



**Improving curve delineation:
A review of the literature and investigation of crashes
on midblock curves in Western Australia 2007-2011**

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Improving curve delineation: A review of the literature and investigation of crashes on midblock curves in Western Australia 2007-2011

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Abstract

Crashes on curves resulting in death and serious injury are generally over-represented for the proportion of the road network curves constitute. Enhancing the delineation of the curve is one of a number of countermeasures that can potentially reduce the likelihood of vehicles failing to maintain lane position on curves, running off the road or colliding head-on with other vehicles. This report describes a range of curve delineation treatments, including low cost effective basic treatments such as pavement markings, post-mounted delineators and Chevron Alignment Markers. Other more advanced treatments, which are higher in cost, were also reviewed. The review noted that the effect of delineation treatments on the reduction in crashes on curves can be as high as 47% for a combination of basic and enhanced delineation treatments. The analysis of crashes on midblock curves in Western Australia 2007-2011 highlighted the involvement of higher speed zones, alcohol and younger, less experienced drivers. The report concluded with the development of a proposed trial of an enhanced Chevron Alignment Marker known as *Chevroflex*. It was recommended that this treatment be trialled at a number of Main Roads WA identified high frequency, horizontal midblock curve crash sites in the South West and Wheatbelt North areas.

Keywords

Curve delineation treatment; single vehicle run off road crashes; head on crashes;

Disclaimer

This report is disseminated in the interest of information exchange. The views expressed here are those of the authors and not necessarily those of Curtin University or Monash University.

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EXECUTIVE SUMMARY

Despite the general improvement in road safety across Australia, certain crash types and scenarios appear more resistant to intervention to counter their contribution to injury. These include single vehicles running off the road, crashes that occur in rural *versus* urban areas, and those involving higher speed zones. One issue common to these crash types and scenarios is the involvement of horizontal curvature of the road.

The overall aim of this study was to recommend specific countermeasures that can be applied and/or trialled in Western Australia to improve the delineation of curves to reduce the incidence of crashes on these road segments. The specific objectives of the study were to:

1. Undertake a review of the published literature on the various initiatives to improve curve delineation and where available, their effectiveness.
2. Provide a summary analysis of Western Australian serious injury crashes relevant to curve delineation.
3. Develop a listing of horizontal curve locations in Western Australian with a comparatively high frequency of crashes for use in the proposed trial of curve delineation treatments.
4. Provide a background and methodology for the proposed trial of a curve delineation treatment.
5. Make general recommendations on initiatives to improve curve delineation on Western Australian roads.

Horizontal curves represent a change in the alignment of the road and represent a demanding driving task. The driver must work to counter the vehicle's natural inclination to travel in a straight and position the vehicle within the lane through the curve, which may be all the more difficult to do if there is inconsistency and unpredictability in the unfolding alignment. Research has shown that when approaching and negotiating a curve drivers direct their vision along the curve to identify roadside cues to help negotiate the road. Thus both 'near' (e.g., pavement markings) and 'far' (e.g., Chevron Alignment Marking boards) treatments (Knapp, 2008) are required to provide early and sufficient perceptual information to the driver to anticipate the change in alignment and degree of curvature

Enhancing the delineation of the curve is widely regarded as a potentially low cost effective treatment, relative to physically realigning the section of road, for improving safety on curves. A number of basic curve delineation treatment options exist and are widely used by

responsible road authorities. Until recently however, little attention had been given to the quantification of the effects of these treatments, singularly or in combination with others, on crashes on curves (Srinivasan et al., 2009). The persistent problem of crashes on curves has thus motivated road authorities and researchers to consider the effectiveness of these treatments, how they can be enhanced, and other experimental delineation treatments.

A number of potential low cost curve delineation treatments were identified, many of which have been shown to be effective as a singular treatment or in combination with other treatments. The most compelling evidence of the effectiveness of delineation treatments on crashes and speeding outcomes included a combination of basic and enhanced treatments such as Chevrons, curve warning signs and flashing roadside beacons. Crash reductions were reported to be as high as 47% for a combination of treatments.

While it is not possible to identify crashes that are a direct consequence of poor delineation on curves, a summary analysis of n=6,741 midblock curve crashes occurring in WA 2007-2011 showed that such crashes are more likely to result in death or serious injury, to occur on roads outside of the metropolitan area, particularly in the South West and Wheatbelt areas of WA. The analyses also highlighted the important involvement of higher speed zones, alcohol, and less experienced, younger drivers in these crashes.

To assist with the development of a proposal to trial a curve delineation treatment, midblock curves (≤ 500 metres in length) with high crash frequencies were identified by MRWA. This resulted in the identification of 61 crash sites State-wide with three or more crashes. The South West and Wheatbelt North were identified as problematic MRWA regions in terms of the number of sites, the number of crashes, the severity of these crashes and the associated cost of crashes. These regions and their sites were subsequently recommended for review for inclusion in an Empirical Bayes investigation of the application of an enhanced delineation treatment, *Chevroflex* Chevron Alignment Markers.

A number of recommendations follow from the information presented in this report.

1. Review of the State-wide use of curve delineation treatments

Recognising the high risk of crashing and serious injury on curves, it is recommended that MRWA consider the implementation of a working group to investigate curve delineation practices and standards across the state. Priority should be given to the audit of roads in the Wheatbelt North and South West because of the relatively higher proportion of crashes on midblock curves in these areas.

2. Dissemination of information to asset owners and managers of the types of delineation practices that can effectively reduce the frequency of crashes and vehicle speeds

There is now a considerable body of research evidence supporting the value of basic and enhanced curve delineation treatment when used in combination. Disseminating this information to asset owners and managers may increase their awareness of the need to focus on curve related crashes and apply for treatment funding under the various Black Spot Treatment programs. Following the outcome of Recommendation 1, this information could be used to work with asset owners to improve the delineation standards if and where necessary

3. Consider the proposed trial evaluation of the *Chevroflex* Chevron Alignment Marker in the identified high crash frequency locations

MRWA has identified a number of problematic regions for midblock crashes on curves. Notwithstanding the need for an audit of these sites to determine if and how they meet the Australian Standard, it is recommended that MRWA consider a trial of the *Chevroflex* Chevron Alignment Marker at the identified high crash frequency sites as an alternative to the standard steel post installation.

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1. INTRODUCTION

The rate of road-related death and serious injury in Australia has steadily declined over time against the trend of increases in both population and the number of registered vehicles. Over the period 1970 to 2008, the fatality rate per 100,000 population declined from 30 to 6.9 persons, while the rate per 10,000 registered vehicles declined from 8.0 to 1.0 person (BITRE, 2010). Similarly the rate of serious injury over the period 1980 to 2006 declined from 218.0 persons per 100,000 population and 42.3 persons per 10,000 registered vehicles in 1980 to 155.9 per 100,000 population and 22.5 per 10,000 registered vehicles (BITRE, 2010). These figures suggest that nationally, road travel and road use has become progressively safer.

Despite the general improvement in road safety across Australia, certain crash types and scenarios appear more resistant to intervention to counter their contribution to injury. These include single vehicle run off road crashes (BITRE, 2011; BITRE 2012), crashes that occur in rural *versus* urban areas (see Palamara, Kaura & Fraser, 2013 for a review), and those involving higher speed zones (BITRE, 2012). One issue common to the discussion of the preceding crash types and scenarios is the risk associated with horizontal curves (e.g., see Johnston, Corben, Triggs, Candappa & Lenne, 2006; Meuleners, 2009; Palamara, Broughton & Fraser, 2012; Oxley et al., 2004; Parliament of Victoria, 2005; Tziotis, Roper, Edmonston & Sheehan, 2006). While more single vehicle crashes occur on straight sections of roads, such crashes are thought to be over-represented on horizontal curves for the proportion of curved versus straight sections of road network (Oxley et al., 2004).

