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FINAL REPORT

Project Title: R46: Review of TMR Guidance for Head-on, Run-off-road and Intersection Crashes in Queensland (Year 3 - 2016/17)

ARRB Project No: PRS16108

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AN INITIATIVE BY:

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SUMMARY

A review of historical crash data revealed that the three key crash types which occur on Queensland roads are intersection, run-off-road and head-on crashes. TMR commissioned ARRB to examine these crash types to identify treatment options to reduce the occurrence and severity of these crashes. This is the final report of a three year project.

The first two years of the project involved the review of head-on, run-off road and intersection crashes on Queensland roads, with Year 1 focussing on head-on and run-off road crashes, and Year 2 focussing on intersection crashes.

For each of the crash types the following was undertaken:

- a review of the literature to identify available treatments and their effectiveness in reducing the likelihood and severity of that crash
- a comprehensive analysis of crash data from 2007 to 2011 to determine any trends, key road features and other factors contributing to the occurrence and severity of these crash types for both local and state-controlled roads in Queensland.

Based on the review of literature and the findings from the crash analysis, recommended engineering treatments to reduce head-on, run-off-road and intersection crashes were provided.

A series of Technical Notes addressing head-on, run-off-road and intersections crashes has been prepared and they are presented in this report.

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CONTENTS

TABLES

FIGURES

1 INTRODUCTION

1.1 Background

There are three key crash types that account for most of the fatal and serious injury (FSI) on Queensland roads: intersection, run-off-road and head-on crashes (Table 1.1). These crash types also have been targeted in the National Road Safety Strategy 2011-2020 (Australian Transport Council 2011)[1] and the respective Action Plan[2].

Table 1.1: FSI crashes by the main crash types on Queensland Roads

Crash type	Percent of FSI crashes on state-controlled roads	Percent of FSI crashes on all Queensland roads
Intersection crashes	38%	37%
Run-off-road crashes	34%	31%
Head-on	7%	6%
Total	79%	74%

Queensland Department of Transport and Main Roads (TMR) commissioned ARRB to examine these three crash types to identify treatment options to reduce the occurrence and severity of these crashes. The project is of three-years duration, with the first year involving a literature review, crash analysis, and the preparation of treatment options for head-on and run-off-road injury crashes. The second year examined intersection crashes. The aim in the final year was to review TMR's existing guidelines and practices relevant to the three key crash types, to identify revisions, and to develop guidance based on the findings from the first two years of the project. Ideally, this guidance would take the form of a Technical Note for each of the crash types.

1.2 Objectives

The overall objectives of the project were to:

- gain a better understanding of road engineering-based measures used to address serious injury crashes so that the most effective treatments can be used in future projects
- improve the effectiveness of road safety engineering countermeasures
- improve economic returns on investments from existing programs such as Safer Roads Sooner.

1.3 Methodology

The following tasks were undertaken in the final year of the project:

- summarise the findings from the first two years of the project to assist in formulating a targeted implementation plan
- identify TMR standards and practices relevant to the three key crash types and engineering treatments, e.g. TRUM manuals, Factsheets, Policy and guidelines, etc.
- based on the work conducted in the first two years of the project, identify gaps in knowledge and guidance

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[1] The *National Road Safety Strategy 2011–2020* was released on 20 May 2011 by the former Australian Transport Council (ATC). It is now overseen by the Transport and Infrastructure Council.

[2] The National Road Safety Action Plan is intended to support the implementation of the *National Road Safety Strategy 2011–2020*. It addresses key road safety challenges identified in the 2014 review of the strategy and details a range of priority national actions to be taken by governments over the three years 2015 to 2017.

- determine the extent of the document revision task
- develop engineering treatment guidance for each of the crash types, in the form of a Technical Note.

2 SUMMARY OF YEARS 1 AND 2

The first two years of the project involved a review of head-on, run-off road and intersection crashes on Queensland roads, with Year 1 focussing on head-on and run-off road crashes, and Year 2 focussing on intersection crashes.

For each of the crash types a review of the literature was conducted to identify the available treatments and their effectiveness in reducing head-on, run-off-road and intersection crashes.

A comprehensive crash analysis was conducted based on 2007 to 2011 crash data to determine any trends, key road features and other factors contributing to the occurrence and severity of head-on, run-off road and intersection crashes for both local and state-controlled roads in Queensland.

Based on the review of the literature and the findings from the crash analysis, engineering treatments to reduce head-on, run-off-road and intersection crashes were recommended. The recommendations provided in the reports of activities for Year 1 and Year 2 of the project were considered in the preparation of the Technical Notes for each accident type. The Technical Notes are provided in Section 5 (head-on crashes), Section 6 (run-off-road crashes) and Section 7 (intersection crashes) respectively.

For further information regarding the first two years of the project refer to the following project reports:

- Year 1 – R28: Review and analysis of head-on, run-off-road and out-of-control crashes on Queensland roads (Affum et al. 2015).
- Year 2 – R46: Review and analysis of intersection crashes on Queensland roads (Luy et al. 2016).

3 REVIEW OF GUIDELINES AND RELEVANT DOCUMENTS

3.1 TMR Standards and Practices

The main standards and guidelines adopted by TMR are:

- Standards published in Austroads Guides. Supplements to the respective Austroads guides have been developed and are contained in the Traffic and *Road Use Management Manual* (TRUM) and the *Road Planning and Design Manual* (RPDM). These documents only include guidance on matters that are specific to Queensland and have precedence over the appropriate Austroads guide.
- Australian Standard AS1742 *Manual of Uniform Traffic Control Devices* (MUTCD).
- The Queensland supplement to the MUTCD provides requirements and recommendations specific to Queensland and has precedence over the equivalent Australian Standard. Practices published in the Queensland MUTCD and its supplements take precedence over the *Traffic and Road Use Management* (TRUM) Manual, except in cases where TRUM manual guidelines have been published after the Queensland MUTCD.

In addition to this, TMR has developed other technical documents which provide advice on various practices and treatments available. A number of documents were provided by TMR for review; the list of documents supplied by TMR is provided in Appendix A.

3.2 Gaps in Knowledge and Revision of Current Guides

From the review of the TMR documents provided and ARRB's knowledge of the Austroads Guides and AS1742 *Manual of Uniform Traffic Control Devices,* a gap analysis was conducted examining the availability and limitations of existing technical guidance for the treatment options recommended in Years 1 and 2 to reduce head-on, run-off-road and intersection crashes. In addition, updated information on the recommended treatment options and new treatments since the completion of Years 1 and 2 were identified and reported.

A table summarising the recommended treatments from the first two years of the project and their coverage in the TMR supplied documents is provided in Appendix B.

4 DEVELOPMENT OF ENGINEERING TREATMENT GUIDANCE

A separate Technical Note was developed for each of the three main crash types – head-on, run-off-road and intersection crashes, and these are presented in Section 5 (head-on crashes), Section 6 (run-off-road crashes) and Section 7 (intersection crashes) respectively. Each Technical Note provides background information highlighting the extent of the crash problem, where crashes occur and who is over-represented in these types of crashes.

The focus of this report, however, is to describe and provide guidance on the available treatment options, including their effectiveness and crash reduction potential and to note emerging treatments that may require further research before the treatment could be applied. Where existing guidance on a treatment is available in current TMR and Austroads Guides and Standards, a brief description of the treatment and a link to the document is provided. However, where there is limited or no guidance available on a specific treatment a more detailed guidance has been prepared. Diagrams and photographs are used to illustrate the options where appropriate.

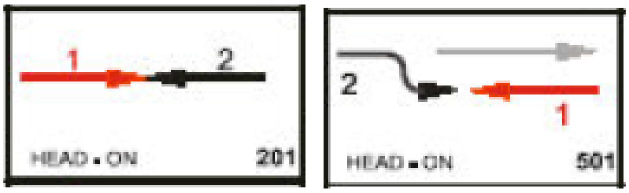
5 TECHNICAL NOTE: HEAD-ON CRASHES

5.1 Introduction

This Technical Note provides background information to the head-on crash problem and associated statistics for Queensland. It provides insight into the contributory factors involved in head-on crashes and gives guidance regarding road-based treatments that may be adopted to reduce the likelihood and severity of head-on crashes.

Austroads (2016a) defines a ‘head-on crash’ as ‘an event in which a vehicle departs from its laneway into opposing traffic, such as that any portion of the leading edge of its vehicle strikes any portion of the leading edge of an opposing vehicle’. This is one of the most severe crash types that may occur. It is therefore important within a Safe System that practitioners are aware of measures available to reduce the incidence and severity of this crash type. A diagram illustrating head-on crash (DCA codes 201 and 501, head-on due to overtaking) is shown in Figure 5.1.

Figure 5.1: Diagram illustrating head-on crash (DCA codes 201 and 501, head-on due to overtaking)



5.2 Queensland Statistics

There were a total of 69 533 injury crashes recorded on Queensland roads between 2007 and 2011, of which 40% resulted in fatal or serious injury (FSI).

Head-on crashes accounted for 4% of all injury crashes, 6% of FSI on Queensland roads, and 7% of FSI on state-controlled roads. Head-on crashes were more severe than other crash types, with 61% of all head-on crashes resulting in fatal or serious injury compared to 40% for all injury crash types. The proportion of FSI head-on crashes was higher on state-controlled roads (64%) than those on locally-controlled roads (56%).

The risk of head-on injury crashes on curves was higher than for all injury crashes with 56% of head-on injury crashes occurring on curves compared to 23% for all crash types.

5.3 Key Contributing Factors

5.3.1 Road Features

Based on crashes between 2007 and 2011 the following road features were found to contribute to the occurrence and severity of head-on crashes:

- There are more head-on injury crashes (47%) on high-speed roads (80 km/h or more) compared to all-injury crashes (27%).
- Fifty-six per cent of head-on injury crashes occurred on curves compared to 23% for all injury crashes. Since a large proportion of the network is made up of straight road sections, the data indicates a substantially higher risk for head-on crashes on a curve.
- Forty-two per cent of head-on injury crashes occurred on a grade, dip or crest compared to 25% for all injury crashes
- Twenty-six per cent of head-on injury crashes occurred on a wet sealed road surface compared to 16% for all injury crashes.

