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Adequacy of barrier and median separation on rural roads

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TITLE

Adequacy of barrier and median separation on rural roads

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ABSTRACT

This study reanalyses the data from research by Doecke and Woolley (2010) that examined road departures with regard to clear zones and roadside barriers, in the new context of wide medians and median barriers (i.e. departures to the right side of the direction of travel). This study includes data from 62 rural crash investigations conducted from 1998 to 2010 in rural areas to which an ambulance was called. Many of the vehicles in the sample of in-depth crash investigations collided with fixed objects within 15 metres of the roadway yet still about 13% traversed 15 metres of lateral width from the roadway and had an occupant who needed to be transported to hospital. Of those 10 cases where no fixed object was struck, only five came to rest within 15 metres of the roadway. Computer simulations were performed based on five of the cases, three 'drift off' type run off road to the right crashes and two single yaw run off road to the right crashes. Each case was simulated using two different driver scenarios. The simulations revealed that wide medians may cater well for vehicles which drift off the road but those that lose control before departing the road will be likely to cross the median. Furthermore, the vehicles that lost control were found to still be travelling at between 55 and 70 km/h after crossing a 15 metre wide median. The computer simulations were also used to examine the appropriateness of median barrier offsets. The barrier was placed at a range of different lateral offsets from the road to examine the optimal positioning of roadside barriers on both wide and narrow medians. In general, smaller barrier offsets produced less severe impacts but all barrier offsets tested would be acceptable. It was concluded that a 15 metre median would cater for drift off crashes but not loss of control crashes. Therefore, to create a true safe system median barriers must be considered. It is also desirable to have a median that is not as wide as currently recommended when a median barrier is installed. Barriers on narrow medians will safely prevent departures to the right. The exact barrier offset (and therefore median width) on a narrow median had little effect on safety.

KEYWORDS

median, barrier, centre line, simulation, accident investigation, run off road accident

Summary

A common rural crash scenario is for a vehicle to depart to the right of its direction of travel. If other vehicles happen to be travelling in the opposite direction, a head on collision may result. If there are no oncoming vehicles, a collision with fixed roadside hazards or a rollover may occur. These crash scenarios are usually dealt with in rural road design by either the provision of a wide median on dual carriageway roads or a combination of a narrow median with crash barrier on single carriageway roads. Current design standards stipulate at least 15 metres width (Austroads, 2009) for such medians before some form of barrier protection is advised. Median barriers can be applied with medians as narrow as 1.6 metres (Austroads, 2009) in Australia, however in Sweden a median of 1.25 metres has been used (McLean et al., 2008). This study reanalyses the data from research by Doecke and Woolley (in press) that examined road departures with regard to clear zones and roadside barriers in the new context of wide medians and median barriers (i.e. departures to the right side of the direction of travel).

This study includes data from rural crash investigations conducted from 1998 to 2010 in rural areas to which an ambulance was called. The current rural study which commenced in 2007 required an ambulance to transport at least one occupant (unless no ambulance was required because an occupant was deceased). To the end of January 2010, 415 rural crashes had been investigated of which 62 crashes were single vehicle crashes that involved a motor vehicle departing the road to the right. These 62 crashes were analysed for factors important to medians. Many of the vehicles in the sample of in-depth crash investigations collided with fixed objects within 15 metres of the roadway yet still about 13% traversed 15 metres of lateral width from the roadway and had an occupant who needed to be transported to hospital. Of those 10 cases where no fixed object was struck, only five came to rest within 15 metres of the roadway. Given these results it seems likely that many vehicles that leave the roadway would still traverse the entire median.

Computer simulations were performed based on five of the cases, three 'drift off' type run off road to the right crashes and two single yaw run off road to the right crashes. Each case was simulated using two different driver scenarios. The first driver scenario simulated the driver attempting to recover to the roadway with steering input only. The second driver scenario simulated the driver employing emergency braking half a second after running off the road. The purpose of the computer simulations with respect to medians was to gain a more detailed understanding of the dynamics of the vehicle throughout the departure into the median. The simulations revealed that wide medians may cater well for vehicles which drift off the road but those that lose control before departing the road will be likely to cross the median. Furthermore, the vehicles that lost control were found to still be travelling at between 55 and 70 km/h after crossing a 15 metre wide median.

The computer simulations were also used to examine the appropriateness of median barrier offsets. The impact velocity normal to the barrier was used as the injury metric. The barrier was placed at a range of different lateral offsets from the road to examine the optimal positioning of roadside barriers on both wide and narrow medians. Barrier normal velocities of above 50 km/h have been found to be safe, particularly for semi rigid and flexible barriers (Grzebieta, 2002). The barrier normal velocities in all simulations were below 50 km/h regardless of barrier offset. Small barrier offsets produced the lowest barrier normal velocities unless the barrier offset exceeded 17 metres.

It was concluded that a 15 metre median on a dual carriageway would cater for drift off crashes but not loss of control crashes. Therefore, to create a true safe system median barriers must be considered. It is also desirable to have a median that is not as wide as currently recommended when a median barrier is installed. Barriers on narrow medians will safely prevent departures to the right. The exact barrier offset (and therefore median width) on a narrow median had little effect on safety.

Contents

1 Introduction

A common rural crash scenario is for a vehicle to leave the roadway and in many of these crashes the vehicle travels across the centreline of the road at some stage. If other vehicles happen to be travelling in the opposite direction, a head on collision may result. If there are no oncoming vehicles, a collision with fixed roadside hazards or a rollover may occur. It should be noted that although the stereotypical head on collision is often associated with overtaking manoeuvres, increasing evidence is indicating that many such collisions are more the result of drift off due to distraction, fatigue or loss of control of the vehicle from entering the left shoulder and then yawing to the right. These crash scenarios are usually dealt with in rural road design by either the provision of a wide median on dual carriageway roads or a combination of a narrow median with crash barrier on single carriageway roads.

Wide medians have been a desirable feature of high speed dual carriageway rural roads for many decades. Such road cross sections eliminate the need for overtaking in the face of oncoming traffic and provide a central recovery area similar in principle to that of a clear zone. It is expected that the wide medians allow errant vehicles to recover or stop safely prior to encroaching into the path of oncoming traffic or colliding with roadside objects to the right of the road. Current design standards stipulate that the median should be 15 metres wide if no median barrier is to be installed (Austroads, 2009).

Over the past decade, there has been a trend to retrofit two way rural roads with narrow medians and median barrier systems. As with dual carriageways, such treatments are expected to eliminate head on collisions in most circumstances. A further benefit is that collisions with roadside hazards on the right side of the road are also virtually eliminated. Median barriers can be applied with medians as narrow as 1.6 metres (Austroads, 2009) in Australia however in Sweden a median of 1.25 metres has been used (McLean et al., 2008).

This study reanalyses the data from research by Doecke and Woolley (in press) that examined road departures with regard to clear zones and roadside barriers in the new context of medians and median barriers.

The percentages of crashes in rural South Australia that are head on crashes from 1990 to 2009 are shown in Figure 1.1. Figure 1.2 shows the percentage of crashes that were classified as either ‘hit fixed object’ or ‘left road out of control’. It can be seen that, although it varies from year to year, the percentage of fatal crashes that are head on crashes has remained between 12 and 24 over the last 20 years. Head on crashes are commonly viewed as particularly undesirable as they involve multiple vehicles and typically involve high changes in velocity resulting in severe injuries to multiple occupants. Figure 1.1 shows that head on crashes are much more likely to be fatal than other rural crashes. The hit fixed object or left road out of control crashes that will be affected by a wide median or median barrier are those where the vehicle departs the road to the right. Doecke and Woolley (in press) found that, in a sample of South Australian rural single vehicle crashes where at least one occupant had been transported by an ambulance, almost half the vehicles departed the road to the right. The prevalence of fatal rural crashes that are classified as either hit fixed object or left road out of control varies between 30 and 47% between 1990 and 2009. Therefore, between 15 and 24% of these fatal crashes can be expected to be influenced by median treatments. Figure 1.2 shows that hit fixed object and left road out of control crashes are more likely to be fatal crashes than other rural crash types. Combining these figures with head on crashes reveals that between 27 and 48% of fatal rural crashes involved a car departing their lane to the right. This represents a substantial road safety problem and must be addressed to progress towards achieving a safe system.