In Western Australia in 2010, 36.4% of fatal crashes and 20.8% of hospitalisation crashes occurred on curved sections of road (Hill, Thompson, Yano & Smith, 2012). Other analyses of Western Australian killed and serious injury crashes for the period 2005-2009 found that 23.1% of these crashes occurred on horizontal curves, with crashes on curves twice as likely to occur in the regional (35.8%) and remote areas (32.4%) of WA compared with the metropolitan area (17.6%) (Palamara et al., 2013). Even after adjusting for the number of vehicles involved in the crash, the road surface, and the posted speed limit, killed and serious injury crashes in the regional and remote areas of WA were twice as likely to occur on a horizontal curve compared with those occurring in metropolitan Perth (Palamara et al., 2013). This

finding is reasonably consistent with that observed by Sauerzapf and Jones (2011) who investigated the association between bend density on WA local government area roads and the incidence of fatal and serious injury crashes. The authors reported that rural (non-metropolitan) local government areas with the highest bend densities had a greater proportion of fatal and serious injury crashes occurring on bends. In contrast, they found that horizontal curvature on metropolitan local government areas was protective: there were fewer serious and minor injury crashes on metropolitan areas with the highest bend densities (Sauerzapf & Jones, 2011).

One immediate explanation for the variable relationship between bend density and crash occurrence across the metropolitan and rural local government areas is that operating speeds on metropolitan curves are on average likely to be lower than those on non-metropolitan curves. Oxley et al. (2004) noted that the risk of the vehicle leaving the road and crashing on the curve is increased if the vehicle speed on approach or in the curve is greater than that for which the road is designed. Other researchers have reported that up to 72% of crashes on curves can be attributed to excess speed and/or steering error (Milleville-Pennel, Jean-Michel, & Elise, 2007). In one study by Preston and Schoenecker (1999) of the association between the speed at which a driver enters a curve and their ability to successfully navigate the curve it was shown that the initial speed of a vehicle has a statistically significant effect on whether or not successful navigation occurs. Drivers who drove lower than or equal to the designated speed limit were 20% more likely to be successful in navigating the curve. Similarly, those who drove above the designated speed limit were more likely to be unsuccessful (Preston & Schoenecker, 1999).

Inappropriate operating speed is just one of a number of factors thought to increase the risk of a crash on a horizontal curve. Many risk and environmental factors increase the possibility of a curve related crash, in particular wet road surfaces, unprotected roadsides, and narrow shoulder width (Chen, Rakotonirainy, Loke, & Krishnaswamy, 2007). Curve characteristics such as length and degree of the curve (Chen et al., 2007; Chen, Rakotonirainy, Sheehan, Krishnaswamy, & Loke, 2006), surface friction, superelevation and sight distance also contribute to crash risk (Chen et al., 2007). Sight distance has also been shown to be a significant determinant in speed choice on road curves (Kanellaidis, 1995). Schneider, Savolainen and Zimmerman (2009) found that injuries were more likely on moderate radius curves

between 500ft – 2,800ft, but small radius curve crashes more often involved older drivers. However, changing curve radius or improving superelevation to increase curve safety are usually not viable options (Reddy, Datta, Savolainen, & Pinapaka, 2008) due to cost and time constraints.

Initiatives to counter crashes and injuries on curves are focussed on how best to reduce the likelihood of the vehicle leaving the road, and secondly, how to minimise the risk of injury should the vehicle leave the road (Johnston et al., 2006). This report is concerned with one initiative of the former group: how best to improve the delineation of the curve to enable the driver to safely negotiate it at the appropriate speed within the vehicle's designated lane. As drivers require and use extensive visual information to position and control their vehicle, the delineation of curves conveys important information to the driver to assist with the positioning of their vehicle on the roadway and to make navigation and control, including speed, decisions (Montella, 2009).

1.1 Aims and Objectives

The overall aim of this study was to recommend a specific countermeasure that can be trialled in Western Australia to improve the delineation of curves to reduce the incidence of crashes. The specific objectives of the study were to:

1. Undertake a review of the published literature on the various initiatives to improve curve delineation and where available, their effectiveness to reduce crashes.
2. Provide a summary analysis of Western Australian crashes relevant to curve delineation.
3. Identify and provide a summary analysis of horizontal curve locations in Western Australian with a comparatively high frequency of crashes.
4. Provide a background and methodology for a proposed trial of a curve delineation treatment at sites identified to have a high crash frequency.
5. Make general recommendations on initiatives to improve curve delineation on Western Australian roads.

2. METHODOLOGY

2.1 Ethics

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

- the relationship between horizontal curvature of the road and the driving task;
- relevant curve delineation treatments; and,
- the effect of curve delineation treatments on crashes.

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.

2.3 The analysis of Western Australian motor vehicle crashes relevant to curve delineation

2.3.1 All crashes on midblock curves 2007-2011

Motor vehicle crash records in Western Australia lack specific information on the contribution or absence of curve delineation treatments to the circumstance of the crash. However, there are various types of crashes based on vehicle Road Use Movement (RUM) codes that imply a failure of drivers to maintain lane position and control of the vehicle. A number of factors *may* contribute to this, one of which is the inadequate delineation of the curve. Examples of these crashes at *midblock curves* include:

- (i) Vehicles running off the road to the near or far side.
- (ii) Vehicles from opposing directions colliding head-on.

These crash types were the main focus of analysis for this project.

Police recorded crashes in Western Australia for the period 2007-2011 were extracted by Main Roads Western Australia (MRWA) from their Integrated Road Information System (IRIS). A total of n=423,652 individual unit records relating to n=197,406 crashes of *all types* were initially retrieved for the period. The dataset

was subsequently reduced to n=7,562 individual unit records across n=6,741 recorded *crashes on midblock curves* (gazetted public roads) involving drivers of passenger vehicles, trucks and buses, and riders of motorcycles, trail bikes and mopeds where the vehicle ran off the road on a right hand or left hand bend (RUM codes 81-84) or collided head on (not during overtaking) with another vehicle (RUM code 21). These crashes accounted for 3.4% of all crashes reported to WA Police for the period 2007-2011.

For the selected crashes a range of descriptive, univariate analyses were undertaken of crash, road, vehicle and driver factors. In addition to this, multivariate analysis was undertaken to identify the factors associated with the severity of the selected crashes on midblock curves.

2.3.2 Midblock curves in Western Australia with high crash frequencies 2007-2011

In consultation with MRWA, criteria were developed for the identification of midblock curves in Western Australia with relatively high single vehicle crash frequencies for the period 2007-2011. This dataset was extracted to provide a list of potential sites for the trial of a selected curve delineation treatment. The selection of midblock crash sites was restricted to those:

- ≤ 500 metres in length from the beginning to end of the Straight Line Kilometre markers for the curve, and,
- with three or more police reported single vehicle crashes – all severities - in the six year period.

This data was extracted using various MRWA datasets. Costings were also supplied for the average crash type and severity of crashes. A total of 61 midblock crash sites met the criteria for inclusion. For the selected crashes a range of univariate analyses were undertaken to describe these high crash locations.

2.4 Structure of the report

Chapter Three provides background information on the driving task, horizontal curves, and the need for curve delineation. This is followed in Chapter Four with a review of basic and advanced curve delineation treatments and where available, the known effectiveness of treatments to reduce crashes. Chapter Five details the findings and discussion of the analysis of all crashes on midblock curves in Western

Australia, 2007-2011. Chapter Six provides a description of the identified 61 sites for potential curve delineation treatment. Also included in this chapter are a description of a selected curve delineation treatment for trialling and an outline of the proposed trial methodology. Chapter Seven concludes the report with a summary and recommendations for further research and initiatives for curve delineation practices.

3. SAFE OPERATING PRACTICE AND THE NEED FOR CURVE DELINEATION TREATMENTS

The driving task is a highly visual one; it requires that drivers be provided with clear and appropriate information about the road and the driving environment to guide the safe operation of their vehicle (Russell, 1998). The human factors concepts of driver expectancy and consistency and positive guidance relate to the safe operation of a vehicle and underline the necessity of effective curve delineation practices. The following summary of these issues draws on the critiques provided by Russell (1998) and Knapp (2008).

3.1 Drive expectancy and consistency

The concept of self-explaining roads promote the idea that road design should be sufficiently simplistic and consistent to reduce driver stress and error in regards to what to expect and how drivers should ‘behave’ (European Commission, nd). The concept proposes that the road should be perceived by the driver in such a way that the driver *intuitively* knows how to behave – presumably because of past experience with roads that are consistently similar in design and feature (European Commission, nd). As Russell (1998 page 156) explains, “..inconsistencies violate a driver’s expectancy; thus either the road should be made more consistent, which may be impractical, or something should be done to change the driver’s expectancy”. Road signage and markings function to reduce the uncertainty about the road environment by creating an expectation of what to expect, for example, that a sharp curve is ahead, and how to respond, i.e., the speed at which the curve should be negotiated.