- Only 3% of all head-on injury crashes on Queensland roads were associated with overtaking manoeuvres; overtaking lanes should be provided as a traffic operation and capacity measure or at specific sites which have severe sight distance restriction or known to have recorded high head-on crashes associated with overtaking.

5.3.2 Other Contributing Factors

Based on crashes between 2007 and 2011 other contributing factors impacting on the severity and occurrence of head-on crashes include:

- Eighty per cent of head-on injury crashes involved drivers disobeying the road rules compared to 67% for all injury crashes.
- Young drivers/riders (17-24 years old) made up the largest proportion of the primary vehicle controllers involved in head-on injury crashes.
- Senior adults (60+ years old) were a contributing factor in 24% of head-on injury crashes compared to 19% for all injury crashes.
- Road condition was a contributing factor in 22% of head-on crashes compared to 10% for all injury crashes.
- Male drivers accounted for 75% of head-on injury crashes, compared to 65% for all injury crashes.
- Motorcycles/mopeds were involved in 9% of head-on injury crashes compared to 7% for all injury crashes; 75% of motorcycle/moped crashes resulted in FSI crashes.
- The risk of a fatal head-on crash involving a heavy vehicle was higher compared to other vehicles. Although the percentage of heavy vehicles involved in head-on crashes was the same for both head-on and all injury crashes (5%), they had more severe crash outcomes, with 21% of head-on crashes involving a heavy vehicle resulting in a fatality and 39% in hospitalisation.

5.4 Treatments

This section provides road-based treatment options to reduce the number and severity of head-on crashes. A description of each treatment option and its effectiveness in reducing crashes is provided.

5.4.1 Road-duplication and Physical Barriers

The most effective way to reduce head-on crashes is to provide physical separation of opposing traffic. This may involve a major road upgrade or duplication to construct a central median to provide an area for errant vehicles to recover in the event of leaving the roadway.

Median safety barriers can also be used to prevent errant vehicles from entering the opposing lanes of traffic. The term ‘safety barriers’ refers to a range of devices designed to restrict the lateral movement of errant vehicles, with the intention of either guiding them back onto the roadway or bringing them to a stop safely.

Median barriers are categorised according to their stiffness. These include

- rigid barriers such as concrete barriers which experience negligible deflection when impacted (refer Figure 5.2)
- semi-rigid barriers such as W-beam metal barriers (refer Figure 5.3)
- flexible barriers such as wire rope barriers (refer Figure 5.4).

Figure 5.2: Example of a rigid concrete safety barrier

Source: ARRB.

Figure 5.3: Example of a semi rigid W-Beam safety barrier

Source: ARRB.

Figure 5.4: Example of a flexible wire rope safety barrier

Source: ARRB.

The selection of an appropriate barrier type should primarily be based on its performance capability and deflection. In other words, the barrier 'must possess sufficient structural integrity to contain and redirect the design vehicle', and the 'expected deflection of a barrier should not exceed available room to deflect' (Austroads 2010).

It is suggested in Austroads (2014a) that the barrier should be installed between 1.5 m and 4 m from the road shoulder. This is barriers placed any closer to the roadway than 1.5 m can lead to significant increases in collisions. On the other hand, locating the barrier and offset further away than 4.5 m results in an increase in the impact angle and a corresponding increase in crash severity (Austroads 2014b). Note, TMR guideline specifies a minimum clearance of 0.5 m to allow for vehicle overhang (TMR *Road planning and design manual, Edition 2, Volume 3: Supplement to*

Austroads guide to road design, Part 6: Roadside design, safety and barriers (TMR 2014a) https://www.tmr.qld.gov.au/business-industry/Technical-standards-publications/Road-planning-and-design-manual-2nd-edition.aspx).

The literature suggests that wire rope or flexible barrier systems are successful in reducing the likelihood and severity of head-on crashes, with a 60-90% crash reduction reported (Austroads 2016a). Therefore, it is recommended for use at sites with a high head-on crash risk subject to design and risk assessment.

The crash reduction factors associated with the use of various types of safety barriers are presented in Table 5.1.

Table 5.1: Effectiveness of barrier treatments

Barrier treatment	Crash type	Crash reduction factor
Rigid Barrier	Head-on	100%
	ROR to the right	–120%
Semi rigid barrier	Head-on	95%
Flexible barrier	Head-on	60 to 95%
	ROR to the right	–40% to –95%
	All FSI	0 to 75%

ROR: run-off-road.

Source: Adapted from Austroads 2016a.

When selecting a barrier system consideration should be given to the types of road users because the performance of some barriers is dependent on the type of traffic, e.g. heavy vehicles, motorcyclists, bicycles and cars (when there are larger angles of impact and the speed of travel is higher than barrier test speeds).

When considering heavy vehicles, it is important to note that a heavy vehicle will not be contained by a normal roadside barrier and a car may be extensively damaged by impact with a barrier designed for trucks. The level of containment required by the safety barrier should be determined based on a risk assessment.

Some features of safety barriers can be hazardous to motorcyclists. These include (Austroads 2010):

- exposed barrier posts
- upper and lower W-beam edges
- protruding reflectors utilising metal components
- barrier systems that are too low – motorcyclists can be catapulted over barrier systems of insufficient height
- discontinuous or jagged barrier surfaces, such as concrete barriers with decorative designs, which present edges to concentrate the forces of impact
- rigid barriers (likely to be involved in front-on collisions) which require an impacting rider to absorb virtually all of the kinetic energy at impact.

Barrier systems can be made more motorcycle friendly by shielding the barrier posts, modifying or replacing posts with more forgiving post shapes or covering exposed posts with specifically-designed impact attenuators. These are illustrated in Figure 5.5, Figure 5.6 and Figure 5.7. These issues should be considered when designing safety barrier systems for use on roads that carry a considerable number of motorcycles or along motorcycle-designated routes.

Figure 5.5: Wire-rope barrier post impact absorbing pads

Source: Ingal Civil Product (2016a).

Figure 5.6: Guardrail post caps

Source: Ingal Civil Product (2016a).

Figure 5.7: Under-run protection for motorcyclists on W-Beam safety barrier

Source: Ingal Civil Product (2016a).

The treatment life for safety barriers is 10 plus years (Austroads 2015a).

For technical information refer to *Road planning and design manual, Edition 2, Volume 3: Supplement to Austroads guide to road design, Part 6: Roadside design, safety and barriers* (TMR 2014a) (https://www.tmr.qld.gov.au/business-industry/Technical-standards-publications/Road-planning-and-design-manual-2nd-edition.aspx).

5.4.2 Raised Profile Centreline

Raised profile centrelines include audible centrelines, audio tactile centrelines or centreline rumble strips. They are raised or grooved patterns placed on or near the road centreline. When wheels reach the centreline a humming or vibrating noise can be heard, alerting the driver that they are crossing the centreline. They are useful in addressing crashes related to driver inattention, distraction and fatigue. They may also improve visibility of the centreline during wet conditions and may discourage illegal crossing of the road centreline such as for overtaking (Austroads 2016a).

Raised profile centrelines can be installed without any changes to the roadway cross-section, making it a cost-effective and fast treatment option. An example of a raised profile centreline is shown in Figure 5.8.

Figure 5.8: Example of raised profile centreline

Source: ARRB.

Some operational issues associated with the use of raised profile centrelines include (Austroads 2016a):

- additional maintenance requirements
- high noise levels
- potential for water ponding if not adequately drained
- potential for presenting a visual obstruction to overtaking manoeuvres.

Cyclists should be considered when installing raised profile centrelines as they encourage vehicles to travel closer to the shoulder.

The effectiveness of ATCL, in terms of a reduction in head-on FSI crashes ranges from 25-65% and 20-55% for all head-on crashes (Austroads 2016a).

Note that the literature suggests that the installation of raised profile centrelines, along with raised profile edgelines, can be effective in reducing lane departure crashes (head-on and run-off road). It has been shown that there is an increase in head-on crashes when only raised profile edgelines are used; however, there has been reduction in both run-off road and head-on crashes when used in combination with raised profiles centrelines (Austroads 2016a).

The treatment life for raised profile centrelines is five to ten years (Austroads 2015a).

For further technical information, refer to *Traffic and road use management, Volume 2: Guide to road safety, Part 5: Road safety for rural and remote areas* TMR (2015a) (https://www.tmr.qld.gov.au/business-industry/Technical-standards-publications/Traffic-and-Road-Use-Management-manual/Volume-2).

5.4.3 Enhanced Pavement Markings

Enhanced pavement markings, also termed long-life road markers, improve the reflectivity of road markers and hence their night-time visibility. This treatment reduces the risk of crashes on roads during times of darkness. Care should be taken if they are applied on poorer-quality roads so that it does not encourage drivers to travel at speeds inappropriate for the road environment (Austroads 2016a).

Enhanced pavement marking treatments include the following:

- Profiled thermoplastic centreline stripes – moderate-cost treatment that improve the visibility of a centreline system at night, particularly in wet conditions. An additional advantage is that it seems to have a mild audio-tactile response, alerting drivers straying from their lanes. This treatment suits sections: (a) with long unbroken centrelines where traffic volumes and crash history do not justify raised profiled centrelines or other more expensive treatments, (b) where there is high wet weather crashes, or (c) where pavement maintenance is not scheduled for at least three years.
- Cold applied plastic materials –a two-part liquid mix of resin-based material and hardener. To improve reflectivity, glass beads are pre-mixed into the product, and additional beads are dropped on during application. Due to its high wear resistance this product is typically used at intersections.
- Road marking tape – may be flat or profiled. Retroreflective glass beads are incorporated into the material during its production. Its cost is high compared to other linemarking options, so their use is generally limited to areas where a high level of performance is required under severe conditions, or to repair or replace sections of deteriorated linemarking. The reflectivity is about four to six times that of water-borne traffic paints; however, their reflectivity quickly diminishes.

The use of enhanced pavement markings results in a 10% reduction in night-time midblock crashes; no specific head-on crash reduction data was available.

The treatment life of thermoplastic markings is five years, whilst the life of reflective tape is three years.