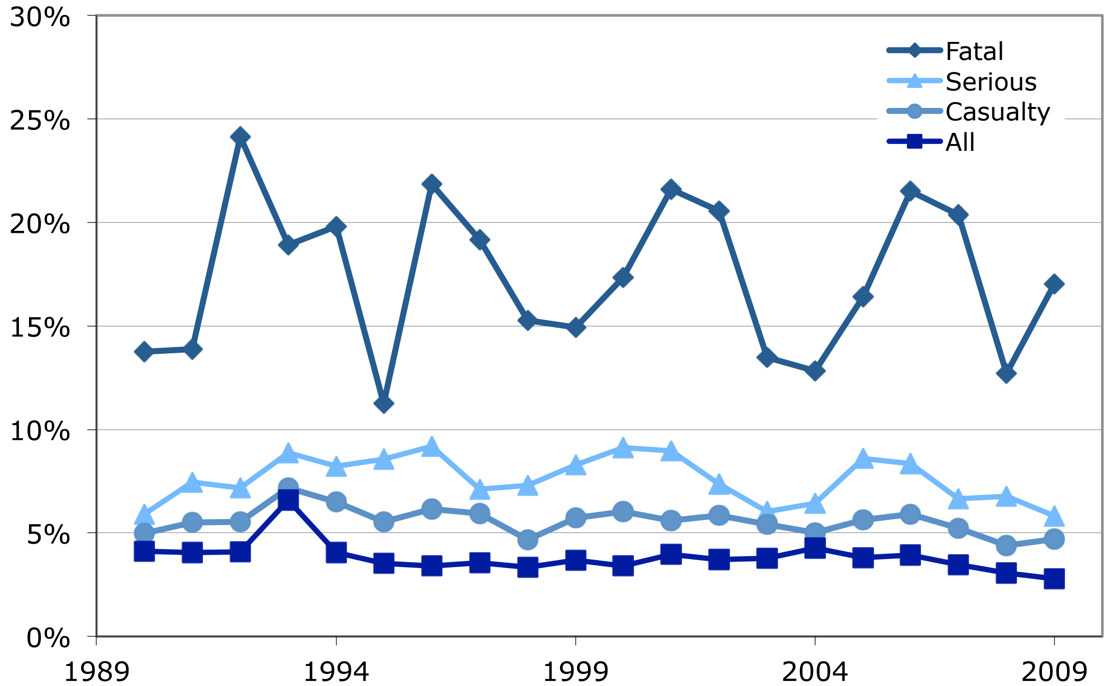

Figure 1.1
Percentage of crashes that were head on crashes from 1990 to 2009 in rural South Australia
(South Australian Traffic Accident Reporting System, 2010)

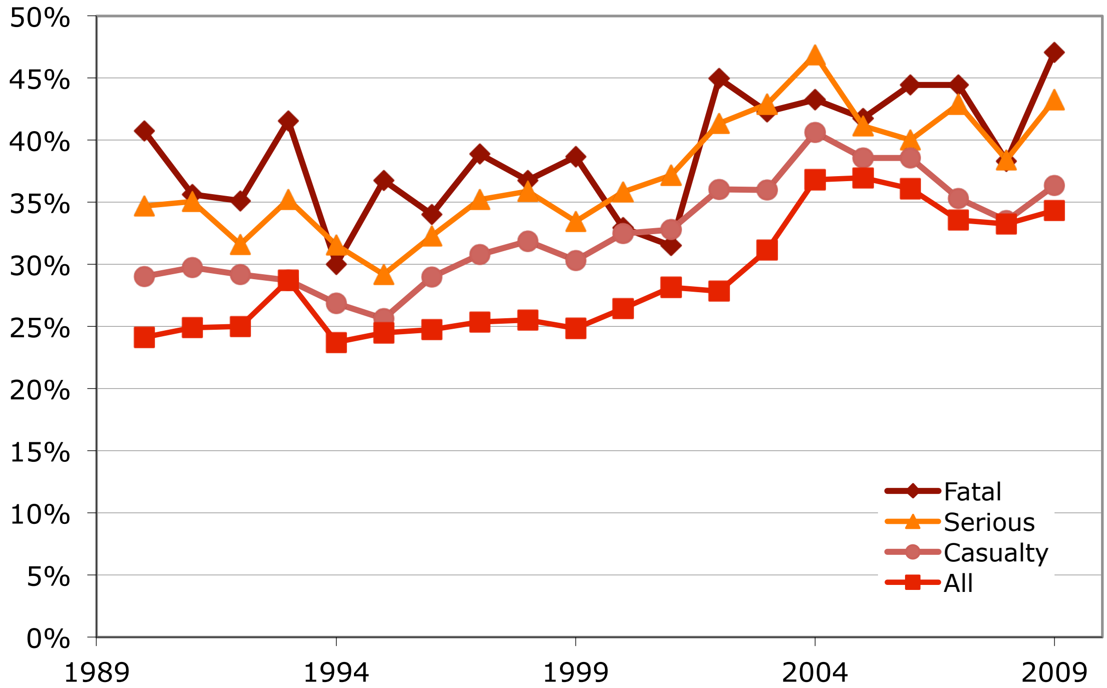

Figure 1.2
Percentage of crashes that were hit fixed object / left road out of control crashes from 1990 to 2009 in rural South Australia
(South Australian Traffic Accident Reporting System, 2010)

2 Literature review

2.1 Early research

The foundational research used to guide the design of medians was conducted by Hutchinson and Kennedy in 1966 and is titled 'Medians of divided highways – frequency and nature of vehicle encroachments'. In this report, median encroachments were observed by physical inspection of encroachment sites and the evidence of the encroachment, such as tyre tracks in snow. The nature of the encroachment was then determined by examining the evidence at the site and any available accident reports (Hutchinson and Kennedy, 1966). A total of 321 cases were used in the analysis and measurements of the lateral displacement of the vehicle were based on the left (outer) wheel track. The major recommendation from this report was that a 30 foot median width (9.1 metres) be used as the desirable minimum standard and that median barriers should be used if this cannot be met. Of the two roads that were examined in this study, one had a 40 foot (12.2 metre) median and one had an 18 foot (5.5 metre) median. Of the 293 cases examined on the road with the 40 foot median, 52 (17.7%) involved a vehicle completely crossing the median, thus having a lateral displacement of greater than 40 feet (12.2 metres). The speed limits on the roads studied were 70 mph or 112.7 km/h.

Cooper (1980) analysed data collected on 59 Canadian roadway sections of varying speed limits. Of 1915 cases 38.4% were found to have a lateral departure distance of greater than eight metres and 18.3% greater than 12 metres. This is similar to the results found by Hutchinson and Kennedy (1966).

2.2 Width of median and barrier installation

An American based study of median design considerations by Donnell et al. (2005) found that there is a positive economic benefit of installing median barriers on highways with median widths up to 70 feet (21.3 metres) where the average daily traffic volume is greater than 20,000 vehicles. Glad et al. (2002) also sought to determine the benefit-cost ratios for the different types of median barriers installed on medians of various widths in Washington State. They concluded that wire rope barriers are the most cost effective barrier type and recommended that such barriers be installed on all highways with a speed limit of 45 m/h (72 km/h) or more and a median width of 50 ft (15.2 metres) or less. Such median barrier installations would be expected to produce benefit-cost ratios between 2.7 and 5.5. A curious finding of the economic analysis in this report is that, while median barrier installation on roads with medians of 60 to 80 feet (18.3 to 24.4 metres) produced benefit cost ratios below one, barrier installation on medians over 80 feet produced benefit-cost ratios above one. A report by Shankar et al. (2004) followed on from Glad et al.'s work in Washington State. Shankar et al. used a statistical model of weighted social costs of median crossovers to conclude, like Glad et al., that barriers should be installed on medians 50 ft (15.2 metres) or less wide. They also concluded that median widths over 60 ft (18.3 metres) do not require a barrier.

Sicking et al. (2009) determined guidelines for implementation of cable median barriers (wire rope barriers) by analysing crash data from freeways in Kansas. These guidelines were presented in the form of the relationship between the median width and traffic volume needed for a median barrier installation to produce a benefit-cost ratio of two. For example a 10 ft (3 metres) median requires a traffic volume of 15,000 vehicles per day, increasing to 23,700 for a 30 ft (9.1 metres) median and 41,700 for a 50 ft (15.2 metres) median. Miaou et al. (2005) also attempted to determine guidelines for implementation of median barrier installation, although they examined both concrete and wire rope barriers. They determined that for traffic volumes of 10,000 vehicles per day a concrete median barrier had a benefit-cost ratio of one or more for medians up to 60 ft (18.3 metres) wide. For traffic volumes of 15,000 vehicles per day this extended to medians of up to 125 ft (38.1 metres) wide. Concrete medians barriers placed on roads with traffic volumes of less than 5,000 vehicles per day were not cost effective for any median width (benefit-cost ratio of up to 0.8 on a 10 ft median). Wire rope median barriers were found to have benefit-cost ratios between about two and four times that of concrete barriers for traffic volumes up to 20,000 vehicles per day.

A study into the real behaviour of barriers on highway medians in France found that the rate of injury for cars impacting a median barrier increased as the width of the median increased. The opposite effect was found for heavy vehicles (Vulin *et al.*, 1987). Conversely, Hu and Donnell (2010) found that increasing the barrier offset from the edge of the road reduced the probability of high severity crash outcomes.

The Austroads Guide to Road Design Part 3 (Austroads, 2009) states that where the function of the median is to provide a recovery area for errant vehicles the width of the median should be 15 metres. If such a width is not provided or if the road has large traffic volumes and is high speed a median barrier should be considered. For the typical depressed median a 10 on 1 slope is said to be desirable while a 6 on 1 slope is the maximum allowable (Austroads, 2009). The American Association of State Highway and Transportation Officials (AASHTO) recommends that median widths be between 15 and 30 metres and that a median barrier should be considered when a 15 metres median can not be achieved (AASHTO, 2002), although they state that traditionally barriers have not been used on medians with widths of 10 metres or more (AASHTO, 2002).

2.3 Median barrier safety benefits

Elvik (1995) undertook a meta-analysis of 32 previous studies that evaluated the safety value of guardrails and crash cushions. This included 232 numerical estimates of safety effects. He concluded that on the basis of these studies

> "the best current estimates of the effects of median barriers are a 30% increase in accident rate, a 20% reduction in the chance of sustaining a fatal injury, given an accident, and a 10% reduction in the chance of sustaining a personal injury, given an accident."

Much research has been conducted into median barriers since Elvik conducted his meta-analysis in 1995. The use of wire rope barriers has also dramatically increased therefore this estimate may not reflect current research and median barrier practice.