3.2 Positive guidance

Road signage and markings effectively provide positive guidance to the driver in relation to how to behave for the given road condition and to negate a potentially hazardous situation (Russell, 1998). This assumes that when armed with the necessary information drivers will make a rational and reasoned decision to drive accordingly to reduce their risk of crashing and injury. In relation to horizontal curves and delineation treatments, signage and road markings can improve the driver’s recognition of the existence of the curve and its sharpness and thus help them position and control their vehicle on the approach to the curve and through it without misadventure (Knapp, 2008).

3.3 The need for effective curve delineation treatments

Horizontal curves represent a change in the alignment of the road and typically increase the demands on the driver. The driver must work to counter the vehicle's natural inclination to travel in a straight line and maintain the vehicle within the lane through the curve (Oxley et al., 2004) which may be all the more difficult to do if there is inconsistency and unpredictability in the unfolding alignment (Oxley et al., 2004). Research has shown that when approaching and negotiating a curve drivers direct their vision along the curve to identify roadside cues to help negotiate the road (Shinar, McDowell & Rockwell 1977 cited in Knapp, 2008). Thus both 'near' (e.g., pavement markings) and 'far' (e.g., Chevron Alignment Marking boards) treatments (Knapp, 2008) are required to provide early and ongoing perceptual information to the driver to anticipate the change in alignment and degree of curvature (Srinivasan et al., 2009).

Relative to physically realigning the section of road, enhancing the delineation of the curve is widely regarded as a potentially low cost effective treatment (Srinivasan et al., 2009). A number of basic curve delineation treatment options exist and are widely used by responsible road authorities. Until recently however, little attention had been given to the quantification of the effects of these treatments, singularly or in combination with others, on crashes on curves (Srinivasan et al., 2009). The persistent problem of crashes on curves has thus motivated road authorities and researchers to consider the effectiveness of these treatments, how they can be enhanced, and other experimental delineation treatments to reduce crashes on curves.

4. CURVE DELINEATION TREATMENTS

This chapter summarises various basic and enhanced curve delineation treatments and provides information where available on their effectiveness. The intention of this section is not to summarise curve delineation practices in Western Australia or to report on the extent of application of the identified delineation treatments on the Western Australian road network. These tasks are beyond the scope of this study as it would require considerable assistance from Main Roads Western Australia (MRWA) and the use of their databases to identify and classify the various delineation treatments across the road network.

MRWA's curve delineation practices are principally based on those detailed in the Australian Standard *Manual of uniform traffic control devices – Part 2: Traffic control devices for general use* [AS 1742.2-2009] (Standards Australia, 2009). MRWA's preferred practice which deviates from AS 1742.2-2009 are detailed on-line (see www.standards.mainroads.wa.gov.au).

4.1 Basic delineation treatments

The objective of all delineation treatments is to provide adequate information to drivers/riders to minimise human error and crash risk (Wegman & Slop, n.d.). The enhanced delineation of a curve provides the driver with a more informed view of the curve on the approach tangent, and secondly, as the driver traverses the curve, it provides a continuous feature to assist the driver in the positioning of their vehicle in the lane. Basic delineation treatments include those such as pavement markings, static signs, Chevron Alignment Markers (CAM), and post-mounted delineators. It should be noted that the most effective way of reducing run-off-road crashes on curves may be to apply delineation treatments in combination rather than individually. This was noted in the safety action plan implemented in Douglas County, Georgia (Anderson, Yunk, Lovas, & Scism, 2010).

4.1.1 Edge and centre lines and improved road markings

Pavement markings for delineation typically consist of painted edge and centre lines. These markings are the most universally used delineation treatment (Chrysler, Re, Knapp, Funkhouser & Kuhn (2009). A meta-analysis conducted by van Driel, Davidse and van Maarseveen (2004, p1) of studies of the effect of edgelines concluded "...applying an edgeline to a road without a centreline increases the speed

of road users, and replacing a centreline by an edgeline decreases the speed..”. However, other studies review by Chrysler et al. (2009) showed that when an edgeline is present, drivers generally move away from the edgeline and maintain a more central lane position when. In one particular study by Sun et al. (2005 cited in Chrysler et al., 2009) the addition of an edgeline did not significantly increase the mean speed of vehicles.

Variation in the width of edgelines has also been investigated with mixed results (Chrysler et al., 2009). Overall, research tends to suggest that wider edgelines (for example 20 centimetres versus 10 centimetres) has the effect of moving drivers close to the centreline without any additional centreline encroachment (Chrysler et al., 2009). In general, there is good evidence to show that having edgelines can reduce crash frequency particularly on narrow roads and at night. However, there appears to be less convincing evidence that substantially increasing the width of edgelines significantly impacts of crash frequency (Chrysler et al., 2009). Additional research undertaken by Chrysler et al. (2009) concluded that vertical delineation through edgelines and centrelines generally improves vehicle positioning upon entry to and the midpoint of the curve, thus facilitating safe negotiation of the curve.

4.1.2 Static signs

Static road signs have two main functions: to warn drivers of upcoming hazards (warning signs) and/or to advise the driver how to approach the hazard (advisory signs). In a survey of seven US states conducted by Slusher and Duncanson (2011), signage was heavily used to improve curve delineation. The Mendocino County Department of Transportation reduced its crash rate by 42.1% over a six year period through the use of effective signs, with a benefit cost ratio of 159-299:1 (Ford & Calvert, 2003).

Warning signs

Warning signs on curves are often used to notify drivers of changes in horizontal alignment and may be used alone or as a supplement to curve speed advisory signs (U.S. Department of Transportation, 2009). Advanced curve warning signs are reported to have a Crash Reduction Factor (CRF) of 30% (Federal Highway Administration [FHWA], 2008). McGee and Hanscom (2006) reported that such signs can reduce crashes by up to 18%. In contrast, Charlton (2007) considers the safety effects to be poor, possibly due to their overuse or inattention by drivers (Charlton, 2007).

Curve speed advisory signs

Curve speed advisory signs are used to advise drivers that there is a curve ahead. In a study of 22 countries, Donald (1997) reported that while all countries surveyed used curve *warning* signs, curve speed *advisory* signs were utilised to varying extents. Studies have reported mixed evidence for the effect of curve speed advisory signs on driver behaviour and crashing. Studies in New Zealand have shown that drivers consistently drove between 10-28km/h above the curve advisory speed (Bennett & Dunn, 1994), a characteristic which is likely to increase the likelihood of a crash. Familiarity of roads may be a contributing factor to such behaviour (Bonneson, Pratt, Miles, & Carlson, 2007). The findings from driver focus groups studied by Lyles and Taylor (2006) confirm that familiarity with the roads contributes to drivers exceeding the advisory speed. However, as with most focus groups, group size was small and therefore not representative of the population as a whole. More recently, a simulator experiment conducted by Jamson, Lai and Jamson (2010) found that static signs with advisory speed limits, and static signs with a generic “reduce speed now” sign reduced vehicle speeds by 41% and 40%, respectively, compared to the baseline (no signage) speed.

In relation to crashes, one study reported a 36% reduction in the number of crashes when curve speed advisory signs were used (American Traffic Safety Services Association [ATSSA], 2011). Black spot treatment evaluations report an estimated 30% reduction in crashes (Andreassen, n.d.).

4.1.3 Chevron alignment markers

Chevron Alignment Markers (CAMs) are more suited to the curve discovery period, where drivers have less time to focus on information in the form of text, and are more adequately provided information through conspicuous (Campbell, Richard & Graham, 2008) and regularly placed signage to aid in perceptual processing (Wegman & Slope, nd). McGee and Hanscom (2006) consider that CAMs “..define the direction and sharpness of the curve best of all the traffic control devices” (p. 14). Cost varies with the number of signs installed and can range between \$30-50 per sign (McGee & Hanscom, 2006; Sperry, Latterell, & McDonald, 2008).