5.4.4 Raised Reflective Pavement Markers

Raised reflective pavement markers (RRPMs) also known as retroreflective pavement markers, cats eyes or road studs. They are used to augment the visibility of road markings. They are reflective in that they are illuminated by approaching vehicle headlights. They are used to supplement pavement markings for increased effectiveness, especially in night and inclement weather (wet or foggy) conditions. The reflective markers complement centrelines, lane lines and edgelines. An example of RRPMs during daylight hours is shown in Figure 5.9.

Figure 5.9: Example of RRPMs during daylight

Source: ARRB.

RRPMs have been used by all road agencies for a number of years and they have been successful in providing delineation of roads in adverse weather and lighting conditions. Their effectiveness is a 5% crash reduction of all crashes, a 10% reduction in all types of night-time crashes and 30% of all types of crashes in wet, night-time conditions.

The treatment life for RRPMs is one to five years (Austroads 2015a).

For further technical information refer to *Traffic and road use management, Volume 3: Guide to pavement markings, Part 2: Pavement marking usage, Chapter 2: Types of markings for application requirements* (TMR 2015b) (https://www.tmr.qld.gov.au/business-industry/Technical-standards-publications/Traffic-and-Road-Use-Management-manual/Volume-3).

5.4.5 Internally-Illuminated Pavement Markers

Internally-illuminated pavement markers (IIPMs), also known as LED raised pavement markers or intelligent road studs, are similar to RRPMs but are self-illuminating (Figure 5.10).

These are considered for use where RRPMs may not be as effective, such as on crests or curves or freeway ramps, where the road alignment does not allow vehicle headlights to adequately illuminate RRPMs (Austroads 2016a). They may also be used where it is important to provide delineation over longer distances than vehicle headlights may illuminate. IIPMs may provide illumination over a length of 900 metres compared to RRPM illumination of 90 metres.

VicRoads undertook a trial of self-activated pavement markers at various sites around Victoria. Styles et al. (2003) found that IIPMs appeared to encourage drivers to travel more slowly and to place their vehicles further from the centre of the road in some circumstances. Nonetheless, the self-activated pavement markers do not appear to be sufficiently robust, being susceptible to theft, vandalism and damage by traffic.

IIPMs are an emerging technology, and some makes are more reliable than others. There is no information available regarding the effectiveness of IIPMs; however, it is suggested that it would be the same as that of RRPMs.

The treatment life of IIPMs is assumed to be the same as RRPMs (one to five years).

Figure 5.10: Example of internally-illuminated pavement markers at night

Source: MRWA (cited in Austroads 2016a).

5.4.6 Painted Medians

Painted medians, also known as flush medians, are a low-cost option used to address head-on crashes by improving the separation of vehicles and discouraging overtaking. Painted medians are used where there is limited road width for the installation of raised medians. Narrowing the road using painted medians may also help to reduce travel speeds and encourage drivers to travel at a more suitable speed for the road environment (Austroads 2016a).

Painted medians can be used in urban and rural areas. In urban areas, they provide some protection to pedestrians crossing the road; as such, they may be coupled with pedestrian crossing facilities, such as refuge islands, to provide added security. An example of a painted median is shown in Figure 5.11.

Austroads (2017) suggests a minimum painted median width of 600 mm. However, Levett, Job and Tang (2009) indicated that the benefits of painted medians were maximised when the width was at least 1.0 metre. It is recommended that painted medians should be at least 1.0 metre wide.

iRAP (2010) indicated a crash reduction of 10-25% when a painted median was installed, whilst Austroads (2012a) suggested a 15% reduction in casualty crashes. Roads and Maritime Services (RMS) NSW (2015) adopt a 40% crash reduction for head-on crashes when a painted median is adopted.

The treatment life for painted medians is five years (Austroads 2015a).

Figure 5.11: Example of a painted median on a curved section of road

Source: ARRB.

5.4.7 Pavement Bars

Pavement bars are raised blocks located within the painted median (Figure 5.12). They are used to augment the median. Although traversable, they provide very strong audio-tactile response, discouraging drivers to cross them (which may also discourage overtaking). They also improve the visibility of the median.

Figure 5.12: Example of painted bars in median

Source: Austroads (2016a).

The use of bars in islands may be an advantage (Austroads 2016b):

- as an approach treatment to a median and or other central obstruction
- if used in place of a narrow median
- where raised islands cannot be accommodated due to limited road width
- where, because of the absence of street lighting or restricted pavement width, raised islands are undesirable and painted islands are not considered effective
- to form islands that over-dimensional vehicles can traverse.

AS1742.2-2009 specifies that they should only be used on roads with an 85th percentile speed less than 75 km/h. For speeds greater than this, RRPMs can be used to augment the painted median. Pavement bars should not be used on roads with a width less than 6.8 metres (Austroads 2016b).

Pavement bars can be hazardous to motorcyclists and cyclists and should only be installed along straight sections of road.

No information is available regarding the effectiveness of pavement bars.

The treatment life is assumed to be five years based on the treatment life for RRPMs.

5.4.8 Wide Centreline Treatment

Wide centreline treatments are a type of painted median treatment; they are used to increase the separation of vehicles (Figure 5.13). The width of the median varies depending of the posted speed limit. TMR interim advice are: for a speed limit of 60 km/h the width is 600 mm, for 70-80 km/h the width is 800 mm, and for 90 km/h or more the width is 1.0 metre (TMR Technical Note 155, https://www.tmr.qld.gov.au/-/media/busind/techstdpubs/Technical-notes/Road-design/TN155.pdf?la=en).

The addition of raised profile line-marking increases the effectiveness of this treatment.

The installation of wide centrelines can usually be achieved within the road width available on a two-way undivided road. For example, a 1.0 metre wide centreline can be formed by reducing the width of a lane from 3.5 metres to 3.25 metres using a combination of narrowing the shoulder and lane widths.

The treatment may be enhanced by the use of reflective markers to further highlight the median strip.

The reduction in lane width and shoulder width may increase run-off-road and out-of-control crashes, and caution should be given to these crash types prior to implementing this treatment. The need to provide adequate pavement strength to withstand the additional pavement loading closer to the road shoulder needs to be considered. Attention should also be given to roadside objects to ensure that the treatment does not increase the risk of FSI collisions with roadside objects or whether there is adequate protection in the shoulder for broken-down vehicles.

A recent study by Luy & Affum (2017) examined the safety benefit of wide centreline treatments on the Bruce Highway based on analysis of five years crash data before and after installation of the wide centrelines. The study found that the installation of wide centrelines reduced head-on FSI crashes by 30% and all head-on crashes by 33%.

A treatment life of five years was adopted based on the treatment life of standard centrelines and RRPMs.

Figure 5.13: Wide centreline treatment with raised profile line-marking on Bruce Highway

Source: ARRB.

For further technical information refer to the *Guidelines for road design on brownfield sites* TMR (2013) (https://www.tmr.qld.gov.au/business-industry/Technical-standards-publications/Brownfields-guidelines.aspx).

5.4.9 Raised Median

Raised medians are often used in urban and semi-urban roads. They are more conspicuous than painted medians and a physical deterrent in terms of preventing cross-median manoeuvres. Raised medians can also accommodate sign posts, lighting and traffic hardware and may be landscaped to improve aesthetics and to reduce headlight glare (Austroads 2016a).

Examples of raised medians are shown in Figure 5.14 and Figure 5.15.

Figure 5.14: Example of a paved raised median

Source: ARRB.

Figure 5.15: Example of a grassed raised median

Source: ARRB.

Austroads (2017) outlines the following requirements for the installation of a raised median:

- requires lighting which can be expensive to install and maintain, especially in isolated areas
- may require a greater network of drainage systems, increased maintenance activities and costs associated with catering for the concentrated rainfall runoff
- could generate safety issues if struck by fast-moving traffic
- may require more space due to greater lane widths to cater for broken-down vehicles and the need for offsets to kerbs
- may block access for through traffic into a right-turn lane at traffic signals, whereas a painted median would assist right-turn manoeuvres by allowing drivers to drive over the median (within the limits of the road rules)
- may have traffic furniture which is prone to damage by errant and over-dimensional vehicles
- is often a more costly treatment.

Austroads (2012a) suggests casualty crash reduction factors of 45% and 55% in urban and rural areas, respectively. TMR has adopted a 30% reduction in head-on crashes for extending raised medians in its crash reduction factor (CRF) matrix.

The treatment life of a raised median is 20 years.

5.4.10 Flexible Bollards

Flexible bollards, also known as safe-hit posts, provide a visual separation and physical obstacle between opposing streams of traffic. They are a possible treatment where there is insufficient road space for the installation of a traditional median or median barrier; they are also installed in conjunction with barrier kerbs (Austroads 2016a).

Mackie, March and Pilgrim (2011) studied the impacts of this treatment on driver behaviour. A treatment consisting of 1.5 metre wide flush median with audio tactile profiled (ATP) road-marking on both centrelines with safe-hit posts at 5 metre centres was applied on a rural road in New Zealand (Figure 5.16). They found that the performance of the median treatment was positive, with motorists driving slightly further away from the median compared with similar nearby control sites. They also found no increase in speeding and possibly improved merging behaviour at the end of the passing lane. Some concerns were raised regarding the visibility when turning into or out of properties. They concluded that further research was needed to gain a longer-term understanding of maintenance issues and crash reduction effects.

There is no research data on the expected crash reduction from the installation of flexible bollards.

A treatment life for flexible bollards of one to five years has been adopted based on the treatment life of RRPMs.

Figure 5.16: Safe-hit posts in central median New Zealand

Source: Mackie, March & Pilgrim (2011).

5.4.11 Median Turning Lanes

The main function of this treatment is to allow turning into driveways and entrances with minimal rear-end crashes. However, studies have found that median turning bays have helped to reduce head-on crashes as these bays serve as a buffer between the opposing streams of traffic.

Two-way turning lanes are typically used in busy urban areas with closely-spaced access points. A single lane is marked in the centre of the road to provide an area for vehicles travelling in either direction to slow down before turning across traffic into driveways (Figure 5.17). This type of lane also provides a space for drivers of turning vehicles who must wait for an adequate gap in the on-coming traffic. In areas where there is pedestrian activity, these lanes may provide some protection to pedestrians crossing the road; they can be coupled with pedestrian treatments such as pedestrian refuge islands to provide added security (iRAP 2010).