Michie and Bronstad (1994) expressed concern about what they believed to be the grossly overestimated risks associated with guardrail installation. The main factor cited as contributing to this overestimation was the large amount of unreported accidents involving guardrails. Citing two previous studies (Galati, 1967 and Carlson *et al.*, 1977) they concluded that only about 10 to 13% of barrier collisions are reported, and that those that go unreported are most likely to be non-injury crashes. Other factors cited were the recording of only the first harmful event in most police crash records rather than the most harmful event and the contribution of obsolete or poorly installed barriers to poor crash performance. Taking all these factors into account they estimated that the chance of being injured or killed in a barrier impact reduced from 59% to as low as 2.4%. They recommended that the wording of road design manuals that warn that barriers are hazards themselves be softened to accurately reflect their hazardousness.

Grzebieta et al. (2002) conducted more severe crash tests than are required by the American, European or Australian standards. They found that the occupants of a small vehicle travelling at about 80 km/h and impacting a barrier at 45 degrees would not only survive but have a low risk of injury if the barrier was a wire rope barrier or a W-beam guardrail. A concrete barrier that appeared to be a New Jersey or F-shape design was found to inflict fatal injuries although it is not clear if this was from the initial impact or the subsequent rollover. A rollover was also induced in an impact with a wire rope barrier at 110 km/h and 20 degrees although there was some doubt as to whether the barrier had been installed correctly. This crash would not have been survivable but this can be confidently associated with the rollover and not the impact with the wire rope barrier. The authors concluded that the W-beam guardrail provided the best protection for the occupants of small vehicles.

Sweden has implemented large lengths of 2+1 configurations on its road network. A 2+1 configuration has a continuous lane in each direction and a middle lane that alternates between the permitted direction of travel at 1.5 to 2.5 kilometre intervals. Median wire rope barrier has been used extensively on these sections of road as part of a “Collision Free Roads” program. At the beginning of January 2008, 1,800 km of Collision Free Roads were in service (Carlsson, 2009). A 79% reduction in fatality rate was observed for mid-block sections of road. The reduction in fatal and serious injury rate varied between 46 and 74%. This is compared to a reduction of 39% for roads with painted 2+1 configuration with a median rumble strip (Carlsson, 2009). The most similar road type with a median barrier experienced almost twice the reduction of the road that did not have the median barrier. This suggested that half of the benefit may come from the road configuration and half from the median barrier.

Villwock, Blond and Tarko (2011) reported that the installation of cable barrier (wire rope barrier) that was either low or high tension eliminated 94% of median crossover crashes. However, they also found that single vehicle crashes increased by 70% when such a barrier was installed on a wide, depressed median, though no increase is observed on narrower medians with a low tension cable. Qin and Wang (2010) found a large reduction in severe median related crashes after installation of a cable barrier but observed a large increase in the number of non-injury crashes. They found the installation of such median barriers to be highly cost effective.

In recent years road authorities in Australia and New Zealand have begun to install wire rope barriers on narrow medians. These installations are in the form of small scale trials rather than long sections of road, making the evaluation of their safety benefit difficult. McTiernan et al. (2009) and Levett et al. (2009) both attempted to determine the safety benefits of 11.15 km of wire rope barrier installed on a two metre wide median in New South Wales. Traffic volumes on the sections of road where the barrier was installed vary from just over 10,000 to just under 20,000 vehicles per day. Both studies found a reduction in casualty crashes although overall crash numbers were low. McTiernan et al. (2009) concluded that if a slightly higher probability of the result being due to chance than usual is acceptable (6 to 8%), this reduction in casualty crashes was statistically significant. An economic analysis was also conducted by McTiernan that found benefit-cost ratios could range from 1.3 to 2.3 for this median barrier installation. Marsh and Pilgrim (2010) evaluated the installation of 3.5 km of wire rope barrier on a median of width 1.5 metres in New Zealand. The traffic volume on the section of road where the barrier was installed was around 22,000 vehicles per day. A lack of overall crash numbers again posed a problem, yet the elimination of an average of 1.33 serious and fatal head on crashes per year in the five years following the installation of the barrier suggests a very positive safety benefit. However, this result is confounded by a reduction in the speed limit from 100 km/h to 80 km/h at the same time the barrier was installed. An increase in non-injury crashes from 3.55 to six per year was also observed.

2.4 Rollovers

Viner (1995) analysed rollover crash data from Illinois police between 1985 and 1989. A total of 16,453 rollover crashes were used in the analysis which included all vehicles except motorcycles. It was found that the dominant cause of rollovers was ‘tire-soil forces’, causing 80.6% of rural and 72% of urban rollovers. This cause was inferred when no event was listed in between ‘ran-off-road’ and ‘overturn’ in the police record. Since police had the option of recording ‘ditch/embankment’ in between the aforementioned events it was suggested that relatively flat slopes and gently rounded ditches may have been present in the majority of these cases. The inference from this work is that rollover crashes may also occur in wide medians independent of fixed objects and barriers.

McLean et al. (2005) examined data from 64 in-depth investigations of rollover crashes on rural roads in South Australia. They found that 19 of these rollover crashes occurred with no prior collision with another vehicle or a fixed object such as a tree or embankment. They also noted that it was probable that many of the 24 vehicles that rolled over after hitting a fixed object would have rolled over had they not collided with the fixed object.

Stine et al. (2010) found that the percentage of rollovers increased with increasing median width, both in vehicle dynamics simulations and real world data. Jurewicz (2010) found a similar result in the context of vehicles departing the road into a clear zone.

Gabauer and Gabler (2007b) analysed data from the Fatal Accident Reporting System and the National Accident Sampling System for the years 2000 to 2005, with respect to vehicle – guardrail collisions. Both of these databases are maintained by the National Highway Traffic Safety Administration (NHTSA) in the United States of America. They found that only two percent of vehicles involved in a guardrail collision rolled over but that 20% of fatal collisions with guardrails were rollover crashes. It was also noted that of 167 crashes in which vehicles overturned, 79% did so after impacting the guardrail.

Note that there are other safety issues in relation to medians on dual carriageway roads. Hazards in medians should obviously be avoided or protected. The ability of vehicles to traverse drainage channels and the performance of crash barriers in close proximity to drainage profiles were considered outside the scope of the current study.

2.5 Summary

The majority of research into medians and median barriers has taken place in a North American context. Many of these studies have sought to quantify how narrow a median must be before a median barrier is required, either on economic grounds or using an acceptable probability of a cross over departure. Such studies have results generally ranging from 30 to 70 ft or 9.1 to 21.3 metres (Hutchinson and Kennedy, 1966; Donnell et al., 2005; Glad et al., 2002; Shankar et al., 2004; Miaou et al., 2005; Sicking et al., 2009). All these studies assume that a median is already present and therefore none compare the construction of a wide median to the installation of a barrier on a very narrow median in terms of economic benefit.

The benefits of wire rope barriers was highlighted by several authors. They were found to be more cost effective than more rigid barriers (Glad et al., 2002; Miaou et al., 2005), provide substantial reductions in serious and fatal injuries in an American (Villwock, Blond and Tarko, 2011; Qin and Wang 2010) and European context (Carlsson, 2009) and measurable safety benefits in an Australasian context (McTiernan et al., 2009; Levett et al., 2009; Marsh and Pilgrim, 2010).

Some concerns have been raised in the literature that a large percentage of rollovers can occur when a car travels over unsealed roadside such as a wide median (Viner, 1995; McLean et al., 2005; Stine et al. 2010; Jurewicz 2010).

3 Methodology

3.1 In-depth crash investigation data

3.1.1 Introduction

CASR has conducted in-depth crash investigations for over 30 years. This study includes data from crash investigations conducted from 1998 to 2010 in rural areas to which an ambulance was called. The current rural study, which commenced in 2007, required an ambulance to transport at least one occupant (unless no ambulance was required because an occupant was deceased). To the end of January 2010, 415 rural crashes had been investigated. In 122 of these crashes a vehicle crossed the centreline, or edge line if a median was present. These 122 crashes were analysed for factors important to medians. Crashes caused by a vehicle deliberately crossing the centreline (such as performing an overtaking manoeuvre) were not included in the crashes examined as they were thought to be fundamentally different. In any case few such cases were found in the in-depth crash investigation database. Motorcycles that crossed the centreline were also considered to have fundamental differences from typical passenger car centreline crosses and were not examined. The ability to collect pertinent information that is not recorded in mass crash data, such as that found in the South Australian Traffic Accident Reporting System, is a key advantage of the in-depth crash investigation methodology.

3.1.2 In-depth crash investigation method

The eligibility criterion for the in-depth crash study was ambulance transport of at least one person involved in a crash on a public road. Rural crashes were investigated up to 100 kilometres from Adelaide. Rural townships that contained roads with speed limits of less than 80 km/h were excluded, as were roads that had speed limits of 80 km/h or above but were still in built up areas. The exception to this rule was the inclusion of the South Eastern Freeway and the Southern Expressway in the sampling area.

Crash investigators were notified of a crash by a pager provided by the South Australian Ambulance Service. CASR staff were on call to attend crash scenes between 0900 and 1630 during weekdays. Fatal accidents that occurred at any time on any day were also investigated as the South Australian Police Force’s Major Crash teams preserved evidence at the scene.

It was the aim of the investigators to reach the scene of the crash before any of the vehicles involved were moved from their final resting positions. As CASR personnel do not have, nor desire, permission to exceed posted speed limits while en route to a crash scene it was not always possible to achieve this aim. If the vehicles had been removed before the arrival of CASR’s investigators and there was insufficient evidence to indicate where their final positions were or the configuration of the accident the case was abandoned.