Crash Reduction Factors of 35% have been reported (FHWA, 2008). Varying crash reduction levels have been reported in the literature in regards to the implementation of CAMs. The ATSSA (2008) reported a 33-49% crash reduction. Similarly, Sperry et al. (2008) reported that chevrons can reduce all crash types by up to 35%. In a study by Montella (2009) the installation of chevron signs alone was associated with a decreasing but non-significant the number of crashes. However, when combined with curve warning signs, daytime, run off road, rainy and property damage only crashes were significantly reduced by 40.8%. All crash types were significantly reduced by 47.6% when CAMs and curve warning signs were coupled with flashing beacons (Montella, 2009).

The Roads and Traffic Authority (RTA) of New South Wales (2009) suggest the use of CAMS if guide posts, curve, and advisory speed signs do not provide sufficient information to the driver. Zegeer et al. (1990) suggests CAMS are most effective at sites with a high night-time accident rate. In their review of the literature Zegeer et al. (1990) found that to be effective, more than three chevrons should be used on a curve of seven degrees or more. In America, studies have shown that night-time run off road crashes were reduced by 32-49% when chevrons were used as a countermeasure (Zegeer et al., 1990).

Further, CAM's are recognised as the most effective delineation treatment for curve speed reduction (Charlton, 2007; Re, Hawkins, & Chrysler, 2010) due to the perceptual guidance provided to the driver.

4.1.4 Post-mounted delineators

Post mounted delineators (PMDs) are used to indicate an unexpected change in road alignment (Chen, Rakotonirainy, Sheehan, Krishnaswamy, & Loke, 2006) and are thought to be most effective at night (McGee & Hanscom, 2006; Zegeer et al., 1990) and during adverse weather conditions. As a relatively low cost basic delineation treatment (McGee & Hanscom, 2006), PMDs are more effective on curves less than five degrees compared to chevrons (Zegeer et al., 1990). In contrast Sperry et al. (2008) note that simple PMD delineators are not effective substitutes for chevrons on curves.

Simulator experiments conducted by Godley, Fildes, Triggs and Brown (1999) to evaluate the effect of perceptual countermeasures (PCMs) on driver behaviour showed that enhanced post layout on the outside of a left curve caused a decrease in vehicle speeds. Similarly, when post height ascended along the curve speed reductions were noted on left and right hand curves, although the left curve speed reduction was somewhat less than when post height was not incrementally increasing (Godley et al., 1999). Further on-road analysis of the two most effective PCMs investigated the effectiveness of enhanced post-spacing at road curves (Fildes et al., 2005). Results showed negligible short term speed reductions compared with speeds 1 month prior to the introduction of the countermeasure but considerable long term speed reductions at three of the six sites one year after the introduction of the countermeasure introduction, no effect at two sites, and a speed increase at one site (Fildes et al., 2005). Finally, the ATSSA (2008) report a 58% reduction in Run Off Road (ROR) crashes through the use of PMDs.

4.2 ENHANCED BASIC TREATMENTS

Enhanced curve delineation treatments represent modifications to basic treatments to aid earlier detection of the hazard curve to improve lane positioning and speed.

4.2.1 Reflectivity

Road signs made with highly retro-reflective material improved night-time visibility (McGee & Hanscom, 2006). Additional retro-reflective material can be added to already existing chevrons for a low cost, (Hallmark, Hawkins, & Smadi, 2012). Sign upgrade programmes adding reflective materials implemented by four US states noted crash reductions of 30% in Iowa, 42% in Mendocino County, and 25% in

Putnam County, with benefit cost ratios of 33.95:1, 159-299:1 and 1.16:1 respectively, (Ripley, 2005). Chrysler et al. (2009) found that adding retro-reflective sheeting to the chevron post had no improved effect on driver speed than that of a normal chevron, while Srinivisan et al. (2009) noted a reduction in crashes in their study through the addition of retro-reflective material to pre-existing signs.

4.2.2 Frangible materials

Manufacturing certain delineation treatments such as signs from wholly frangible materials can decrease the risk of injury for road users should they impact with the treatment. Examples of this include flexible guideposts and Chevrons. Two products from the UK manufacture, Glasdon (see www.glasdon.com) exemplify the use of these materials in guideposts and CAMs. Flexmaster and Vergemaster are flexible hazard marker guide posts with and without beacon lighting that have a 'knock down-spring back capacity' in the event of collision. It is reported to be particularly motorcycle friendly though no injury reduction data has been presented. Similarly, Glasdon manufacture *Chevroflex Ultra*, which is a flexible 'knock down-spring back' CAM inserted flush with the ground, which thus negates the use of infrangible upright steel posts and minimises the risk of injury to road users, particularly motorcyclists, in the event of a collision. No information could be found on the trial application and effectiveness of these products.

4.2.3 Raised pavement markers

Raised pavement markers are delineation devices used along centre or edgelines to supplement pavement markings (McGee & Hanscom, 2006). This treatment provides a longer range of visual delineation for the driver and are said to be particularly effective in aiding navigation at night and during adverse weather if reflective materials are used (Bahar et al., 2004; McGee and Hansom, 2006). Bahar et al. (2004) summarised studies on the safety effectiveness of permanent RPMs. Interestingly, while few studies found a decrease in crash rates, many found significant increases in night-time crashes and reason to question the benefits for the use of RPMs on sharper curves (Bahar et al., 2004; Smiley, Bahar, & Persaud, 2004; Torbic et al., 2004). Other reviews indicate that RPM reduce the amount of variation in lane position, assisting vehicles to move away from the centre line. Crash reduction factors of up to 24% have been reported by the FHWA (2008).

4.2.4 Flashing beacons

Flashing beacons placed at the entry to and along the curve have the capacity to increase early visibility of the hazardous curve but is known to be an expensive method for improving delineation as constant power is required unless they are solar powered (around \$1000 plus additional running costs) (Sperry et al., 2008). However, the reported crash reduction factor is very good, up to 30% (Sperry et al., 2008). Where other treatments have not improved safety, flashing beacons may provide useful, though expensive, treatment (McGee & Hanscom, 2006). Sequential flashing beacons were one of a suite of delineation treatments evaluated by Montella (2009) and found to be most effective (up to 47.6% crash reduction at 12 months post installation) when used in combination with curve warning signs and CAM along the curve.

4.2.5 Transverse rumble strips

Transverse and centre line rumble strips have the potential to provide additional auditory information to the driver regarding the sharpness of the curve and their encroachment on the centre line (as noted in head-on collisions in curves). Although thought not to be effective on large radii curves with slow speed limits transverse, rumble strips have been found to be particularly effective in reducing driver curve approach speeds on low curviness curves with reduced sight distance. (Lank & Steinauer, 2011).

4.2.6 Dynamic curve warning systems

Vehicle activated dynamic curve warning systems detect the speed of advancing vehicles on the approach to a curve and consequently advise the driver to slow down to a more appropriate speed (McGee & Hanscom, 2006). One investigation of this treatment noted that the overall impact on vehicle speeds were minimal (Preston & Schoenecker, 1999). McGee and Hanscom (2006) report however, that these systems *can* reduce vehicle curve speeds though the cost of dynamic curve warning systems is much higher than static curve speed advisory signs and can range from, but not limited to \$18,000 - \$61,000 per installation.

Despite the cost, dynamic curve warning systems are of a renewed interest in road safety. One project in particular aims to report on the effectiveness of Sequential Dynamic Curve Warning Systems (SDCWS) on rural roads and horizontal curves in

Missouri, Texas, Washington and Wisconsin (FHWA, 2011). The system consists of a series of solar-powered, programmable and vehicle activated LED-enhanced chevron signs which blink as a vehicle traverses the curve, to warn drivers to slow down (FHWA, 2011). The first year evaluation report was expected by January 2013 but has not been located.

4.3 Concluding Comments

In summary, curve delineation treatments consist of universal and basic treatments such as pavement markings, post-mounted delineators, and CAM. Some of these treatments have been noted to enhance early detection of the hazardous curve and to improve awareness of the sharpness of the curve, reduce speed and crashes, and reduce the risk of injury. There is a significant body of research into delineation treatments with most having been evaluated in combination with others rather than singularly. This perhaps underlines the philosophy that delineation treatments should, where possible, be applied in a suite of initiatives. Summarising the effectiveness of any single treatments is thus difficult and is complicated further by the variation across studies in study design, aims, road geometry and driver behaviour. Nevertheless, the following information is presented as a guide to effectiveness of the combination of delineation measures on crashes.