Figure 5.17: Example of a median turning lane

Source: ARRB.

iRAP (2010) suggests a 10-25% crash reduction for the use of median turning bays.

The treatment life for median turning bays is one to five years (iRAP 2010).

5.4.12 Overtaking Lanes

Overtaking lanes allow motorists to overtake slower-moving vehicles without moving into the opposing traffic lane. They reduce driver frustration and inappropriate overtaking. An overtaking lane provides increased road capacity and helps to reduce the incidence of head-on collision due to overtaking.

Only 3% of head-on crashes in Queensland are due to overtaking; hence their use as a road safety improvement measure should be limited to sites with a high number of head-on crashes due to overtaking, and severe sight distance restrictions (it is not appropriate as a network-wide treatment for head-on crashes).

Austroads (2015b) suggests a 30% reduction in head-on crashes through the provision of overtaking lanes.

Overtaking lanes have a treatment life of 10-20 years (iRAP 2010).

5.4.13 Two Plus One (2+1) Lane Treatments (with Wire Rope)

On two-way roads, a 2+1 lane treatment is implemented to prevent head-on and median cross-over crashes. The treatment consists of a three-lane cross-section. The outside lanes serve as a general traffic lane for one direction each. The centre lane serves as an overtaking lane for each direction of travel, alternating every 1-2.5 km, with a transition zone of up to 300 metres in length (Figure 5.18). The opposing traffic is usually separated by a wire rope barrier.

Figure 5.18: Typical 2+1 road configuration

Source: ARRB.

Whilst the 2+1 treatment may create more compact and slower conditions, it allows for overtaking in certain sections of the road in both directions. Driver frustration is reduced due to the frequent overtaking opportunities.

It is considered that this treatment is suitable for roads with an overtaking head-on crash history, for which traffic flows are not sufficient to support a dual, divided, carriageway. The treatment is recommended for roads with traffic flow rates of up to 1200 veh/h in one direction of travel (Potts & Harwood 2003).

Swedish experience indicates a 50% reduction in fatal crashes compared to a single carriageway road. This is achieved largely by eliminating head-on crashes and reducing fatal crashes to minor injury crashes (Bergh, Carlsson & Larsson 2003).

Carlsson (2009) evaluated a 2+1 road in Sweden which had a 13 metre wide cross-section with a wire rope barrier. The results indicated an 80% reduction in fatal crashes (all crash types). For motorcyclists, the number of FSI crashes (all crash types) was reduced by 40-50%.

No information was available for the treatment life for the 2+1 lane treatment. It is suggested it would be similar to wire rope median barriers of 30 years.

For further technical information, refer to *Guidelines for road design on brownfield sites* (TMR 2013) (https://www.tmr.qld.gov.au/business-industry/Technical-standards-publications/Brownfields-guidelines) and *Road planning and design manual, edition 2* (TMR 2014a) (https://www.tmr.qld.gov.au/business-industry/Technical-standards-publications/Road-planning-and-design-manual-2nd-edition).

5.4.14 Curve Treatments

Crash data shows that 56% of head-on injury crashes occur on horizontal curves and 42% of head-on injury crashes in Queensland occur on vertical grades, dips or crests. Drivers tend to use more of the travel lane when negotiating a horizontal curve compared to a straight section of road and head-on crashes may occur when drivers ‘cut the corner’. This highlights the importance of the treatment of curves and the provision of good, clear curve delineation with appropriate advanced warning to allow road users to predict the road alignment and adjust their speeds accordingly.

Curve widening and improvements may prevent vehicles from travelling outside their lane and travel closer to the centre of the road (Figure 5.19). These include increasing curve radius, providing transition curves between the straight and the bend, elimination compound curves and improving superelevation.

Figure 5.19: Curve widening on shoulders

Source: Austroads (2015a).

Vertical road realignment may be used to reduce grades, increase the radius of a crest for adequate sight distance, minimise vertical acceleration changes (for example, sag curves can be very uncomfortable for vehicle occupants) and address drainage problems (water can collect in sag curves, causing a safety problem) (iRAP 2010).

According to Austroads (2014a), increasing the radius of horizontal curves can reduce all casualty crashes by 10-50% while reconstructing the superelevation on a curve can reduce head-on crashes by up to 50% (Austroads 2015b). Vertical realignment can reduce all casualty crashes by 10-25% (iRAP 2010).

The treatment life for curve widening is five to ten years and greater than 20 years for horizontal and vertical realignment (iRAP 2010).

For further technical information refer to *Guidelines for road design on brownfield sites* (TMR 2013) (https://www.tmr.qld.gov.au/business-industry/Technical-standards-publications/Brownfields-guidelines.aspx) and *Road planning and design manual, Edition 2: Volume 3, Supplement to Austroads guide to road design Part 3: Geometric design* (TMR 2016a) (https://www.tmr.qld.gov.au/business-industry/Technical-standards-publications/Road-planning-and-design-manual-2nd-edition).

5.4.15 Speed Management

Speed has a major impact on the occurrence and severity of head-on crashes, so measures to provide safe travel speeds will lead to improved road safety. Small changes in speeds can result in significant crash and injury reductions or increases. Consistent application of curve design and treatments along a route will also influence speed choice appropriate for the road environment. Engineering measures to reduce and manage operating speeds on roads are now discussed.

Advanced warning signs, speed advisory signs and chevron alignment markers

Advanced warning signs are used to raise attention levels on curves and hazards and slow down motorists. Speed advisory signs are used to advise motorists of the comfortable travel speed of a curve. Chevron alignment markers (CAMS) are used to indicate the presence and severity of curves (Figure 5.20).

Figure 5.20: Delineation of curve using CAMS

Source: ARRB.

Research indicates that curve warning signs and speed advisory signs can reduce head-on crashes by 30% (Austroads 2015b) and all casualty crashes by 25% (Austroads 2012a). Austroads (2012a) indicates 25% reduction in all casualty crashes from the use of CAMS.

The treatment life of advanced warning signs, speed advisory signs and chevron alignment markers is one to five years (iRAP 2010).

For further technical information on the application of CAMS, refer to *Queensland Manual of uniform traffic control, Part 2* (TMR 2014d) (https://www.tmr.qld.gov.au/business-industry/Technical-standards-publications/Manual-of-uniform-traffic-control-devices).

Vehicle-activated Signs

Vehicle activated signs (VAS) are roadside signs which only target selected drivers to control speeds, on curves, at intersections and railway crossings to improve safety. The signs are triggered when a vehicle's approach speed exceeds the pre-set threshold speed. A warning message is displayed to alert the driver to the hazard leading to a change in driving behaviour (e.g. speed reduction) (Figure 5.21). There has been a 30-35% reduction in off-carriageway crashes due to the use of VAS.

Figure 5.21: Examples of VAS used on approach to curve

Source: TMR (2016a).

Burbridge, Eveleigh & Van Eysden (2010) conducted a study on VAS installed at 11 sites in Queensland. Analysis of the data from all the sites indicated a consistent reduction in average speed, 85th percentile speed and frequency of speed non-compliance on approach to the sign site.

This indicated a change in driver behaviour in response to the presence of the sign. They found that the bulk of the speed reductions occurred within a month after activation, and that this reduction remained stable over the following months.

The treatment life for VAS is five to ten years (Austroads 2015a).

For further information, refer to Technical Note TN160 – *Vehicle activated signs* (TMR 2016a) (https://www.tmr.qld.gov.au/business-industry/Technical-standards-publications/Technical-Notes/Traffic-engineering).

Transverse rumble strips

Transverse, or roadway, rumble strips are an audio-tactile treatment applied transverse, or across, the travel lane to warn of approaching curves (Figure 5.22). They tend to be used to supplement curve signage when the conventional signage and delineation is not working.

Figure 5.22: Use of transverse rumble strip on approach to curve

Source: Federal Highway Administration (FHWA) (2006).

Some concerns with the use of transverse rumble strips are:

- noise issues for nearby residents
- motorists using the opposing lane to avoid the rumble strip
- can be hazardous to motorcyclists and cyclists.

There is no information available regarding the effectiveness (in terms of crash reduction) of transverse rumble strips used on the approaches to curves. However, Charlton and Bass (2006) found a reduction in average vehicle speeds of 0.1-6% when transverse rumble strips were placed on the approaches to curves. iRAP (2010) suggests a casualty crash reduction of 10-25% for the general use of rumble strips.

The treatment life for transverse rumble strips is five to ten years based on longitudinal rumble strips.

Readers are referred to TMR (2015c) for further technical information.

For further information, refer to *Traffic and road use management, Volume 2: Guide to road safety, Part 5: Road safety for rural and remote areas* (TMR 2015c) (https://www.tmr.qld.gov.au/business-industry/Technical-standards-publications/Traffic-and-Road-Use-Management-manual/Volume-2) .

Perceptual countermeasures

Innovative road pavement markings such as transverse bars (Figure 5.23), additional marker posts, enhanced edge-post spacing with ascending post heights for curves, and other perceptual countermeasures may be useful to highlight deceptive corners and may aid motorists in adjusting their speed prior to entering the curve.

Figure 5.23: Transverse bars

Source: Courtesy of Virginia Department of Transportation (cited in FHWA 2006).

Martindale & Urlich (2010) trialled the use of transverse markings on the approach to an intersection and bridge in New Zealand. They found the main long-term benefit to be a reduction in vehicle speed at the start of the treatment. They reported a reduction in mean speed of 4-12 km/h and 85th percentile speed of 3 km/h, indicating the treatment does have alerting properties. Charlton and Baas (2006) found the transverse lines to be effective in reducing vehicle speeds by 8-14% on approaches to hazards. No information regarding crash reduction and the treatment life was available for perceptual countermeasures.

Point-to-point Speed Cameras

Point-to-point speed cameras use pairs of cameras to determine an average speed given a known distance between the cameras. The camera technology can determine if a vehicle has travelled faster than the minimum legal travel time over a specific section of road by reading and matching vehicle number plates at each camera site. Compared with traditional spot-speed fixed cameras, which have a site-specific effect, the point-to-point camera system has a link-long influence on drivers and their speeds, despite enforcement being visible only at the start and end of the enforced road length.