The information collected on each case included:

- Photographs of the crash scene and vehicles involved
- Video of drivers approach
- Details of the road environment, including traffic control measures
- A site plan of the crash scene including physical evidence (tyre marks etc.) and vehicle positions pre-impact, at impact and final resting positions
- Details and measurements of the vehicles involved

- Information on the official police Vehicle Crash Report (VCR)
- Crash history of locations and drivers involved
- Interviews with crash participants and witnesses
- Injury data for crash participants who attended major metropolitan hospitals

3.1.3 Analysis method

The site diagrams that were produced for each investigated crash were used to determine the departure angle, the longitudinal distance travelled after leaving the roadway, and the lateral distance travelled after leaving the roadway. An example of such a diagram can be seen in Figure 3.1.

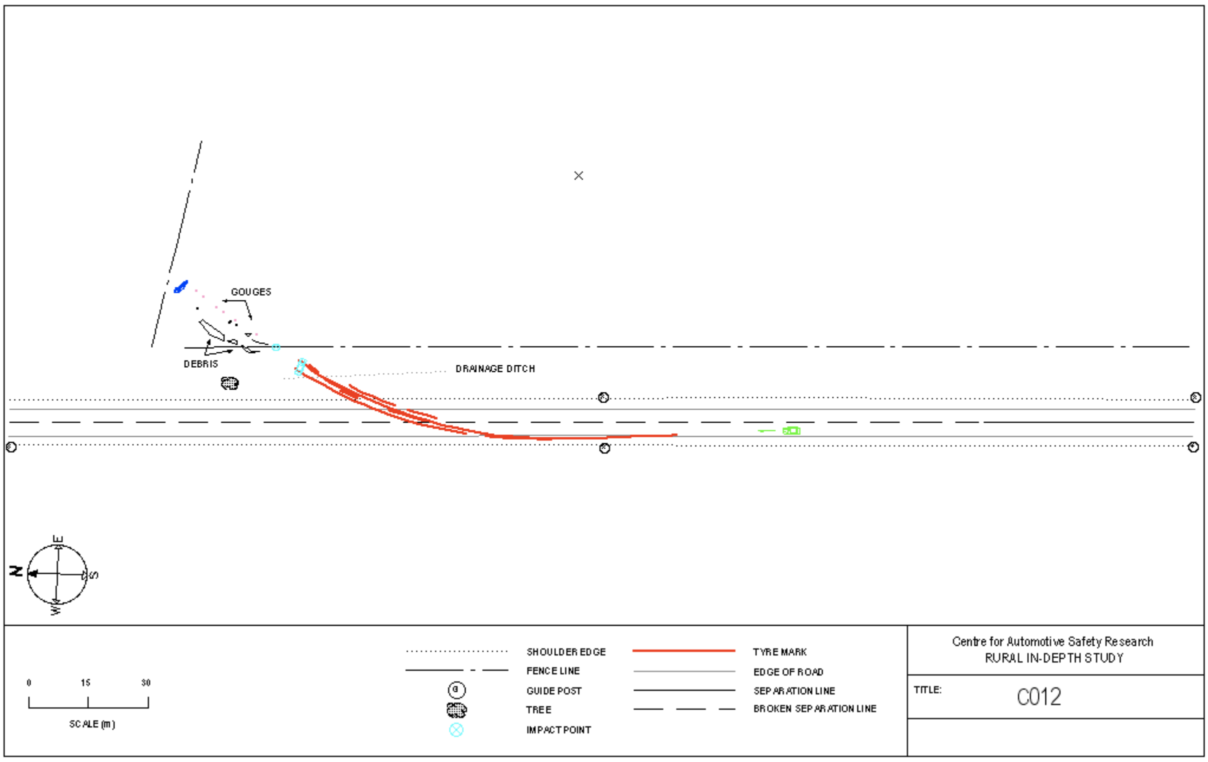

Figure 3.1
An example site diagram

The departure point of the vehicle was defined as the location where one of its tyres crossed the centreline of the road. The departure angle was measured from the tyre mark left by the wheel that first crossed the centreline as this was assumed to be equal to the velocity vector of the vehicle. Theoretically the greater the yaw rate of the vehicle the less accurate this assumption will be, but none of the investigated crashes appeared to have yaw rates high enough to cause a significant error. The lateral distance was measured perpendicularly from the point on the vehicle furthest away to the centreline. Figure 3.2 shows these measurement methods diagrammatically. If a vehicle began to move back towards the left side of the road because it was beginning to recover or because it struck a hazard the position of maximum lateral displacement was used. If the vehicle left the road more than once without striking a fixed object the road departure that produced the greatest lateral displacement was used. If a vehicle was directed sharply farther away from the road due to a hazard strike than it otherwise would have travelled given its initial trajectory, the location of the vehicle at the location where it struck the hazard was used for the lateral displacement measurement.

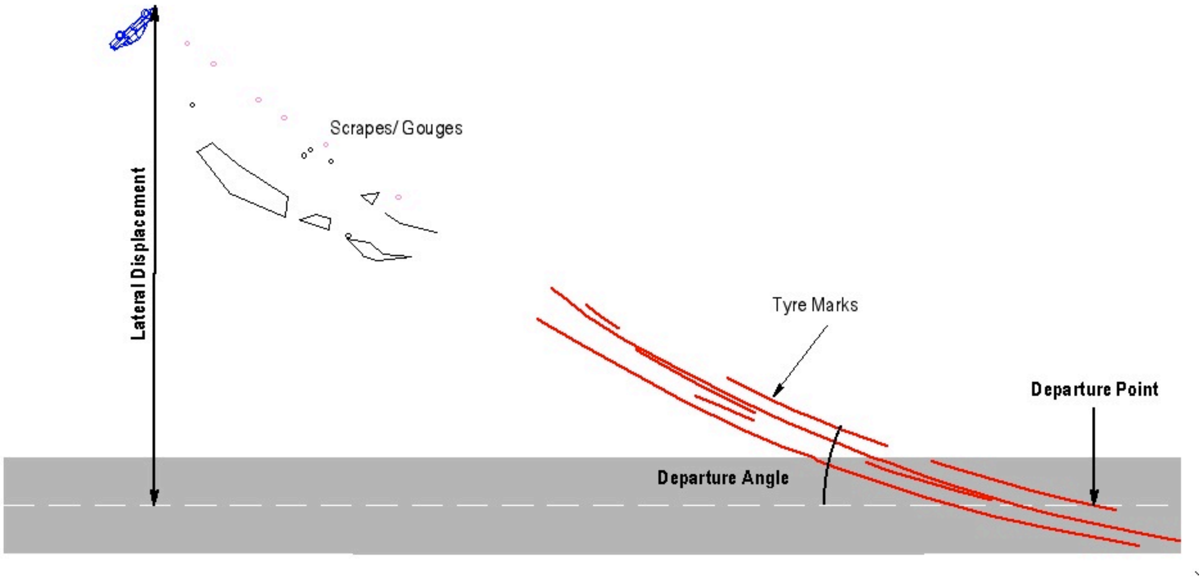

Figure 3.2
Measurement method of the vehicle departure displacements and angle

Other data from the crashes that were used in the analysis included

- type of run off road crash
- speed zone
- severity of the crash
- if the vehicle rolled over or not
- type of road surface
- if the vehicle had left the road prior to the departure that was used in the analysis

The run off road crashes were categorised into types by the amount of changes of direction the vehicle undertook before leaving the road. A ‘drift off’ type run off road crash indicates the vehicle simply drove off the road without losing control. A single yaw type run off road crash indicates that the vehicle was experiencing a yaw (or sideslip) angle before leaving the road, a double yaw indicates an initial yaw before an overcorrection resulting in a yaw in the opposite direction, and a triple yaw indicates an initial yaw before two subsequent overcorrections resulting in a yaw direction the same as the original yaw. Examples of the tyre marks left by these different types of run off road crashes can be seen in Figure 3.3.

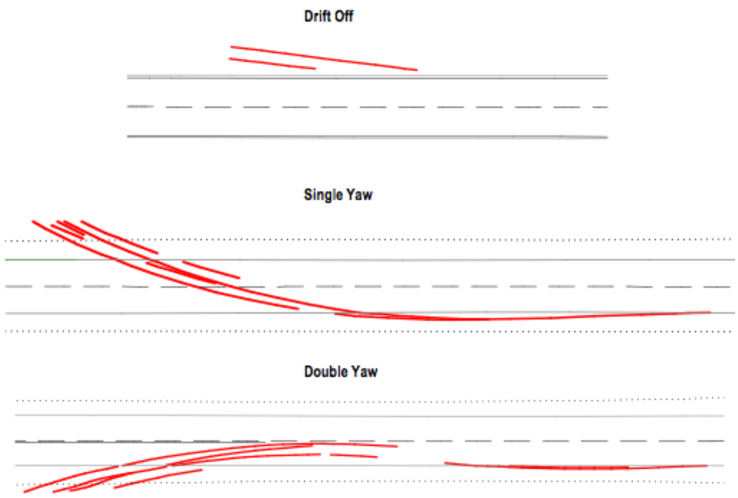

Figure 3.3
Tyre marks left by the different types of run off road crashes (in red)

Full simulation of all the crashes in the sample was outside the scope of this report but it was thought that it would be useful to obtain an estimate of the speed at which vehicles left the road for as many cases as possible. This was achieved by using the critical speed method (see Equation 1). The method was used for all cases that involved yawing and sufficient yaw marks had been recorded on the site diagram.

$$v = \sqrt{gr\mu} \quad (1)$$

where v = speed

g = acceleration due to gravity

r = radius of tyre mark

μ = coefficient of friction

The accuracy of this method, which is often employed by police reconstructionists, has been determined experimentally by Shelton (1995) and analytically by Brach (1997). Both agree that the method will typically underestimate the initial speed by about five percent given that the vehicle is not accelerating or braking but underestimates of over 10% are possible. Part of this underestimate occurs because the calculation is actually determining the average speed over the arc of the tyre mark used for the radius measurement and since the vehicle is slowing somewhat as it yaws this speed is lower than the initial speed prior to the yaw. In our method this error will be reversed as we used the arc of the tyre mark immediately before road departure to calculate the speed at departure.