Table 4.1 Estimated crash reductions associated with various curve delineation treatments

Treatment	% Reduction in Crashes
a) Chevron Alignment Marker	16*
b) Chevron Alignment Marker, Curve Warning and Sequential Flashing Beacon	38-43* to 47**
c) Fluorescent curve signs	25*

*FHWA (nd); ** Montella (2009)

5. DESCRIPTION OF MOTOR VEHICLE CRASHES IN WESTERN AUSTRALIA 2007-2011 RELEVANT TO CURVE DELINEATION

This chapter presents the findings and discussion of the analysis of n=6,741 police reported *crashes on midblock curves* occurring on Western Australian roads 2007-2011 involving drivers of passenger vehicles, trucks and buses, and riders of motorcycles, trail bikes and moped. These crashes involved vehicles running off the road on a right hand or left hand bend (RUM codes 81-84; n=6,067; 90%) or colliding head on (not during overtaking) with another vehicle from the opposite direction (RUM code 21; n=674; 10%). The selected crashes accounted for 3.4% of *all crashes* reported to WA Police during the period 2007-2011.

5.1 Crash severity

The frequency of the severity of the selected midblock curve crashes is presented in Table 5.1. Just under two-thirds of crashes resulted in property damage only, with around 21% of crashes resulting in the death or hospitalisation of an involved road user. The latter proportion is substantially higher than the 5.8% observed for *all crash types* for the period.

Table 5.1 Severity of RUM code crashes 21 and 81-84 on midblock curves; Western Australia, 2007-2011

Crash Severity	n	%
Fatal	239	3.5
Hospitalised	1180	17.5
Medical Treatment	996	14.8
Property Damage Only - <i>Major</i>	3630	53.8
Property Damage Only - <i>Minor</i>	696	10.3
Total	6741	100.00

5.2 Location

Approximately half of the selected midblock curve crashes occurred in the metropolitan Perth region. Of the remainder, around 34% occurred in the regional areas of Western Australia and 16% in remote Western Australia. The distribution of selected crashes in the non-metropolitan area is substantially higher than that observed for *all crash types* recorded during the same period: 50% *versus* 16.7%.

Table 5.2 Location of RUM code crashes 21 and 81-84 on midblock curves; Western Australia, 2007-2011

Location	n	%
Metropolitan	3367	49.9
Regional	2275	33.7
Remote	1099	16.3
All	6741	100

Further analysis of the crashes occurring in the regional and remote areas of Western Australia showed a high proportion of crashes on midblock curves in the South West (18.9%) followed by Wheatbelt North (9.2%) regions. These two regions accounted for 56% of the selected crashes on midblock curves occurring in the non-metropolitan area.

Table 5.3 Region of RUM code crashes 21 and 81-84 on midblock curves; Western Australia, 2007-2011

Region	n	%
Metropolitan	3367	49.9
Gascoyne	49	0.7
Goldfields-Esperance	205	3.0
Great Southern	321	4.8
Kimberly	109	1.6
Mid-West	279	4.1
Pilbara	222	3.3
South West	1275	18.9
Wheatbelt North	621	9.2
Wheatbelt South	293	4.3
All	6741	100

5.3 Road ownership

Approximately 67% of selected crashes on midblock curves occurred on roads owned/managed by local government and 33% on roads owned/managed by State or federal government.

Table 5.4 Road ownership for RUM Code 21, 81-84 crashes on midblock curves ; Western Australia, 2007-2011

Road owner	n	%
Local government	4520	67.2
State / Federal government	2204	32.8
All	1828	100

n = 17 missing road ownership

5.4 Road surface

Nearly nine in ten selected crashes on midblock curves occurred on roads with a sealed surface. Crashes on *unsealed* midblock curves were proportionally greater in the non-metropolitan area (22.9%) versus the metropolitan area (1.5%). These proportions are likely to be consistent with the distribution of sealed and unsealed roads across Western Australian road network.

Table 5.5 Road surface for RUM code crashes 21 and 81-84 on midblock curves; Western Australia, 2007-2011

Road surface	n	%
Sealed road	5862	87.8
Unsealed road	815	12.2
All	6677	100

n = 64 missing road surface

5.5 Vehicle type

Around 90% of crashes on midblock curves involved a passenger vehicle, with motorcycles, moped and trail bikes accounting for a further 6% of crashing vehicles. Motorcycles and derivatives accounted for a higher proportion of crashing vehicles in the metropolitan (6.4%) and regional (6.85) areas versus remote area (3.3%), while trucks and heavy vehicles accounted for a substantially higher proportion of crash involved vehicles in the remote (28.8%) area versus the regional (4.6%) and metropolitan areas (1.9%).

Table 5.6 Vehicle type for RUM code crashes 21 and 81-84 on midblock curves; Western Australia, 2007-2011

Vehicle type	n	%
Passenger car	6778	89.6
Motorcycle / moped / trail bike	430	5.7
Bus	25	0.3
Truck/Heavy Vehicle	329	4.4
All	7562	100

5.6 Lighting

The majority of selected crashes on midblock curves occurred during daylight hours (50.6%) with a further 19% occurring at night when no street lighting was available or operating. Somewhat expectedly, crashes on midblock curves when no lighting

was operating or available were more frequent in remote (22.9%) and regional (25.3%) areas compared with metropolitan Perth (13.5%).

Table 5.7 Lighting for RUM code crashes 21 and 81-84 on midblock curves; Western Australia, 2007-2011

Light condition	n	%
Daylight	3318	50.6
Dawn or dusk	428	6.5
Dark – street lights on	1568	23.9
Dark – streets lights off	77	1.2
Dark – no street lights available	1169	17.8
All	6560	100

n = 181 missing light condition

5.7 Posted speed limit

No information on the posted speed limit at the location of the selected crashes on midblock curves was available for nearly one in five crashes. As shown in Table 5.8, just over 50% of crashes in known speed zones occurred in zones of 80km/hour and higher with crashes at the open speed limit of 110 km/hour (28.4%) most common. As to be expected, substantially more crashes occurred on midblock curves with higher posted speed limits (80+ km/hour) in regional (74.2%) and remote (79.8%) Western Australia compared with metropolitan Perth (27.1%).

Table 5.8 Post speed limit for RUM code crashes 21 and 81-84 on midblock curves; Western Australia, 2007-2011

Speed limit	n	%
≤40	59	1.2
50	1306	25.8
60	716	14.1
70	423	8.3
80	577	11.4
90	255	5.0
100	292	5.8
110	1440	28.4
All	5068	100

n = 1673 missing speed limit

5.8 Age of driver/rider

The age of drivers/riders involved in a midblock curve crash during the study period is presented in Table 5.9. Drivers/riders aged 16-24 and 25-39 years accounted for

around seven in ten drivers/riders crashing on midblock curves. Older age drivers aged 60+ years accounted for 6% of crashing drivers/riders.

Table 5.9 Age of drivers/riders involved in RUM code crashes 21 and 81-84 on midblock curves; Western Australia, 2007-2011

Age Category (years)	n	%
16-24	2760	39.8
25-39	2248	32.4
40-49	938	13.5
50-59	574	8.3
60-69	281	4.0
70+	138	2.0
All	6939	100

n = 623 missing or under legal driving age (16 years)

5.9 Gender of driver/rider

As shown in Table 5.10, male drivers/riders accounted for nearly three-quarters of those involved in a midblock curve crash during the study period.

Table 5.10 Gender of driver/rider involved in RUM code crashes 21 and 81-84 on midblock curves; Western Australia, 2007-2011

Road surface	n	%
Female	1951	27.0
Male	5282	73.0
All	7233	100

n = 329 missing driver/rider gender

5.10 Alcohol

The validity of the following information (Table 5.9) on the involvement of the Blood Alcohol Concentration (BAC) level for crashing drivers/riders is tempered by the absence of a BAC reading for nearly 56.8% of the drivers/riders involved in the selected crashes on midblock curves. Notwithstanding this, around one-third of crashing driver/riders recorded a BAC level above 0.00gm%, with BAC levels exceeding 0.049gm% recorded by over one quarter of drivers/riders. This latter percentage is considerably higher than the 9% recorded for drivers/riders involved in reported crashes *of all types* over the same period.