Point-to-point speed cameras are operational in Queensland, Victoria, New South Wales and South Australia.

Transport NSW (2015) analysed the performance of point-to-point speed enforcement data. The results showed a reduction in the number of heavy vehicle crashes. Infringement data for average speed offences in point-to-point enforcement lengths showed a high level of compliance and a low number of infringements. Note that, in New South Wales, point-to-point cameras are only used to measure the speeds of heavy vehicles.

The result of evaluation studies of point-to-point speed cameras in Europe was reported in Austroads (2012b). Many of these studies reported reductions in FSI crashes in the order of between 33-85%. There were also positive effects on speeds with reductions in both mean and 85th percentile speeds, and high compliance rates with the posted speed limit.

5.4.16 Road Surface Condition

Poor skid-resistance can occur when the road surface becomes worn (aggregate becomes polished) under the action of traffic or, temporarily, if there is a build-up of oil or debris on the road or if road drainage is poor (IRAP 2010; Austroads 2009). This may result in a loss of control of vehicles, particularly in wet conditions and on curves.

Improvements to skid resistance can be achieved through:

- changes to the geometrical and physical characteristics of the road
- changes to the surfacing of the road including cleaning and re-surfacing treatments
- traffic engineering treatments to provide guidance to road users and reduce travel speeds.

Improved skid resistance and road surface condition with good road drainage, particularly at high-risk curves, will assist in preventing vehicles travelling outside their lane. It is important that the road surface has an appropriate level of skid resistance in both wet and dry conditions.

Austroads (2012a) provides a crash reduction of 35% for all crash types for skid resistance improvement.

The treatment life for improved skid resistance is five to ten years (iRAP 2010).

For further information regarding skid resistance refer to *Skid resistance management plan* (TMR 2016b) (https://www.tmr.qld.gov.au/business-industry/Technical-standards-publications/Skid-Resistance-Management-Plan).

5.4.17 Shoulder and Pavement Edge Breaks

Poor shoulder condition, edge breaks and drop-offs can reduce the effectiveness of the shoulder recovery area for a vehicle which is out of control. Widening and edge treatments make it easy for errant drivers to re-enter the travel lanes, and avoid steep angle entry which may lead to head-on and run-off-road crashes due to over steering. The shoulder should be regularly maintained to reduce the occurrence of an edge break and drop-off (Figure 5.24).

Figure 5.24: Edge drop along shoulder

Source: Austroads (2015a).

5.4.18 Provision for Motorcyclists and Heavy Vehicles

Crash statistics indicate that motorcyclists are over-represented in head-on injury crashes and heavy vehicles are over-represented in fatal crashes in Queensland. Due consideration should be given to these vehicles when determining treatments for popular motorcycle routes and roads with a high proportion of heavy vehicles.

Treatments to reduce the crash risk and severity of head-on crashes for motorcyclists include (Austroads 2016c):

- improvements to the road surface (re-surfacing) on curves
- improvement to curve approaches and departures
- improving and maintaining delineation.
- the use of curve warning/quality signage including motorcycle-specific signage schemes and standalone signs
- The provision of a smooth, consistent and predictable road surface, including not having changes in surface friction, delamination, potholes, water pooling or flowing on the surface, rutting, corrugations and depressions from surface covers or tram/train tracks
- lane widening and sealed shoulder widening on curves
- the provision of wide centrelines
- the provision of frequent, safe and legal opportunities for motorcyclists to pass vehicles that are operating at a slower speed, particularly on roads in mountainous or rolling terrain which have narrow formations and poor sight distances.

Treatments to reduce the risk and severity of head-on crashes involving heavy vehicles include:

- physical separation of opposing traffic through road duplication
- consideration of heavy vehicles in barrier design – heavy vehicle will not be contained by a normal roadside safety barrier and a car may be extensively damaged by impact with a barrier designed for trucks (a rigid barrier, depending on height and other details, provides the highest level of containment of heavy vehicles)
- separation of vehicles or road users of different size
- improved delineation and signage
- curve treatments, including curve widening and advisory signs on sharp curves
- speed management
- improved road surface condition
- the use of wide centreline treatments
- the provision of overtaking opportunities.

6 TECHNICAL NOTE: RUN-OFF-ROAD CRASHES

6.1 Introduction

This Technical Note provides background information to the run-off-road crash problem and associated statistics for Queensland. It provides insight into the contributory factors involved in run-off-road crashes and gives guidance regarding road-based treatments that may be adopted to reduce the likelihood and severity of run-off-road crashes.

Austroads (2015c) defines a run-off-road crash as occurring 'when a vehicle leaves the road and often collides with a roadside object such as a tree or pole'. It is therefore important within a Safe System that practitioners are aware of the measures available to reduce the incidence and severity of this crash type.

6.2 Queensland Statistics

Between 2007 and 2011, there were a total of 69 533 injury crashes recorded on Queensland roads, of which 40% resulted in fatal or serious injury (FSI).

Run-off-road crashes, including out-of-control crashes, represent 26% of all injury crashes, 33% of FSI on all Queensland roads and 36% of FSI on state-controlled roads. Approximately 48% of run-off-road injury crashes occur on state-controlled roads.

The risk of FSI crashes was higher for run-off-road and out-of-control crashes, with 51% of run-off-road crashes and 52% of out-of-control crashes resulting in fatal or serious injury compared to 40% for all injury crash types.

The risk of run-off-road injury crashes on curves was higher than for all injury crashes.

There was a 55% reduction in fatal out-of-control crashes between 2007 and 2011, but a 10% increase in out-of-control FSI crashes.

6.3 Key Contributing Factors

6.3.1 Road Features

Based on crash data between 2007 and 2011 the following road features were found to contribute to the occurrence and severity of run-off-road crashes:

- The majority of run-off-road injury crashes on state-controlled roads (47%) occurred on high speed zones (80 km/h or more).
- The proportion of fatal run-off-road and out-of-control crashes increased as the posted speed limit increased.
- There was a substantially higher risk of run-off-road and out-of-control crashes on a curve, with 44% of run-off-road injury crashes and 47% of out-of-control injury crashes occurring on curves compared with 23% for all injury crashes.
- Vertical grade had an impact on the likelihood of run-off-road crash occurrence, but no effect on the severity of the crash (over 30% of run-off-road and out-of-control injury crashes occurred on a grade, dip or crest).
- There were more run-off-road crashes on wet road surfaces (22%) compared to all injury crashes (16%).

- The risk of a run-off-road injury crash during poor lighting conditions (i.e. dark and dusk/dawn) was higher (46%) than for all injury crashes (30%); more than a third (35%) of out-of-control injury crashes occurred in poor lighting conditions.
- Most of the run-off-road injury crashes (72%) resulted in a collision with a roadside object and a further 17% resulted in an overturned vehicle.
- There were more out-of-control injury crashes on unsealed roads (13%) compared to all injury crashes (3%).

6.3.2 Other Contributing Factors

Other contributing factors impacting on the severity and occurrence of run-off-road crashes include the following:

- There were comparatively more run-off-road injury crashes during the night compared to all injury crashes.
- The top five contributing factors recorded for run-off-road injury crashes were: disobeying the road rules (49%), young adults (17-24 years old) (37%), controller condition (33%), alcohol related (25%) and road condition (19%).
- The top five contributing factors recorded for out-of-control injury crashes were: disobeying the road rules (37%), controller condition (31%), young adults (17-24 years old) (30%), road condition (25%) and alcohol related (17%).
- Fatigued drivers were a contributing factor in 27% of the run-off-road crashes and 22% of the out-of-control crashes on state-controlled roads.
- Young controllers (17-24 years old) comprised 36% of the primary vehicle controllers involved in run-off-road injury crashes and 30% in out-of-control injury crashes.
- Male controllers were involved in two-thirds of run-off-road injury crashes and 78% of out-of-control injury crashes and with a higher risk of these resulting in severe crashes.
- Motorcycles/mopeds (69%) and bicycle riders (59%) had the highest risk of FSI resulting from a run-off-road crash; motorcycles/mopeds were over-represented in out-of-control injury crashes.

6.4 Treatments

6.4.1 Shoulder Treatment

The provision of a sealed and unsealed shoulder provides an area whereby a vehicle may successfully recover during a run-off-road event. Run-off-road crashes can be significantly reduced if wide shoulders are provided (Figure 6.1), particularly where none existed previously.

Figure 6.1: Recently sealed shoulder on two lane road

Source: ARRB.

The width of the shoulder should not be too wide as drivers may use them as an additional lane. Delineation is generally improved due to the provision of edge lines during shoulder widening or when sealing a shoulder.

Austroads (2015a) provides run-off-road casualty crash reduction of:

- 30% for sealing existing unsealed shoulder (0.6-1.0 m)
- 44% for 0.5 m sealed shoulder (where none existed previously)
- 72% for 1.0 m sealed shoulder (where none existed previously)
- 76% for 1.5 m sealed shoulder (where none existed previously).

Research reported in Austroads (2011a) showed that the high crash risk for a narrow seal (lane width and sealed shoulder width less than 3.0 metres) can be substantially reduced by the provision of wide unsealed shoulders.

The treatment life for a sealed road shoulder is ten plus years (Austroads 2015a).

For further information, refer to *Guidelines for road design on brownfield sites* (TMR 2013) (https://www.tmr.qld.gov.au/business-industry/Technical-standards-publications/Brownfields-guidelines.aspx).

6.4.2 Shoulder Rumble Strips

Profiled edge lining, including shoulder rumble strips and audio tactile edge lines (ATLM), consist of a series of grooves or raised strips placed along the road shoulder (see Figure 6.2). When a vehicle’s tyre runs along the profiled edge lines it generates a vibration or noise to alert the driver to move back into their lane. They are effective in reducing fatigue-related crashes. They can also improve the visibility of edge lines during the night and in wet weather.

The use of shoulder rumble strips in the urban environment may not be desirable to cyclists and may produce increased noise levels. They can also be hazardous to motorcyclists as they tend to track closer to the shoulder when travelling around curves.

For audio-tactile edge lines to be effective, the shoulders on that length of road should have a minimum width of 500 mm, desirably 1 metre, to allow the driver to correct and then re-enter the running lane.