Since no differentiation was made on the diagrams between yaw and skid marks some inferences had to be made. If the radius of the tyre marks was found to be decreasing it was inferred that no braking was taking place and the radius of that tyre mark could be used in equation one, but if the radius was increasing, especially trending towards infinity (a straight line), braking was assumed and an earlier tyre mark was used. If the tyre marks became straight lines before they left the road the skidding equation, Equation 2, was used in conjunction with the critical speed equation to determine the departure speed.

$$v_f = \sqrt{v_i - 2g\mu d} \quad (2)$$

where v_f = final velocity

v_i = initial velocity

g = acceleration due to gravity

μ = coefficient of friction

d =distance of skidding (length of skid mark)

Since no coefficients of friction were measured at the crash locations, a value of 0.7 was used for dry sealed roads and 0.55 for unsealed roads. Wet roads typically had insufficient visible tyre marks so no value needed to be estimated for wet conditions. These estimates were based on estimates given in Rivers (1981). Of the sample of 132 crashes, 71 had sufficient tyre marks to calculate the departure speed.

3.2 Computer simulation

3.2.1 Introduction

The in-depth crash investigation data can demonstrate some of the typical trajectories of vehicles when they leave the road to the right. Departure speeds can also be estimated using the critical speed method. Computer simulation can be used to provide a more comprehensive understanding of the speed of a vehicle that has run off the road throughout its departure. Computer simulation can also allow testing of the relative merits of various median and median barrier combinations. Due to the time-consuming nature of computer simulation the scope of this project did not allow for comprehensive simulation of all the crashes that were analysed in Section 3 with every possible roadside treatment. Instead, 14 crashes were selected for reconstruction that covered the range of crashes found in the in-depth crash investigation cases.

The simulation environment used for these purposes was Human Vehicle Environment (HVE) which incorporates the vehicle dynamics package Simulation Model – Nonlinear (SIMON). SIMON was developed and validated by Engineering Dynamics Corporation (EDC).

SIMON uses a non-linear semi-empirical tyre model in conjunction with a full suspension model to simulate vehicle dynamic behaviour with a high degree of accuracy (Day, 2004). The option of using radial springs to represent the tyre allows for realistic traversing of irregular terrain.

3.2.2 Method

The vehicle travel paths in the simulations were based on actual crashes from the in-depth crash investigation database. Cases with likely travel speeds of above 120 km/h were not considered for simulation as they are considered outside the scope of a safe system in Australia. The characteristics of the chosen cases can be seen in Table 3.4. The majority of the crashes simulated were left road to the right crashes. Three left road to the left and head on crashes were also simulated. Single yaw and drift off manoeuvres were found in the majority of the crashes, though three vehicles had undertaken a double yaw before leaving the road or colliding head on with another vehicle. Note that the lateral displacement shown in Table 3.4 represents the actual crash in which the lateral displacement may have been restricted by a roadside hazard or an oncoming vehicle.

Table 3.4
Characteristics of the crashes that the simulations were based on

Case	Crash type	On road Manoeuvre	Departure Angle (degrees)	Lateral Displacement (metres)	Speed Zone (km/h)	Departure Speed (km/h)	Rollover	Severity
C043	Left road - right	Drift off	6	9.2	110	-	Yes	Admitted
C044	Left road - right	Drift off	7	8.0	110	-	No	Admitted
C070	Left road - right	Drift off	5	7.1	110	-	No	Admitted
C054	Left road - right	Single yaw	13	6.3	100	80	No	Treated
R238	Left road - right	Single yaw	19	8.0	100	103	No	Admitted
R151	Left road - left	Single yaw	16	0.4	80	80	No	Treated
R106	Left road - left	Double yaw	17	0.9	100	85	No	Fatal
R135	Left road - left	Double yaw	25	2.0	100	64	Yes	Admitted
R011	Left road - right	Drift off	1	5.8	100	-	No	Fatal
C130	Head on	Drift off	-	5.4	100	-	No	Treated
C197	Head on	Double yaw	18	5.2	100	93	No	Fatal
R149	Head on	Single yaw	12	5.7	100	109	No	Admitted
C012	Left road - right	Single yaw	20	9.1	110	113	Yes	Fatal
C072	Left road - right	Single yaw	19	32.4	110	104	Yes	Admitted

The exact geometry of the road surface and shoulder was modelled from the site plan. The clear zone was modelled as a flat plane extending from the shoulder.

The characteristics of the vehicle involved in the road departure were also input into the HVE program including mass, wheelbase, track, approximate centre of gravity, external dimensions and tyre size. Generic values contained within HVE were used for other values such as suspension characteristics (e.g. spring rates). In HVE the total coefficient of friction is produced by multiplying the friction value of the tyre by the friction factor of the surface. A friction factor of 1.0 would represent a surface with the same frictional properties as the flat bed tester used to measure the tyre properties. Friction factors of 0.85 to 0.9 were used for dry bitumen and were appropriately modified if the bitumen was wet at the time of the accident.

The tyre marks of the vehicle that had been recorded at the scene of the accident were imported into the HVE environment. Simulations were then run using different steering inputs and initial speeds until an acceptable match of the simulation and actual tyre marks was achieved. For the simulation of the drift off type crashes where no tyre marks were present on the roadway, an initial steering input was chosen to match the departure angle of the vehicle as evidenced by tyre marks off the road.

Anecdotal evidence from CASR’s interviews of crash involved drivers suggests two different driver control scenarios are possible when a vehicle loses control and runs off the road. The first scenario involves the driver attempting to recover with steering input only until they either strike a fixed object or successfully recover. The second scenario involves the driver attempting to recover but when they feel they are beyond the ‘point of no return’ they initiate emergency braking. This point of no return may be a certain yaw angle or when the vehicle leaves the road. The simulations of this scenario assumed leaving the road as the point of no return and a half a second reaction time was used. Both of these driver control scenarios were used to determine the dynamics of vehicles throughout road departures.

Steering rates and maximum steering angles in an unexpected emergency situation are unknown. Forkenbrock and Elsasser (2005) conducted experiments to assess human driver steering capability using a double lane change manoeuvre and several vehicles. The smallest value of overall peak steering rate for a 2003 Toyota Camry was 718 degrees per second. The peak steering wheel angles varied between 316 degrees and 477 degrees for the same vehicle. In these tests the drivers were fully prepared to steer therefore it was thought that they may be higher than in an unexpected emergency situation hence the maximum steering rate and angle used in the simulations was 500 degrees per second and 300 degrees per second respectively.

A barrier was placed in the simulation environment to investigate the injury potential of median barriers. The relevant vehicle dynamic values were recorded at the point at which the vehicle first struck the barrier. The barrier was moved progressively further away from the centre of the road to test different barrier offsets.

To assess the suitability of barriers it is necessary to be able to assess the occupant's risk of fatality or serious injury. The crash injury metric that is currently used under the Australian/New Zealand Standard for road safety barrier systems (AS/NZS 3845:1999) is occupant impact velocity determined by the flail space model. This uses procedures outlined in the National Cooperative Highway Research Program (NCHRP) Report 350. This method models the occupant as unrestrained (Gabauer and Gabler, 2007b). Since unrestrained occupants are seven times more likely to receive an injury with an AIS of two or more in a barrier collision than a restrained occupant (Gabauer and Gabler, 2007a) and belt usage rates in Australia are typically over 95% (Wundersitz and Anderson, 2009; Roberts *et al*., 2006) it was not chosen for this analysis.

Change in velocity, or delta-V as it is commonly known, is the traditional vehicle based metric of real world crash severity (Gabauer and Gabler, 2007b). Delta-V is simply calculated by subtracting the velocity immediately after the impact from the velocity immediately before the impact. The injury predictive capabilities of delta-V intuitively do not apply to an oblique barrier impact. For example consider an oblique impact with a rigid barrier. The barrier absorbs no energy, all the energy loss in the impact would come from the deformation of the vehicle structure and the vehicle rebounds quickly from the barrier with little reduction in speed. Now consider the same oblique impact with a flexible barrier. The barrier and the vehicle structure both absorb energy and the vehicle remains in contact with the barrier for a large amount of time (for an impact) and rebounds with a much reduced speed. In these impacts the delta-V would be larger for the flexible barrier impact despite it being less likely to cause injury, hence delta-V is not an ideal injury metric for barrier collisions.

Schmidt et al. (1998) stated that impact speed is a good measure of impact severity in special cases such as barrier impacts. In a barrier impact the component of the impact velocity that is normal to the barrier would have a direct relationship to the forces acting on a restrained occupant and therefore the injury severity of the occupants. For this reason it is used as the injury metric in this analysis and will be referred to as the barrier normal velocity. Figure 3.5 explains the barrier normal velocity diagrammatically. It may be helpful to think of it as being equivalent to the vehicle impacting the barrier head on at this speed, although the front of the vehicle may not be pointing directly at the barrier, as can be seen in Figure 3.5.

