013). Main Roads Western Australia. Personal communication.

Transport Canada. (2011). *Road safety in Canada*. Retrieved from http://www.tc.gc.ca/eng/motorvehiclesafety/tp-tp15145-1201.htm#s37. December 2013.

Treacy, P., Jones, K., & Mansfield, C. (2002). Flipped out of control: single-vehicle roll over accidents in the Northern Territory. *Medical Journal of Australia, 176*, 260-263.

Tziotis, M., Roper, P., Edmonston, C., & Sheehan, M. (2006). *Guide to road safety part 5: Road safety for rural and remote areas* (Project No. SP1051). New South Wales: Austroads.

World Health Organization. (2011). *Decade of Action for Road Safety 2011-2020*. Author.

Zivkovic, G. (2000). *Dynamic performance of new design - energy absorbing bollards* (SAHC/BOLL-03). Lonsdale, SA: Automotive Safety Engineering Pty Ltd.

Zwerling, C., Peek-Asa, C., Whitten, P., Choi, S., Sprince, N., & Jones, M. (2005). Fatal motor vehicle crashes in rural and urban areas: decomposing rates into contributing factors. *Injury Prevention, 11*, 24.

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