Typically raised profiled edge lines have been used throughout Australia. VicRoads is currently implementing a mass action ATCL marking program which involves the installation of audio tactile centrelines and edge lines (where possible) on high-speed, undivided rural roads across Victoria. The aim is to reduce the risk of fatal and serious injuries due to run-off-road and head-on crashes in the most efficient way, given the high cost of addressing these crash types through other infrastructure treatments on these roads. To date, 750 km of a total of 4 400 km has been completed.

Figure 6.2: A longitudinal rumble strip or raised profile edge line

Source: iRAP (2010).

In the USA and Canada, snow plough blades passing over raised rumble strips tend to scrape them off the road surface, so milled rumble strips are used extensively (Figure 6.3). The US Transportation Research Board (2009) reported that the provision of milled shoulder and edge rumble strips led to reductions in single-vehicle run-off-road fatal and serious injury crashes of 18% on rural freeways, and 29% on two-lane rural roads. Milled rumble strips are currently being trialled in NSW and TMR are currently developing a trial of milled rumble strips to be conducted in Queensland.

Figure 6.3: Milled rumble strips adjacent to edgeline

Source: Federal Highway Administration (2015).

Austroads (2012a) reported a crash reduction of 20% for all casualty crashes and a 40% reduction for run-off-road crashes after the installation of profiled edge lines.

The treatment life for ATLM is one to five years (iRAP 2010). The treatment life for milled rumble strips is greater, the same as that of the pavement.

For further information, refer to *Traffic and road use management – Volume 2 – Guide to road safety, Part 5: Road safety for rural and remote areas* (TMR 2015b) (https://www.tmr.qld.gov.au/business-industry/Technical-standards-publications/Traffic-and-Road-Use-Management-manual/Volume-2).

6.4.3 Clear Zone and Hazard Removal

A clear zone is an area adjacent to the edge of the trave lane where errant vehicles may travel without striking any hazards (Figure 6.4). Ideally, the clear zone should be free of unforgiving roadside objects such as trees, poles, deep ditches and other street furniture. It has been shown that the relative risk of run-off-road casualty crashes reduces with increasing clear zone width. In the situation where it is not possible to have hazard free clear zone (particularly on curves), the hazards should be protected/shielded with a safety barrier or designed to be frangible.

Figure 6.4: Wide clear zone (route sign with frangible pole)

Source: ARRB.

Austroads (2015a) indicates the following crash reduction for widening of an existing 0-2 metre clear zone:

- 24% for widening of 2-4 metres
- 49% for widening of 4-8 metres
- 54% for widening >8 m.

Studies have shown that the benefits associated with improving roadside conditions are greater on horizontal curves than on straight sections.

Widening of the clear zone has a treatment life of five to ten years (Austroads 2015a).

For technical information refer to *Road planning and design manual, Edition 2: Volume 3, Supplement to Austroads guide to road design, Part 6: Roadside design, safety and barriers* (TMR

2014a) (https://www.tmr.qld.gov.au/business-industry/Technical-standards-publications/Road-planning-and-design-manual-2nd-edition.aspx).

6.4.4 Side Slope Improvements

Very steep cuttings and embankments (Figure 6.5) represent an unforgiving roadside hazard, which may contribute to increased severity. The batter slope is important in determining the effective width of the clear zone.

Side slope improvement will reduce the likelihood of a vehicle overturning in the event of a run-off-road or loss-of-control crash and may also reduce the severity of these crash types. Flatter slopes provide and area that is traversable, allowing an errant vehicle to recover and return to the roadway.

If a slope is non-recoverable and/or not clear of hazards it should be protected by installing a safety barrier. Where there is a downward slope a run-out may be required at the base of the slope.

Figure 6.5: Steep embankment within the clear zone

Source: Austroads (2015a).

iRAP (2010) indicates the effectiveness of side slope improvement is 10-25% reduction in casualty crashes. Treatment life of side slope improvement is 20 plus years (iRAP 2010).

For further information refer to *Road planning and design manual, Edition 2: Volume 3, Supplement to Austroads guide to road design, Part 6: Roadside design, safety and barriers* (TMR 2014a) (https://www.tmr.qld.gov.au/business-industry/Technical-standards-publications/Road-planning-and-design-manual-2nd-edition.aspx).

6.4.5 Roadside Safety Barriers

Safety barriers can be used to prevent errant vehicles leaving the road and striking roadside hazards. If a hazard is unable to be removed, then road users should be shielded from the hazard by a safety barrier.

Barriers should be used where the potential damage caused by the hazard is greater than that of the barrier itself. Before the decision is taken to install a safety barrier, all other methods of hazard risk reduction must be explored. This includes consideration of the removal, relocation or modification of existing hazards. Only when other steps are proven to be impractical, should a safety barrier be considered as a solution to the problem.

The term 'safety barriers' refers to a range of devices designed to restrict the lateral movement of errant vehicles, with the intention of either guiding them back onto the roadway or bringing them to a stop safely.

Safety barriers are categorised according to their stiffness. These include:

- rigid barriers such as reinforced concrete barriers which experience negligible deflection when impacted (Figure 6.6)
- semi-rigid barriers such as W-beam metal barriers (Figure 6.7)
- flexible barriers such as wire rope barriers (Figure 6.8).

Figure 6.6: Rigid concrete safety barrier

Source: ARRB.

Figure 6.7: Semi rigid W-Beam safety barrier

Source: Austroads (2010).

Figure 6.8: Flexible wire rope safety barrier

Source: Photo courtesy of AusRAP (cited in Austroads, 2015a).

The selection of an appropriate barrier type should primarily be based on its performance capability and deflection. In other words, the barrier 'must possess sufficient structural integrity to contain and redirect the design vehicle', and the 'expected deflection of a barrier should not exceed available room to deflect' (Austroads 2010).

It is suggested in Austroads (2014a) that barrier be installed between 1.5 metres and 4 metres from the road shoulder. This is because barriers placed any closer to the roadway lead to significant increases in collisions with the barrier and offset further away lead to increase in impact angle resulting in increased crash severity (Austroads 2014b). Note, TMR guideline specifies a minimum clearance of 0.5 m to allow for vehicle overhang (TMR *Road planning and design manual, Edition 2, Volume 3: Supplement to Austroads guide to road design, Part 6: Roadside design, safety and barriers* (TMR 2014a) https://www.tmr.qld.gov.au/business-industry/Technical-standards-publications/Road-planning-and-design-manual-2nd-edition.aspx).

Flexible barriers have been found to significantly reduce the severity of crash outcomes. Crash studies on the use of flexible wire-rope barriers on a sample of high-speed Victorian roads reported a lower average crash severity than other barrier types (Austroads 2014b).

The crash reduction factors for the use of various types of median barriers are presented in Table 6.1.

Table 6.1: Effectiveness (CRF) of barrier treatments

Barrier treatment	Crash type	Crash Reduction Factor
Rigid barrier	All fatal crashes	90%
	All crash types	–15%
Semi-rigid barrier	ROR (all crashes)	30%
	ROR (fatal)	44-56%
	All crash types (injury crashes)	5-91%
Flexible barrier	ROR and cross median (injury crashes)	79-86%

Source: Adapted from Austroads (2014c) and Austroads (2016a).

When selecting a barrier system, consideration should be given to all the types of road users as some barriers may have reduced performance for heavy vehicles, motorcycles, bicycles and cars (when there are larger angles of impact and at speeds higher than barrier test speeds).

When considering heavy vehicles, it is important to note that a heavy vehicle will not be contained by a normal roadside safety barrier and a car may be extensively damaged by impact with a barrier designed for trucks. The level of containment required by the safety barrier should be determined based on a risk assessment.

All barrier types are hazardous to motorcyclists, who have a high risk of sustaining serious injury or death from sliding into or colliding with the barrier.

Some features of safety barriers can be hazardous to motorcyclists. These include (Austroads 2010):

- exposed barrier posts
- upper and lower W-beam edges
- protruding reflectors utilising metal componentry
- barrier systems that are too low as motorcyclists can be catapulted over barrier systems of insufficient height
- discontinuous or jagged barrier surfaces, such as concrete barriers with decorative designs, which present edges to concentrate the forces of impact
- rigid barriers (likely to be involved in front-on collisions) which require an impacting rider to absorb virtually all of the kinetic energy at impact.

Barrier systems can be made more motorcycle friendly by shielding the barrier posts, modifying or replacing posts with more forgiving post shapes or covering exposed posts with specifically designed impact attenuators. Examples of these are illustrated in Figure 6.9, Figure 6.10 and Figure 6.11. These issues should be considered when designing safety barrier systems where there are a considerable number of motorcycles using a road or along motorcycle routes.

Figure 6.9: Wire-rope barrier post impact absorbing pads

Source: Ingal Civil Products (2016a).

Figure 6.10: Guardrail post caps

Source: Ingal Civil Products (2016a).

Figure 6.11: Under-run protection for motorcyclists on W-Beam safety barrier

Source: Ingal Civil Products (2016a).

The treatment life for safety barriers is ten plus years (Austroads 2015a).

For technical information refer to *Road planning and design manual, Edition 2: Volume 3, Supplement to Austroads guide to road design, Part 6: Roadside design, safety and barriers* (TMR 2014a) (https://www.tmr.qld.gov.au/business-industry/Technical-standards-publications/Road-planning-and-design-manual-2nd-edition.aspx).

6.4.6 Impact Attenuators

Impact attenuators and crash cushions are used to protect errant vehicles from impacting with fixed hazards (Figure 6.12). They absorb energy at a controlled rate to decelerate a vehicle in a short distance to a safe stop before impact with the hazard (Austroads 2010). Some crash cushions redirect the vehicle away for the hazard.

Figure 6.12: Example of a crash attenuation cushion

Source: Ingal Civil Products (2016b).

Impact attenuation does not influence the incidences of crashes but reduces the severity of crashes. Austroads (2012a) provides casualty crash reduction of 50% and fatal crash reduction of 70% for the installation of impact attenuators.

The treatment life for impact attenuators is ten plus years (Austroads 2015a).