Table 5.11 Blood Alcohol Concentration Level of drivers/riders involved in RUM code crashes 21 and 81-84 on mid-block curves; Western Australia, 2007-2011

Blood Alcohol Concentration Level (gm%)	n	%
Zero	2279	69.7
0.001-0.049	140	4.3
0.050-0.079	139	4.3
0.08-0.10	136	4.2
≥ 0.101	574	17.6
All	3268	100

n = 4294 missing driver/rider BAC level

5.11 Discussion

The conclusions from the analysis of the selected crash data are tempered by the inability to readily and easily identify the existence of and types of delineation treatments at the location and time of the selected crashes. Thus, it is unknown whether delineation treatments were absent, inadequate, up to Australian Standards, or circumvented by the driver/rider. Despite this limitation midblock curve crashes involving drivers/riders running off the road or colliding head-on with another vehicle from an opposing direction highlight the importance of providing and maintaining appropriate delineation treatments to assist drivers/riders with lane position and control.

The analyses showed that crashes on midblock curves are a significant contributor to death and serious injury. This study noted that 20% of midblock curve crashes resulted in death or hospitalisation, which is more than three times the proportion for *all crash types* over the same period. The findings also highlighted the additional importance of appropriate curve delineation on non-metropolitan area roads. Around 50% of crashes on midblock curves were noted to have occurred on non-metropolitan roads, which is substantially higher than the 16.7% of *all crash types* for the same period. Two non-metropolitan regions – the South-West and the Wheatbelt (North and South) – accounted for nearly a third of all midblock curve crashes across the state and close to two-thirds of those occurring in the non-metropolitan area. Clearly roads in these areas should be a priority for an investigation of the existence and adequacy of delineation treatments. The responsibility for such a review and implementing whatever curve delineation treatments are necessary is the responsibility of both the state road authority (i.e.,

MRWA) and local government, particularly the latter since nearly seven in ten crashes on midblock curves occurred on roads owned or managed by local government.

The various Black Spot Funding Programs provide both the state and local authorities with opportunities to identify high crash locations, such as midblock curves, and to secure funding to improve their safety. The most recent evaluation of the state Black Spot Program in Western Australia 2005-2006 (Meuleners & Hendrie, 2009) did not unfortunately specifically identify and evaluate treatments related to the improved delineation of curves. Given the problem of crashes on curves, particularly in the non-metropolitan area, and the proven effectiveness of many lower-cost delineation treatments, it would seem appropriate to investigate the need for and utility of curve delineation treatments under the State Black Spot program. Further to this, there may be a need to investigate the understanding that local asset owners in rural WA have of the required standards for curve delineation and how frequently road audits are undertaken to identify problem and below standard roads and required, effective treatments.

The comparatively higher likelihood of crashes on midblock curves in the non-metropolitan area is also likely to be associated with higher speed limits in these areas. Speed has been identified as a significant risk factor for crashes on curves (Oxley et al., 2004) and failure to negotiate the curve at higher speeds is likely to result in a more serious injury outcome given the human tolerances to crash forces compared with one at a much lower speed. Indeed the findings of this brief analysis showed that just over 50% of midblock curve crashes occurred in posted speed limits of 80km/hour and higher. Not so surprisingly, 72% of midblock curve crashes in these speed zones occurred in the non-metropolitan area.

Whether excess speed was a contributing factor to these crashes cannot be determined from the available data. As previously highlighted, delineation treatments such as Chevron Alignment Markers (Chrysler et al, 2009) and post-mounted delineators and/or raised pavement markers have been found by some researchers to significantly reduce vehicle speeds through the curve (Knapp, 2008). In the Western Australian context it would seem prudent to consider the application of delineation treatments which impact on vehicle speed and other initiatives such as

transverse road markings which have been previously identified to reduce vehicle speeds (see Martindale & Urlich, 2010). At any rate the findings reported here highlight the importance of not only appropriate delineation initiatives but also appropriate speeds limits and advisory signs and other speed management measures on curves in the non-metropolitan area.

The findings also highlight the need to consider curve delineation treatments that might specifically address motorcycle and derivative riders who, because of their vulnerable road user status, have a higher likelihood of injury in the event of a crash. This road user group represented just under 5.7% of controllers crashing on midblock curves during the study period, which is similar to the 5.2% of registered vehicles in Western Australia (2011) they account for (Road Safety Council of Western Australia, 2012). Delineation is considered to be an important requirement for motorcyclists (Cairney & Beesley, 2012). The requirement is to provide delineation treatments that provide riders with continuous information on the sharpness of the curve, the rise and fall of the road in the curve, and assist with identifying the ‘vanishing point’ in the curve which they should steer toward (Cairney & Beesley, 2012). It is imperative however, that delineation treatments for motorcyclists neither cause the rider to lose traction or skid (e.g., on pavement markings), cause the rider to lose control (e.g., due riding over a raised pavement marker or raised edge-line) or increase the likelihood of injury should the rider collide with the delineation treatment (e.g., infrangible post-mounted delineator or Chevron Alignment Marker board). As noted in the literature review, there is some evidence from a trial of the YWLIWG treatment in Buckinghamshire, UK to suggest that the placement of ‘guide posts’ of uniform height evenly spaced along the curve and past the crown of the curve can assist motorcyclists in maintaining focus on the bend, negotiating the curve, leading to a reduction in crash involvement (Institute of Highway Incorporated Engineers, 2006). A modified version of this treatment trialled in Victoria also showed some positive effects on rider behaviour in terms of speed and lateral positioning though this was not consistently observed across left and right hand bend treatments (Cairney & Beesley, 2012).

Negotiating curves at night and in conditions of poor visibility undoubtedly increase the demands on the drivers to maintain road position and control (Chrysler et al.,

2009). Consequently, enhanced and experimental delineation treatments such as fully reflective post-mounted delineators and Chevrons, raised LED pavement markers and flashing beacons that accentuate and illuminate the curve at night or in poor visibility conditions can assist drivers in recognising the hazard of the curve and to maintain lane position. The analysis of midblock curve crashes showed that around one in five midblock curve crashes occurred at night in the absence of lighting. Further investigation is clearly required to determine the lighting needs and potential application of high visibility delineation treatments on curves with a relatively high frequency of run-off road, loss of control and head-on crashes at night.

As previously noted, drivers negotiate a curve by scanning the roadside for visual cues and information to determine the sharpness of the curve to help them control their position on the road and their vehicle's speed and steering (Knapp, 2008). One objective of delineation is thus to increase the driver's detection of the curve and its hazard potential and to facilitate an appropriate response to this information. This process is likely to be compromised if the driver's perceptual, cognitive, and motor control skills and abilities are impaired, such as through alcohol or other psychoactive drugs. Drivers affected by alcohol are known to experience difficulties in relation to perceiving the road environment, processing the demands they face, and responding timely and appropriately (WHO, 2007). Even at Blood Alcohol Concentrations below the legal limit (e.g., 0.04gm%) driver impairment can be sufficient to significantly increase the likelihood of involvement in a crash (Verster, 2009). It is little wonder then that alcohol related crashes are characterised by vehicles running off the road, both on straights and curves (WHO, 2007). In this study around one-quarter of drivers/riders crashing at midblock curves evidenced BAC levels equal to or greater than the legal limit of 0.05gm%. This proportion is considerably higher than the 9% of all drivers/riders with an equivalent BAC level involved in crashes *of all types* for the same period.

The observed relationship between alcohol impairment and the inability to safely negotiate curves presents challenges for the delineation of curves. Previous research undertaken by Johnston (1984) into the relationship between curve negotiation and alcohol impairment noted that at 0.05gm% drivers did not necessarily increase their

(mean) travel speed through the curve but did evidence poorer lane positioning at the curve mid-point and more frequent lane departures compared with sober drivers. For alcohol affected drivers, Johnston (1984) found that Chevron Alignment Marker boards were a useful ‘long range’ delineation treatment and that Chevrons in combination with a wide edge-line were the most optimum treatment for assisting alcohol affected drivers negotiate the curve. It is likely that other delineation treatments that use a combination of highly visual and auditory delineation treatments (e.g., raised pavement markings and edge/centre lines and even raised transverse markings on approach to the curve) may assist ‘impaired’ drivers recognise the curve and help with lane positioning and vehicle speed.