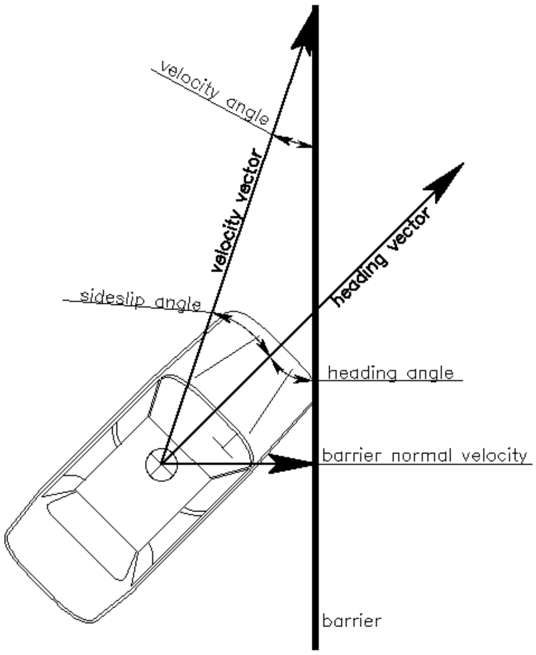

Figure 3.5
Vehicle dynamics parameters in a barrier impact

4 Results

4.1 In-depth crash investigation data

4.1.1 General characteristics

Table 4.1 displays the crashes that crossed the centreline by the crash type. Of the crashes investigated just under half left the road to the right (49%). Many vehicles (36%) collided with another vehicle when they crossed the centreline. Some vehicles did depart the road to the left after initially crossed the centreline, but such crashes were comparatively few (15%). It is possible that head on crashes are overrepresented in the sample due to the minimum criterion of ambulance transport; a head on crash on a high speed rural road would be high likely to meet the criterion while a vehicle that departs the road may be fortunate enough to not strike a fixed object or rollover.

Table 4.1
Centreline cross crashes by crash type

Crash type	Number	Percentage
Left road to left	18	14.8%
Left road to right	60	49.1%
Head on	44	36.1%
Total	122	100.0%

The on-road manoeuvres of the vehicles in the centreline cross crashes are shown in Table 4.2. Crashes in which the vehicle yawed a single time were most common, representing just under half of the crashes. Crashes where the vehicle simply drifted across the centreline were also common (37%). Double yawing manoeuvres were relatively rare. This may suggest that drivers often overcorrect the initial yawing movement before they cross the centreline, and depart the road to the left. A triple yaw manoeuvres were very rare, with only two occurring in all the centreline cross crashes investigated.

Table 4.2
Centreline cross crashes by on road manoeuvre

On-road manoeuvre	Number	Percentage
Drift	45	36.9%
Single yaw	59	48.4%
Double yaw	16	13.1%
Triple Yaw	2	1.6%
Total	122	100.0%

More than half the cases investigated were located in a 100 km/h speed zone, as can be seen in Table 4.3. About 24% occurred in the highest speed zone in South Australia, 110 km/h. Less than a fifth occurred in 80 km/h zones, and 90 km/h zones were rare.

Table 4.3
Centreline cross crashes by speed zone

Speed zone (km/h)	Number	Percentage
80	23	18.8%
90	3	2.5%
100	67	54.9%
110	29	23.8%
Total	122	100.0%

Table 4.4 shows the crash severity of the centreline cross crashes investigated by crash type. Minor or non injury crashes were relatively rare for all crash types. This is not surprising given to criterion for in-depth crash investigation of ambulance transport. These low severity crashes were most common for left road to the right crashes, making up 18% of all such crashes in the in-depth cases. The proportion of the crashes that required hospital treatment were very similar across all crash types considered, ranging from 27 to 30%. The proportion of crashes that required hospital admission were higher for head on crashes that the left road crashes (34% compared to about 27%). A crash was most likely to be fatal if it was a left road to the left crash (39%). For all crash types at least a quarter of the crashes were fatal.

Table 4.4
Centreline cross crashes by crash type and severity

Crash severity	Left road to the left		Left road to the right		Head on	
	Number	Percentage	Number	Percentage	Number	Percentage
Non injury	1	5.6%	6	10.0%	4	9.1%
Doctor / Minor injury	0	0.0%	5	8.3%	1	2.3%
Treated	5	27.8%	16	26.7%	13	29.5%
Admitted	5	27.8%	16	26.7%	15	34.1%
Fatal	7	38.9%	17	28.3%	11	25.0%
Total	18	100.0%	60	100.0%	44	100.0%

Rollover was common in the run off road to the right crashes investigated with over a third of crashes involving some form of rollover (Table 4.5).

Table 4.5
Rollover occurrence in run off road to the right crashes investigated

Rollover	Number	Percentage
Yes	23	37.1%
No	39	62.9%
Total	62	100.0%

Table 4.6 shows vehicles were much less likely to have departed the road to a minor extent prior to crossing the centreline if a sealed shoulder was present (24% compared to 43%). Note that for the purpose of this table no defined shoulder has been grouped with unsealed shoulder, though only six crashes occurred on a stretch of road with no shoulder. Five cases were not included in this table as they occurred on unsealed roads.

Table 4.6
Prior road departure in centreline cross crashes by shoulder type

Prior road departure	Sealed shoulder		Unsealed shoulder	
	Number	Percentage	Number	Percentage
Yes	7	24%	38	43%
No	22	76%	50	57%
Total	29	100%	88	100%

The effect of prior road departure on the angle at which the vehicles crossed the centreline is shown in Table 4.7. Vehicles that departed the road to a minor extent prior to crossing the centreline had a greater angle at which they crossed the centreline.

Table 4.7
Average centreline cross angle by prior road departure in centreline cross crashes

Prior road departure	Mean	Median
Yes	18.8	18
No	12.7	12.5

4.1.2 Departure displacements and angles

The cumulative distribution of the lateral displacement to the right of the centreline of the 122 centreline cross crashes, disaggregated by crash type are shown in Figure 4.1. Head-on crashes have relatively small lateral displacements. This is to be expected; if a vehicle travels the width of the median (if any) and the oncoming lane it will have avoided a head on crash and will leave the road altogether. Vehicles that left the road to the left had similarly small lateral displacements to head on crashes. These vehicles have crossed the centreline before ultimately departing the road to the left therefore it is also expected that their lateral displacement to the right of the centreline would be not that great. The vehicles that left the road travelled large distances laterally. Approximately half of these vehicles travelled further than nine metres laterally, 20% travelled further than 13 metres laterally and about 10% travelled further than 20 metres.

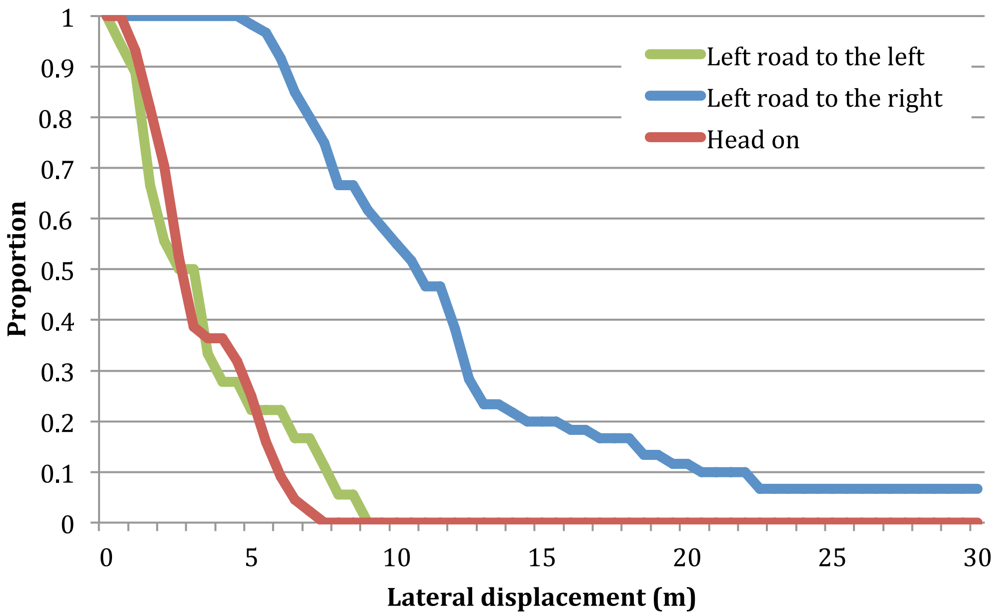

Figure 4.1
Cumulative distribution of lateral displacement to the right of the centreline.

Table 4.8 shows various characteristics of the lateral displacement of the centreline cross crashes by crash type. The difference between the crashes where the vehicle left the road to the right and the head on and left road to the left crashes can be clearly seen. Vehicles that left the road to the right had an average lateral displacement of about 13 metres to right of the centreline. For vehicles that were involved in a head-on or left road to the left crash this value was only 3.3 metres. It is interesting to note that a car can cross the centreline by as little as 0.4 metres and be involved in a head-on crash. One vehicle left the road and travelled as much as 80 metres laterally to the right of the centreline, however this was a single outlying occurrence that explains a large part of the gap between the mean and median values of the crashes where the vehicle left the road to the right. The median values of lateral displacement to the right of the centreline for left road to the right crashes remains much higher than the corresponding value for head on or left road to the left crashes.