For further information refer to *Road planning and design manual, Edition 2: Volume 3, Supplement to Austroads guide to road design, Part 6: Roadside design, safety and barriers* (TMR 2014a) (https://www.tmr.qld.gov.au/business-industry/Technical-standards-publications/Road-planning-and-design-manual-2nd-edition.aspx).

6.4.7 Curve Treatments

Crash data shows that 44% of run-off-road injury crashes occurred on horizontal curves and 31% of run-off-road injury crashes occurred at vertical grades, dips or crests. This highlights the importance of the treatment of curves and the provision of good, clear curve delineation with appropriate advanced warning to allow road users to predict the road alignment and adjust their speeds accordingly.

Curve widening and improvements may prevent vehicles from travelling outside their lane and closer to the centre of the road. These include increasing curve radius, providing transition curves between the straight and the bend, elimination compound curves and improving superelevation.

Figure 6.13: Curve widening on shoulders

Source: Austroads (2015a).

Vertical road realignment may be used to reduce grades, increase the radius of a crest for adequate sight distance, minimise vertical acceleration changes (for example, sag curves can be very uncomfortable for vehicle occupants) and address drainage problems (water can collect in sag curves, causing a safety problem) (iRAP 2010).

Increasing the radius of horizontal curves can reduce all casualty crashes by 10-50% (Austroads 2014a). Vertical realignment can reduce all casualty crashes by 10-25% (iRAP 2010).

All of these curve treatments have a treatment life of 20 years or more (iRAP 2010).

For technical information refer to the *Guidelines for road design on brownfield sites* (https://www.tmr.qld.gov.au/business-industry/Technical-standards-publications/Brownfields-guidelines.aspx) (TMR 2013) and *Road planning and design manual, Edition 2, Volume 3, Supplement to Austroads guide to road design, Part 3: Geometric design* (TMR 2016c) (https://www.tmr.qld.gov.au/business-industry/Technical-standards-publications/Road-planning-and-design-manual-2nd-edition).

6.4.8 Speed Management

Speed has a major impact on the occurrence and severity of run-off road crashes, so measures to provide safe travel speeds will lead to improved road safety. Small changes is speeds can result in significant crash and injury reductions or increases. The consistent application of curve design and treatments along a route will also influence speed choice appropriate for the road environment. Engineering measures to reduce and manage operating speeds on roads are now discussed.

Advanced warning signs, speed advisory signs and chevron alignment markers

Advanced warning signs are used to raise attention levels of curves and hazards and slow down motorists. Speed advisory signs are used to aid motorists of the comfortable travel speed of a curve. Chevron alignment markers (CAMS) are used to indicate the presence and severity of curves. An example of delineation of curve using CAMS is shown in Figure 6.14.

Figure 6.14: Delineation of curve using CAMS

Source: ARRB.

Research indicates that curve warning signs and speed advisory signs can reduce run-off road crashes by 30% (Austroads 2015b) and all casualty crashes by 25% (Austroads 2012a). Research indicates 25% reduction in all casualty crashes from the use of CAMS.

The treatment life of advanced warning signs, speed advisory signs and chevron alignment markers is one to five years (iRAP 2010).

Refer to *Queensland Manual of uniform traffic control devises supplement, Part 2 traffic control devices for general use* for information on application of CAMS (TMR 2014d) (https://www.tmr.qld.gov.au/business-industry/Technical-standards-publications/Manual-of-uniform-traffic-control-devices).

Vehicle-activated signs

Vehicle-activated signs (VAS) are triggered when a vehicle's approaching speed exceeds the threshold speed limit (the sign displays the hazard). TMR has adopted a 30-35% reduction in off-carriageway crashes for the use of VAS (TMR 2014). Examples of VAS used on an approach to a curve are shown in Figure 6.15.

Figure 6.15: Examples of VAS used on approach to curve

Source: TMR (2016),

Burbridge et al (2010) conducted an analysis of 11 sites with VAS. The data indicated that there was generally a consistently reduction in average speed, 85th percentile speed and frequency of speed non-compliance on approach to the sign site. This suggested a change in driver behaviour in response to the presence of the sign. They found that the bulk of the speed reductions occurred within a month after activation, but that this reduction remained stable over the following months.

The treatment life for VAS is five to ten years (Austroads 2015a).

Refer to the Technical Note TN160 – *Vehicle activated signs* for technical information (TMR 2016a) (https://www.tmr.qld.gov.au/business-industry/Technical-standards-publications/Technical-Notes/Traffic-engineering).

Transverse rumble strips

Transverse or roadway rumble strips are an audio-tactile treatment applied transversely across the traffic lane to warn of approaching curves. These tend to be used when the conventional signage and delineation are not working; they supplement curve signage. Some examples of the use of transverse rumble strips on the approach to curves are shown in Figure 6.16.

Figure 6.16: Use of transverse rumble strip on approach to curve

Source: FHWA (2006),

Some concerns with the use of transverse rumble strips are:

- noise issues for nearby residents
- motorists using an opposing lane to avoid the rumble strip
- can be hazardous to motorcyclists and cyclists.

There is no information available regarding the effectiveness (in terms of crash reduction) of transverse rumble strips used on the approaches to curves. However, Charlton and Bass (2006) found a reduction in average vehicle speeds of 0.1-6% when trialling transverse rumble strips on approaches to curves. iRAP (2010) indicates a casualty crash reduction of 10-25% for the general use of rumble strips.

The treatment life for transverse rumble strips is five to ten years (Austroads 2015a).

Refer to the *Traffic and road use management, Volume 1 – Guide to traffic management, Part 10: Traffic control and communication devices* (TMR 2016d) (https://www.tmr.qld.gov.au/business-industry/Technical-standards-publications/Traffic-and-Road-Use-Management-manual/Volume-1) *and Traffic* and *road use management, Volume 2 – Guide to road safety, Part 5: Road safety for rural and remote areas* (TMR 2006) (https://www.tmr.qld.gov.au/business-industry/Technical-standards-publications/Traffic-and-Road-Use-Management-manual/Volume-2) on Transport and Main Roads' website for technical information.

Perceptual countermeasures

Innovative road pavement markings such as optical speed bars (Figure 6.17), additional marker posts, enhanced edge-post spacing with ascending post heights for curves, and other perceptual countermeasures may be useful to highlight deceptive corners and may aid motorists in adjusting their speed prior to entering the curve.

Figure 6.17: Transverse bars

Source: Virginia Department of Transportation (cited in Federal Highway Administration 2006)

Martindale & Urlich (2010) trialled the use of transverse markings on the approach to an intersection and bridge in New Zealand. They found that the main benefit in the longer term was a reduction in vehicle speed at the start of the treatment, with a reduction in mean speed of 4-12 km/h and 85th percentile speed of 3 km/h, indicating that it is does have alerting properties. Charlton and Baas (2006) found the transverse lines to be effective in reducing vehicle speeds by 8-14% on approaches to hazards. No information regarding crash reduction and the treatment life was available for perceptual countermeasures.

Point to point cameras

Point-to-point speed cameras involve the use of pairs of cameras to determine an average speed given a known distance between cameras. The camera technology can determine if a vehicle has travelled faster than the minimum legal travel time for a specific section of road by reading and matching vehicle number plates at each camera site. Compared with traditional spot-speed fixed cameras, which have a site-specific effect, the point-to-point camera system has a link-long influence on drivers and their speeds, despite enforcement being visible only at the start and end of the enforced road length.

Point-to-point speed cameras are operational in Queensland, Victoria, New South Wales and South Australia.

Transport NSW (2015) analysed the performance of point-to-point speed enforcement data. The results showed a reduction in the number of heavy vehicle crashes since the cameras commenced operation. Infringement data for average speed offences in point-to-point enforcement lengths show a high level of compliance and a low number of infringements. Note that, in New South Wales, point-to-point cameras are only used to measure heavy vehicles speeds.

Evaluation studies of point-to-point speed cameras in Europe were reported in Austroads (2012b). Many of these studies reported reductions in KSI (killed or serious injury) crashes after the installation of point-to-point speed enforcement in the order of between 33-85%. There was also positive effects on speed with reductions in mean and 85th percentile speeds, and high compliance rates with the posted speed limit.

6.4.9 Road Surface Condition

Poor skid-resistance can occur when the road surface becomes worn (aggregate becomes polished) under the action of traffic, or temporarily if there is a build-up of oil or debris on the road or if road drainage is poor as shown in Figure 6.18 (IRAP 2010). This may result in a loss of control of vehicles, particularly in the wet and on curves.

Figure 6.18: Poor skid resistance – polished road surface

Source: ARRB.

Improvements to skid resistance can be achieved through:

- changes to the geometrical and physical characteristics of the road
- changes to the surfacing of the road, including cleaning and re-surfacing treatments
- traffic engineering treatments to provide guidance to road users and reduce travel speeds.

Improved skid resistance and road surface condition with good road drainage, particularly at high-risk curves, will assist in preventing vehicles travelling outside their lane. It is important that the road surface has an appropriate level of skid resistance in both wet and dry conditions.

Austroads (2012a) provides a crash reduction of 35% for all crash types for improving the skid resistance of the road surface.

The treatment life for improved skid resistance is five to ten years (iRAP 2010).

For further information regarding skid resistance refer to TMR's Skid resistance management plan (TMR 2016b) (https://www.tmr.qld.gov.au/business-industry/Technical-standards-publications/Skid-Resistance-Management-Plan).

6.4.10 Shoulder and Pavement Edge Breaks

Poor shoulder condition, edge breaks and drop-off can reduce the effectiveness of the shoulder recovery area when a vehicle loses control. Widening and edge treatments make it easy for errant drivers to re-enter the travel lanes and avoid steep angle entries which may lead to head-on and run-off-road crashes due to over steering. The shoulder should be regularly maintained to reduce the risk of edge break occurring. An example of an edge drop off a shoulder is shown in Figure 6.19.

Figure 6.19: Edge drop along shoulder

Source: Austroads (2015a).

6.4.11 Motorcyclists and Cyclists

Crash statistics indicate that motorcyclists and cyclists have a higher risk of fatal and serious injury when involved in a run-off-road crash in Queensland. Due consideration should be given to these vehicles when determining treatments for popular motorcycle and cyclist routes.