The analysis of midblock curve crashes identified that nearly three-quarters of vehicle controllers were male. This percentage is slightly higher than the 66% of all fatal and hospitalisation crashes involving male drivers/riders for the period 2005-2009 in Western Australia (Palamara et al., 2013). It is possible that males are less likely to negotiate a hazardous curve not because of some innate gender-related skills deficit, but because of their higher likelihood of engaging in at-risk on-road behaviours such as speeding and drink driving (see Palamara et al., 2013).

Finally, just under three-quarters of drivers/riders crashing on midblock curves were aged 16-39 years. Like gender, this age group is known for its disposition to engage in risk taking behaviours such as speeding and drink driving (see Palamara et al., 2013), both of which are likely to impact on the safe negotiation of a curve. Also at issue for young novice drivers is their noted inability to identify hazards and to over-estimate their skill in dealing with hazards such as those represented by curves (OECD, 2006). At this stage there is no evidence to indicate which forms of enhanced delineation treatments are likely to impact on the driving behaviour of younger, less experienced versus older, more experienced drivers.

6. PROPOSED TRIAL OF A CURVE DELINEATION TREATMENT

This section presents the background and summary methodology for a proposed trial of a treatment to improve curve delineation along midblock curves in Western Australia with high crash frequencies. At the commencement of the section a description will be presented of an extracted dataset of midblock curves with high crash frequencies upon which the proposed trial can be based.

6.1 Summary description of midblock curves in Western Australia with high crash frequencies

In consultation with Main Roads Western Australia, criteria was developed for the extraction of midblock curves with high crash frequencies for the period 2007-2011 to provide a dataset of potential sites for the trial of the Chevrolflex Alignment Markers. Midblock curve crash sites were restricted to those:

- ≤ 500 metres in length from the beginning to end of the Straight Line Kilometre markers for the curve, and,
- those with three or more police reported crashes – all severities - in the five year period.

This data was extracted using various Main Roads WA datasets. Costing were also supplied for the average crash type and severity of crashes. A total of 61 midblock curve crash sites met the criteria for inclusion (see Appendix A). The number of crashes at each site ranged from three to eleven, with 23 locations exceeding the minimum inclusion of three crashes for a total of 258 recorded crashes. Approximately 84% of these crashes were run off road hit object crashes and 16% run off road non-collision crashes. The total cost of these crashes based on average crash type costs was calculated to be \$47.81 million.

Table 6.1 Frequency count of crashes on selected midblock curve locations; Western Australia 2007-2011

Frequency Count of Crashes	Number of sites	%
Three	38	62.3
Four	8	13.1
Five	3	4.9
Six	4	6.6
Eight	4	6.6
Ten	3	4.9
Eleven	1	1.6
Total Crashes	61	100

The severity of crashes is presented in Table 6.2. Just under 3% of crashes resulted in the death of an involved road user with a further 34.5% of crashes involving the hospitalisation or medical treatment of an involved road user. The majority of crashes resulted in major property damage only. The total injury severity cost of these crashes was calculated to be \$77.4 million.

Table 6.2 Severity of crashes at selected midblock curve locations; Western Australia 2007-2011

Crash Severity	Number of crashes	%
Fatal	7	2.7
Hospitalisation	44	17.0
Medical Treatment	45	17.5
Property Damage Only-Major	135	52.3
Property Damage Only-Minor	27	10.5
All Severity	258	100

The South West, Metropolitan and Wheatbelt North Main Roads WA regions were noted to record the highest number of selected crash sites accounting for over 80% of crash sites (Table 6.3). The South West region accounted for 40.3% of recorded crashes; the Metropolitan and Wheatbelt North regions accounted for 32.1% and 12.7% respectively of the total number of recorded crashes. More importantly, the South West and Wheatbelt North regions recorded three fatal crashes each (86% of fatal crashes) and 47% of hospitalisation crashes. The Metropolitan region recorded one fatal crash and 38.6% of hospitalisation crashes.

Table 6.3 Region of selected midblock curve crash locations; Western Australia 2007-2011

Region of midblock curve crash sites	Number of sites	%
Goldfields East	4	6.6
Great Southern	1	1.6
Metropolitan	11	18.0
Mid-West	4	6.6
Pilbara	2	3.3
South West	28	45.9
Wheatbelt North	10	16.4
Wheatbelt South	1	1.6
All	61	100

Calculation of the mean of the density of crashes (the number of crashes divided by the length of section) showed that Goldfields East (29.1 crashes), Metropolitan (23.1), South West (19.0), Wheatbelt South (12.1) and Wheatbelt North (10.6) had the highest crash densities.

The preceding summary of the extracted dataset has highlighted that:

- there are eight midblock curve locations across Western Australia that have recorded between eight and eleven crashes in a five year period;
- fifty-one of the n=258 crashes occurring across 61 locations involved the death or hospitalisation of an involved road user;
- the South West and Wheatbelt North regions represent a high priority for intervention based on the number of recorded crash sites, the number of recorded crashes, the severity of the crashes occurring in these regions, and the proportion of total crash and crash severity costs these locations account for; and that,
- there is a need to audit the South West and Wheatbelt North region crash sites to determine their appropriateness for inclusion in the proposed trial of the selected delineation treatment (see Section 6.2).

6.2 Chevroflex Ultra

The delineation treatment proposed to be trialled is the flexible Chevron Alignment Marker (CAM) known as *Chevroflex Ultra* (see Appendix B). This is manufactured by Glasdon, UK and distributed in Australia by RUD Chains P/L. The following information on the product is based on marketing materials produced by Glasdon and RUD Chains and conversations with RUD sales personnel and other others who have experience with the product.

6.2.1 General Description

Unlike traditional fixed post and metal CAMs, the *Chevroflex* CAM consists of flexible uprights (blades) that slot into a bank of metal sockets embedded in the ground. Each metal socket structure can hold five uprights to construct the CAM. The sockets can be spaced along the curve at appropriate intervals or joined to create a CAM of a particular length. Compared with traditional CAM, the *Chevroflex* system extends from ground level up (as high as 1.8 metres) to create a ‘wall’ effect. Coupled with a high visibility boarder, it is claimed that drivers and riders will detect the *Chevroflex* CAM much sooner and thus have awareness of the hazardous curve earlier than that offered by traditional metal CAM.

The flexible nature of the uprights that construct the *Chevroflex* CAM means that in the event of a ‘drive through’ (i.e., a vehicle collides with the CAM) the product will

return to its original shape. This has two benefits. Firstly, as the product will not impede or obstruct the vehicle, collision forces are negligible, thus reducing the risk of injury to road users, particularly motorcycle riders. Secondly, the product's ability to retain its shape means that maintenance requirements and costs are minimal. In the event of being impacted it remains operational as a curve delineation treatment unlike traditional CAM which cease to be functional and require maintenance. For these reasons the product is considered to be highly cost-effective.

6.2.2 The use of *Chevroflex Ultra* in Australia and elsewhere

Discussions with the Australian distributor indicate that *Chevroflex* CAMs have been in wide use internationally, particularly the United Kingdom, for over 25 years. In regard to its use in Australia, at this point in time it appears that *Chevroflex* is currently used in Queensland with another installation planned for Tasmania.

According to Transport and Main Roads Queensland (personal communication with Glen Cancian, 2013), n=119 *Chevroflex* CAMS have been installed at curves along a 15-20 kilometre section of the Nerang Murwillumbah Road. The installation was partly prompted by the occurrence of a high number of motorcycle crashes on this road. Motorcycle friendly guard rails were also installed at the same time. The installation commenced in 2010 and was due for review in 2012. The failure of some of the units (thought to be due to extreme environmental conditions) meant that additional *Chevroflex* units were installed in 2011. The project is now not due for review until the end of 2013. No information was provided in relation to a planned evaluation of the installation, either in relation to crash outcomes or intermediate outcomes such as reduction in mean speeds etc. Transport and Main Roads Queensland have agreed to provide more information in due course.