Table 4.8
Lateral displacements to the right of the centreline by crash type

	Mean	Median	Min	Max
Left road to the left	3.3	2.5	0.4	8.6
Left road to the right	13.3	10.8	4.9	80.4
Head on	3.3	2.7	0.7	7.3

4.1.3 Departure speeds

Table 4.9 shows the relationship between crash injury severity and the speed at which the vehicle crossed the centreline. It is clear that an increase in departure speed will cause an increase in the injury severity of the crash, regardless of crash type. The mean and median departure speeds at a given injury severity level are consistently higher for crashes where the vehicle left the road than for head on crashes. Of the vehicles that the left the road the ones that departed the road to the left have lower mean or median speeds for crashes where at least one occupant was admitted to hospital or was fatal injured than those that departed the road to the right, but similar speeds for crashes that only required hospital treatment of occupants. It is interesting to note just how low the minimum speeds for the serious or fatal injuries are. A vehicle could cross the centre line at just 44 km/h and at least one occupant be seriously injured upon having a head on crash with an oncoming vehicle. At just 68 km/h this could result in fatal injury. Note that in the case of the head on crashes the speed of the oncoming vehicle is not taken into account in Table 4.9. For crashes where the vehicle left the road these minimum speeds increase to 64 to 69 km/h for serious injury and 83 to 85 km/h for fatal injury.

Table 4.9
Injury severity by departure speed and crash type for centreline cross crashes

Crash injury severity	Left road to the left			Left road to the right			Head on		
	Mean	Median	Min	Mean	Median	Min	Mean	Median	Min
Treated	76	76	70	74	72	59	63	59	52
Admitted	85	90	64	97	100	69	81	82	44
Fatal	101	99	85	106	111	83	94	97	68

4.2 Computer simulation

4.2.1 Wide median scenarios

Figure 4.2 shows a plot of the lateral displacement and speed of the simulated vehicles for the scenario where the driver attempted to recover with steering input only. There is a large amount of variation in the lateral displacement of the vehicles even within a given crash type. The difference in on-road manoeuvre is one of the main contributors to this variation. Vehicles that simply drifted across the centreline are able to begin to recover to the correct side of the road while only travelling a few metres laterally; however the vehicles that lost control (single or double yaw) before crossing the centreline travel between about 20 and 65 metres laterally before recovering. The lateral displacement of vehicles that ultimately departed the road to the left was very small. Only one such vehicle is shown in Figure 4.2 despite three simulations being performed of such crashes as the lateral displacement displayed is based upon the centre of gravity of the vehicle, and the centre of gravity of the other two vehicles did not cross the centreline, despite some of their car having done so. Five of the 12 vehicles would cross a 15 metre median. The speed at which these vehicles would depart the far side of such a median is as high as 87 km/h, and in all cases above 60 km/h.

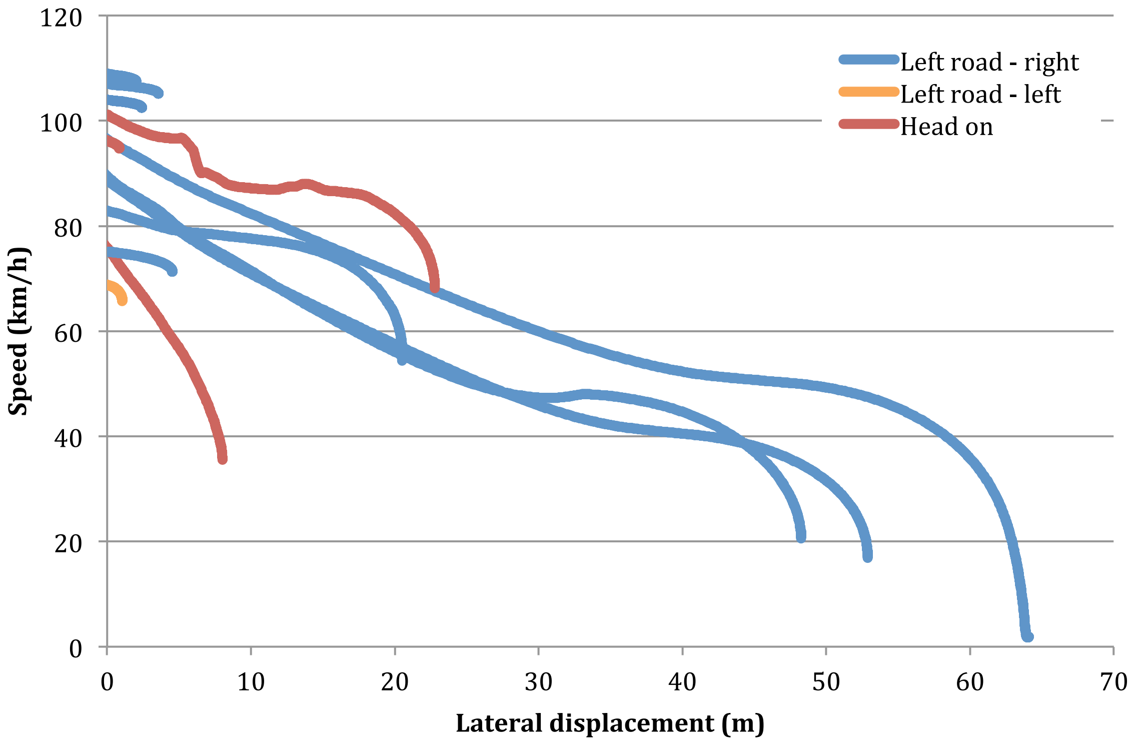

Figure 4.2
Lateral displacement and speed of the vehicle for simulations of centreline cross crashes where the driver attempted to recover with steering input only

The lateral displacements and speeds of the vehicles for the scenario where the driver employed emergency braking are shown in Figure 4.3. The lateral displacements have much less variation than seen when the driver was attempting to recover with steering input (Figure 4.2). In three of the 11 cases shown the vehicle travelled further than 15 metres laterally. The speed at which these vehicles would depart the far side of such a median is as high as 56 km/h and in all cases is above 30 km/h.

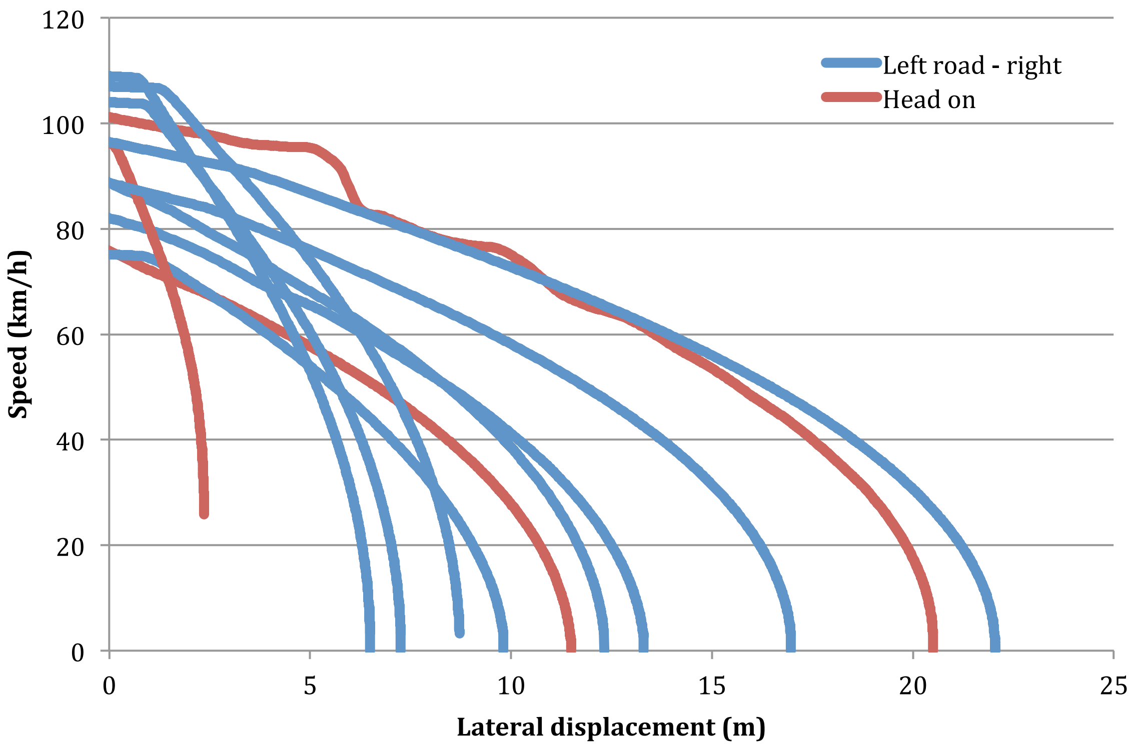

Figure 4.3
Lateral displacement and speed of the vehicle for simulations of
centreline cross crashes where the driver employed emergency braking

Figure 4.4 shows the barrier normal velocity of the vehicles for the simulations where the driver attempted to recover with steering input only, relative to the lateral offset of the barrier from the centreline. Over all the barrier offsets shown the barrier normal velocity remains at a level that should not cause serious injury, though the smaller the lateral offset of the barrier the lower the barrier normal velocity. Increasing the barrier lateral offset would eliminate some of the barrier strikes altogether, though this may not be entirely desirable. For example, the vehicles that ultimately left the road to the left would do so unimpeded if they did not strike the barrier at all; by striking the barrier their speed and finally their departure to the left may be reduced or even prevented.

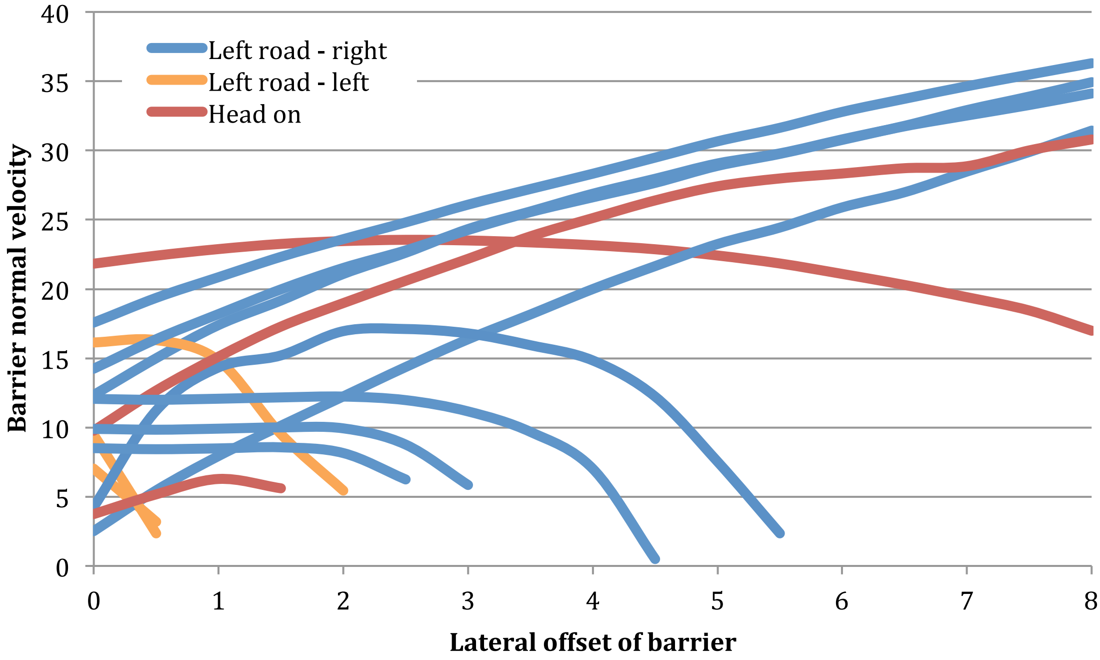

Figure 4.4
Barrier normal velocity relative to barrier lateral offset for
simulations where the driver attempted to recover with steering input only

The barrier normal velocity of the vehicles relative to the lateral offset of the barrier from the centreline for the simulations where the driver employed emergency braking are shown in Figure 4.5. There is little practical difference between the results shown in Figure 4.4, though the maximum barrier normal velocity is reduced. Also, less barrier strikes would be prevented as the barrier lateral offset is increased over the range shown than the scenario where the driver attempted to recover with steering input only.

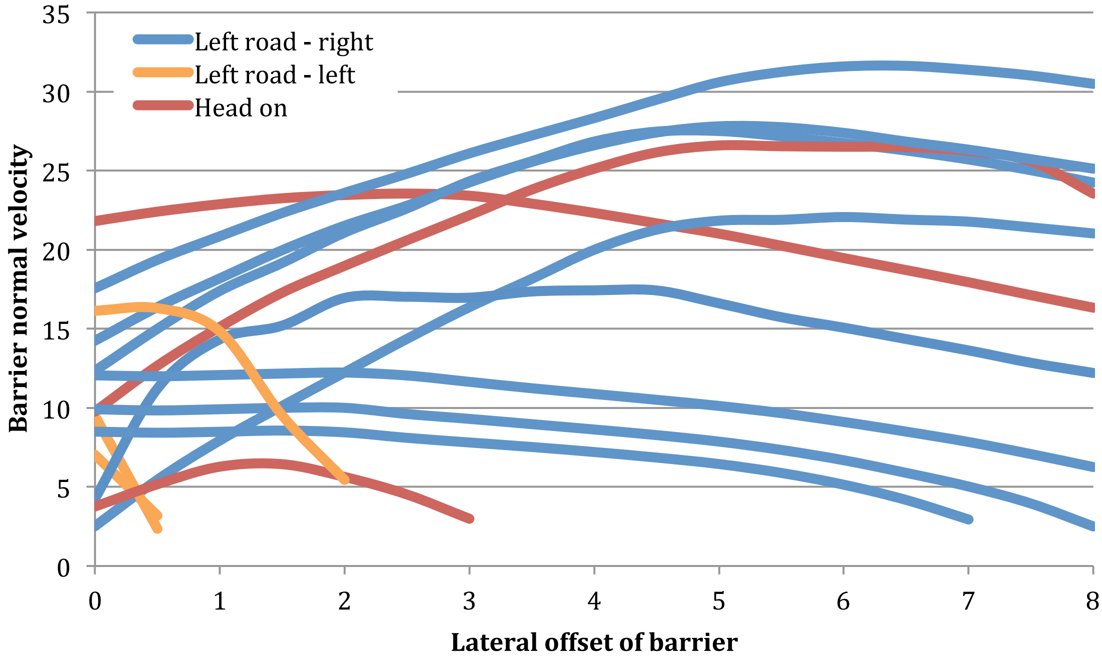

Figure 4.5
Barrier normal velocity relative to barrier lateral offset for simulations where the driver employed emergency braking

5 Discussion

The run off road crashes that were used for this analysis are not a representative sample of run off road crashes in South Australia. The sample is almost entirely made up of crashes where a patient was at least treated in hospital due to the ambulance transport criterion. The few cases that resulted in property damage only were included as the data needed for this analysis had been collected before it was realised that the criterion had not been met for the in-depth crash investigation study. There is also a further bias towards fatal crashes as these cases were investigated regardless of time of day while other cases were only investigated from 0900 to 1630 on weekdays. In the context of a Safe Systems approach, this bias is not important. It is possible that the daytime crashes involved lower speeds when compared to night time crashes but this would require further investigation. A brief analysis of speed survey data from four rural sites showed that during the hours 1700 to 0859 the mean travelling speed was between 1.5 and 3.4 km/h greater than during the hours 0900 to 1659. This slight increase in speed would likely result in a small increase in lateral and longitudinal displacement in the event of a run off road crash. Departure angle may also decrease marginally in loss of control run off road crashes if speed is slightly increased. It should also be noted that the sample size is small.

A high prevalence of rollover crashes in the sample (n=23) points to a significant risk of rollover in a run off road crash. Most of the vehicles in the sample which did not hit a fixed object did rollover. This is not surprising given the criterion of ambulance transport for the in-depth investigations. Given that Viner (1995) found that about 80% of rollovers are initiated by tyre-soil forces it cannot be assumed that wide medians are not hazardous at all.

Almost half of the crashes in the sample occurred on bends yet much less than half of the road network consists of bends, thus there is an overrepresentation of crashes on bends in the sample. This is consistent with the findings of a report on severe and fatal crashes due to roadside hazards in South Australia by Kloeden et al. (1999). Providing adequate protection on bends should therefore be a high priority.

The current guidelines for wide medians in Australia (Austroads, 2009) suggest a median 15 metres wide to allow for the recovery of errant vehicles. Many of the vehicles in the sample of in-depth crash investigations collided with fixed objects within 15 metres of the roadway yet about 13% traversed 15 metres of lateral width from the roadway and had an occupant who needed to be transported to hospital. Of those 10 cases where no fixed object was struck, only five came to rest within 15 metres of the roadway. Given these results it seems likely that many vehicles that leave the roadway would still traverse all of the median. The simulations revealed that wide medians may cater well for vehicles which drift off the road but those that lose control before departing the road will be likely to cross the median. Furthermore, the vehicles that lost control were found to still be travelling at between 55 and 70 km/h after crossing a 15 metre wide median.

Barrier normal velocities of above 50 km/h have been found to be safe, particularly for semi-rigid and flexible barriers (Grzebieta, 2002). The barrier normal velocities in all simulations were below 50 km/h regardless of barrier offset. Small barrier offsets produced the lowest barrier normal velocities unless the barrier offset exceeded 17 metres.

6 Conclusions

On a dual carriageway road a 15 metre median is adequate for drift off crashes but not enough to prevent vehicles that have lost control from crossing the median. For a true Safe Systems approach barrier protection must be considered. The closer the barrier is to the edge of the road, the lower the barrier normal velocity and likely injury outcomes. Given these considerations, the provision of a suitable barrier and barrier offset may be more important than the median width per se.

Median barriers installed on narrow medians (i.e. 4 metres or less) will safely prevent departures to the right. When considering installing a median barrier on single carriageway with a narrow median, the exact barrier offset (and therefore median width) has little effect on the severity of the impact. Little variation in barrier normal velocity was observed in the simulations over the first two metres of lateral displacement.

7 Further work

It is anticipated that continuing work by CASR on this subject will simulate road departures on bends to determine if the conclusions of this report are applicable to bends as well as straight sections of road.

More work is needed to investigate the role of modern median barrier designs in causing rollovers and the relative risk of rollovers in clear zones needs to be established. It could be that rollover risk is higher with clear zones alone.

Only departures to the right have been considered in this report. It is possible that departures that involve multiple yawing events before final departure from the road to the left may be influenced by the presence of a median barrier on a narrow median.

A related topic to the work presented in this report is the use of narrow medians on rural roads without barriers. Future work could examine how effective such medians would by determining the extent to which vehicles encroach into oncoming lanes.

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