6.2.3 Cost

RUD Chains Australia P/L has at this stage provided a best estimate of the costs associated with the supply and installation of the *Chevroflex* product (personal communication with Keith Lawrence, 2013). The average cost for the supply of a single *Chevroflex* unit with all fittings is \$1,100-\$1,200, with anticipated installation costs of \$1,000. These figures are likely to vary with the volume of product purchased and local installation costs. Notwithstanding this point, a bank of four to seven *Chevroflex* CAMs installed on a curve could cost between \$8,800 and

\$15,400. Transport and Main Roads Queensland have advised that the supply and installation cost for each CAM was approximately \$1,800 (personal communication with Glen Cancian, 2013). Though upfront cost of *Chevroflex* appears high compared with the cost of traditional steel post mounted CAMs, Glasdon UK considers that the reduced maintenance and replacement costs for the product and continued hazard marking in the event it is impacted make the product a more economic option in the longer term.

6.2.4 Effectiveness of *Chevroflex*

There is a dearth of evidence in relation to the impact of the *Chevroflex* CAMs on outcomes such as crash frequency and severity or other intermediate measures such as vehicle speed or lane position. Discussions with Transport and Main Roads Queensland and RUD Australia have failed to provide any useful information in relation to these outcomes. It is hoped that Queensland will be able to provide some outcome information in relation to crashes by the end of 2013 or early 2014. Internet searches have similarly failed to uncover reports on the effectiveness of the installation elsewhere such as the UK despite its many years of use. This unfortunately limits the conclusions that can be drawn about the cost-effectiveness of a *Chevroflex* installation.

6.3 Overview of the research design for a trial of *Chevroflex*

The *Chevroflex* product is purported to be a 'high end' cost effective means to improve curve delineation. It is reputed to require limited maintenance, have low 'down time', and seemingly presents low risk of injury to road users, particularly vulnerable users such as motorcyclists, should they collide with the marker. The identification of a number of midblock curves with high crash frequencies in the South West and Wheatbelt North region presents an opportunity to trial this product for improved delineation. These regions can potentially provide up to 38 sites for inclusion in a trial, subject to site audit and judged suitability for the application of the *Chevroflex* product. Matching the treatment to the site is particularly critical for a valid assessment of the effectiveness of the CAM. It is assumed the potential sites include minimal delineation treatments such as pavement markings (edge and centre line) and guide posts. This assumption can be investigated through the interrogation of Main Roads WA databases that detail the existing infrastructure of the road

network. It may be that many of these sites require considerable work to improve their delineation in line with Australian Standards.

It is recommended that the research design for this study be based on the Empirical Bayes observational methodology used by Montella (2009) in his evaluation of the effectiveness of a range of curve delineation treatments. This ‘before and after’ design without control group considered the impact of treatments (including a combination of CAM, curve warning signs, sequential flashing beacons) on 15 curves along a motorway in Italy. The sites in that study were selected for treatment because of their high frequency of crashes. This methodology reflects a quasi-experimental design because sites were not randomly allocated to treatment and no-treatment conditions as would be the case in a Randomised Control Treatment design. In many respects it would be unethical to withhold treatment from identified high crash frequency sites for the purpose of establishing a group of control sites.

As Montella (2009) explains, the Bayes observational ‘before and after’ design is an appropriate and rigorous methodology for the purpose of evaluating an intervention of this nature because it will accomplish the following:

- Properly account for regression to the mean, which is an issue because high crash locations are to be selected for treatment;
- The ability to account for change over time in outcomes (historical threats to validity) not due to the treatment being evaluated;
- Reduce the level of error or uncertainty around the estimates of the effect of the treatment on the outcomes being investigated, e.g., crashes and crashes types; speed related measures.
- Overcome the difficulty of using crash rates which require that traffic volumes in the before and after periods be taken into account.

In the Montella (2009) study crash data 12 months prior to treatment and 12 months following treatment were analysed. Because these treatments were undertaken on curves on a very high volume motorway with a high frequency of crashes (mean of 15 crashes in the preceding 12 month period), the short ‘before and after’ periods provided sufficient data for analysis. However, for the proposed Western Australian trial it is recommended that a longer ‘after’ period is considered (minimum 24 - 36 months) because of an anticipated lower volume of traffic and thus lower frequency

of crashes. It is also recommended that other intermediate measures of the effect of the *Chevroflex* product be considered, such as mean vehicle speed through the curve and lane position. As many high frequency crash sites as possible from the South West and Wheatbelt North, subject to finances, should be included in the trial to maximise the statistical power of the study to determine a true effect of the *Chevroflex* on both intermediate and crash outcomes.

An estimate of the cost of the study would depend, among other things, on the supply and installation costs, the number of appropriate sites for inclusion, the number of *Chevroflex* units to be installed, a budget for maintenance, and the cost of collecting and analysing both speed, vehicle position, and crash data. Notwithstanding these issues, based on the average cost of \$4.1million for a non-metropolitan area fatal-hospitalisation crash (Willingness to Pay method reported by Hill et al., 2012), the cost-benefit is *likely* to be very high if a reduction in only one fatal or hospitalisation crash is associated with the installation of a bank CAM given the rudimentary costs listed above.

7. SUMMARY AND RECOMMENDATIONS

This project has provided an overview of the rationale for improving the delineation on curves and the types of basic and enhanced treatments to achieve this. A number of potential low cost treatments were identified, many of which have been shown to be effective as a singular treatment or in combination with other treatments. The most compelling evidence of the effectiveness of delineation treatments on crashes and speeding outcomes included a combination of basic and enhanced treatments such as Chevrons, curve warning signs and flashing roadside beacons. Crash reductions were reported to be as high as 47%.

Whilst it is not possible to identify crashes on curves that are a direct consequence of inadequate delineation, crash data provides reasonably clear evidence of horizontal curves being associated with a higher than expected incidence of fatal and hospitalisation crashes, due to run off road and head-on crashes. Analysis of the WA data 2007-2011 also showed that run off road and head-on crashes on midblock curves are more likely to occur on non-metropolitan area roads. Consistent with this, the analyses highlighted the important involvement of higher speed zones. Other issues such as alcohol, driver inexperience and youthfulness were identified as contributing factors.

To assist with the development of a proposal to trial a curve delineation treatment, midblock curves (≤ 500 metres in length) in Western Australia with high crash frequencies were identified by MRWA. A total of 61 crash sites with three or more crashes occurring during the period 2007-2011 were identified. The South West and Wheatbelt North regions were identified as problematic areas in terms of the number of sites, the number of crashes, the severity of these crashes, and the associated cost of crashes. These regions and their sites were subsequently recommended for review for inclusion in an Empirical Bayes investigation of the application of an enhanced delineation treatment, *Chevroflex* Chevron Alignment Markers. Based on the rudimentary costs for installing a bank of Chevroflex CAMS and the noted average cost of a non-metropolitan area fatal/hospitalisation crash, the installation is likely to have a very high cost-benefit ratio if a reduction of only one fatal or hospitalisation crash is initially observed.

A number of recommendations follow from the information presented in this report:

1. Review of the State-wide use of curve delineation treatments

Recognising the high risk of crashing and serious injury on curves, it is recommended that MRWA consider the implementation of a working group to investigate curve delineation practices and standards across the state. Priority should be given to the audit of roads in the Wheatbelt North and South West because of the relatively higher proportion of crashes on midblock curves in these areas.

2. Dissemination of information to asset owners and managers of the types of delineation practices that can effectively reduce the frequency of crashes and vehicle speeds

There is now a considerable body of research evidence supporting the value of basic and enhanced curve delineation treatment when used in combination. Disseminating this information to asset owners and managers may increase their awareness of the need to focus on curve related crashes and apply for treatment funding under the various Black Spot Treatment programs. Following the outcome of Recommendation 1, this information could be used to work with asset owners to improve the delineation standards if and where necessary.

3. Consider the proposed trial evaluation of the *Chevroflex* Chevron Alignment Marker in the identified high crash frequency locations

MRWA has identified a number of problematic regions for crashes on midblock curves. Notwithstanding the need for an audit of these sites to determine if and how they meet the Australian Standard, it is recommended that MRWA consider a trial of the *Chevroflex* CAM at selected high crash frequency sites as an alternative to the standard steel post installation.

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Appendix One

Listing of high frequency midblock curve crash sites in Western Australia, 2007-2011

Appendix Two

Chevroflex Product Information