Treatments to reduce the crash risk and severity of run-off-road crashes for motorcyclists and cyclists include (Austroads 2016c):

- improvements to the road surface (in particular re-surfacing) on curves
- improvement to curve approaches and departures
- improving and maintaining delineation
- the use of curve warning/quality signage, including motorcycle-specific signage schemes and standalone signs
- the provision of a smooth, consistent and predictable road surface; this includes not having changes in surface friction, delamination, potholes, water pooling or flowing on the surface, rutting, corrugations and depressions from surface covers or tram/train tracks
- lane widening and sealed shoulder widening on curves

- a hazard-free clear zone – any hazards that are deemed necessary (e.g. signage, guide posts, light poles) should be set back as far as practicable from the road shoulder and be motorcyclist/cyclist friendly or protected by a less severe hazard such as a motorcycle-friendly safety barrier.

7 TECHNICAL NOTE: INTERSECTION CRASHES

7.1 Introduction

This Technical Note addresses intersection crashes in Queensland. It provides background information to the intersection crash problem and associated statistics for Queensland. It also provides insight into the contributory factors involved in these crashes and gives guidance regarding road-based treatments that may be adopted to reduce the likelihood and severity of intersection crashes.

Intersection crashes represent the highest proportion of crashes on Queensland roads, particularly in urban areas. In rural areas, or where vehicles travel at higher speeds, intersection crashes can be particularly severe. It is therefore important within a Safe System that practitioners are aware of the measures available to reduce the incidence and severity of this crash type.

7.2 Queensland statistics

In Queensland, between 2007 and 2011, there were a total of 69 533 injury crashes recorded on Queensland roads, of which 30 716 were intersection crashes. Intersection crashes accounted for 44% of all injury crashes and 40% of FSI crashes during the five year period.

On state-controlled roads, intersections crashes accounted for 40% of injury crashes and 36% of FSI crashes, even though intersections account for less than 5% of the network.

There was an overall reduction of 15% in intersection injury crashes over the five year period. However, no such decline was observed in fatal intersection crashes.

7.3 Key contributing factors

7.3.1 Road feature

Based on crashes between 2007 and 2011 the following road features were found to contribute to the occurrence and severity intersection of crashes:

- Most of the intersection injury crashes occurred at T-junctions (47%), cross-intersections (34%) and roundabouts (10%), the three most common intersection types.
- The majority of the intersection injury crashes occurred at intersections with no traffic control (33%), intersections with traffic lights (31%) and give way signs (27%), and stop signs (8%).
- The main intersection injury crashes were angle crashes (57%), rear-end (21%), hit object (10%) and pedestrian crashes (4%).
- DCA code 202 (right-through opposing turn) crashes account for 25% of intersection FSI crashes on state roads and 19% on locally-controlled roads.
- About 61% of DCA code 202 crashes that resulted in FSI occurred at intersections with traffic lights.
- About 41% of FSI and 37% of all injury crashes that occurred at intersections controlled by traffic signals were DCA code 202 crashes.
- About 86% of the intersection angle injury crashes occurred at T-junctions (43%) and cross-intersections (43%).
- The majority of rear-end intersection injury crashes occurred at intersections with no traffic control (39%), intersections with traffic lights (33%) and give way signs (27%).

- Most of the rear-end intersection injury crashes occurred at T-junctions (55%), cross-intersections (24%) and roundabouts (10%).
- Most of the pedestrian injury crashes at intersections occurred at T-junctions (49%) and cross-intersections (44%), especially those controlled by traffic lights. More than half (52%) of pedestrian injury crashes at intersections occurred at intersections controlled by traffic lights.
- The majority of hit object intersection injury crashes occurred at T-junctions (52%), followed by roundabouts (19%) and cross-intersection (16%).
- Most of the intersection injury crashes involving parked vehicles occurred at T-junctions (73%).
- Railway crossings had the highest FSI rate (52%) and highest fatality rate (9%), followed by multiple road intersections (42% FSI).
- Railway crossings controlled by sign only had the highest FSI rate (63%), followed by railway crossings controlled by flashing lights (53%).
- There are more intersection injury crashes (89%) on low-speed roads (below 80 km/h) than all other injury crashes (73%).
- Crashes at unlit intersections were more severe than other lighting conditions – unlit intersections recorded the highest proportion of FSI and fatal night-time crashes.

7.3.2 Other Contributing Factors

Other contributing factors impacting on the severity and occurrence of intersection crashes include:

- The top five contributing factors recorded for intersection injury crashes were disobeying road rules, young adult drivers (16 to 24 years old), senior adult drivers (60 and above), controller condition, and alcohol.
- Middle-aged controllers (25 to 59 years old) make up the largest proportion of primary vehicle controllers involved in intersection injury crashes (60%), partly because they have the widest range.
- Disobeying road rules was a factor in a high proportion of intersection injury crashes (79%), more than for all other injury crashes (67%).
- As the primary vehicle controller, male drivers were involved in 59% of the intersection injury crashes.
- The risk of an FSI intersection crash was highest for motorcycle/moped (55%), heavy vehicles (40%) and cyclists (40%).

7.4 Intersection Treatments

7.4.1 Grade Separation

The most effective way to reduce safety outcomes at intersection is separate conflicting vehicle movements using grade separation (Figure 7.1). This is achieved by the use of overpasses and interchanges. The use of grade separating can also improve the flow of traffic.

Grade separation with interchanges and overpasses is typically used as part of freeway systems where there are large traffic flows to justify the high cost. The use of on-ramps and off-ramps can increase weaving and merging manoeuvres and result in crashes.

Figure 7.1: Grade separated intersection

Source: Austroads (2015a).

IRAP (2010) indicates a 25-40% crash reduction by the use of grade separation. Austroads (2015a) indicates 55% crash reduction for grade separation of cross-intersections and 20% crash reduction for the grade separation of Y-junctions.

The treatment life of grade separation is greater than 20 years (iRAP 2010).

7.4.2 Intersection Delineation

Clear delineation is required at intersections to inform drivers of the presence of an intersection and to clearly show the layout and the priority of traffic movements that may occur. If road users are unaware of the intersection it may result in collision with other vehicles or late breaking by drivers who are required to stop or need to turn.

Improved delineation is typically a low cost treatment and can include line-markings, signage, street lighting and traffic islands (Figure 7.2).

Good delineation can result in a reduction in vehicle speeds and intersection crashes, and increase the awareness of the intersection and provide a clear path to direct vehicle through the intersection. Median islands can also provide refuge for pedestrian crossing the road.

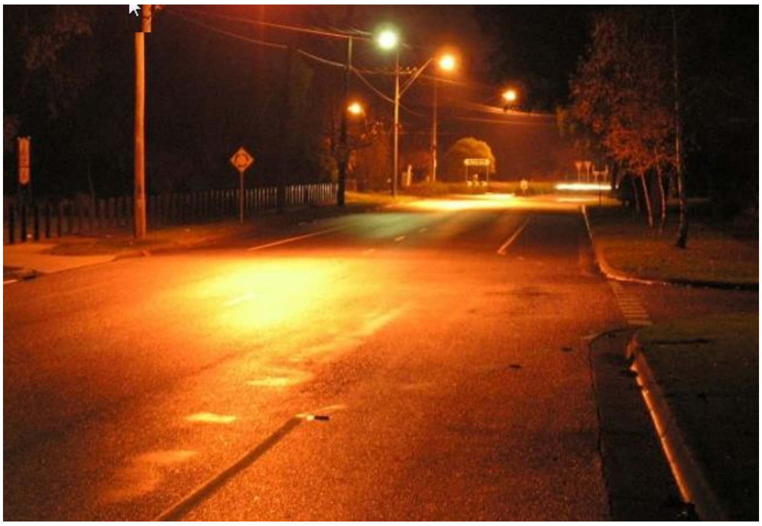
It is important that old linemarking is properly removed to avoid confusion. Advanced warning signs should be placed at a sufficient distance prior to the intersection to allow enough time for drivers to react.

The installation of street lighting at intersections can reduce night-time crashes by making the intersection features more visible at night or in poor light conditions for both vehicles and vulnerable road users (Figure 7.3). It can assist drivers to see the approaching intersection, the intersecting roads and other road users. The provision of street lighting can introduce a road side hazard and the use of frangible poles or shielding by a safety barrier should be considered.

Figure 7.2: Example of an intersection with good delineation

Source: Austroads (2011b).

Figure 7.3: Street lighting on approach to roundabout



Source: Austroads (2015a).

iRAP (2010) indicates delineation improvements has a casualty crash reduction of 10-25%. Austroads (2012a) indicates a night-time crash reduction of 30-50% for the installation of street lighting at intersections.

The treatment life of delineation improvements (linemarking and signage) is one to five years and street lighting is 10-20 years (iRAP 2010).

7.4.3 Installation of Traffic Signals

Traffic signals are installed at T-junctions and cross-intersections to separate oncoming traffic by phases to reduce the likelihood of right-angle crashes (Figure 7.4). Traffic signals can also produce a more efficient movement of traffic and in some cases, may increase the capacity of the intersection.

Although traffic signals can reduce overall crashes, this can result in an increase in some crash types such as rear-end crashes and opposing-turn crashes if separate turning phase are not provided (no turning arrows).

Visibility of the signals needs to be considered in the urban environment. Mast arms can be used to increase the visibility of the signals. In high speed environments and where visibility is poor the signals may also be accompanied by warning signs or vehicle-activated signs.

Figure 7.4: Traffic signal displays mounted on a mast arm

Source: Austroads (2015a).

Before installing traffic signals consideration should be given to traffic volumes, pedestrian movements, intersection approach speeds and crash history at the site. Austroads (2015a) indicates the effectiveness of the installation of traffic signals is a 30% casualty crash reduction (where no previous signals exist).

The treatment life for traffic signals is 10 plus years (Austroads 2015a).

Refer to *Traffic and road use management, Volume 1 – Guide to traffic management, Part 9: Traffic operations* (TMR 2016e) (https://www.tmr.qld.gov.au/business-industry/Technical-standards-publications/Traffic-and-Road-Use-Management-manual/Volume-1) for technical information.

7.4.4 All-red Time Extension

The clearance phase, or red time, is where all movements are stopped by a red light to ensure the intersection is cleared before another group of vehicles receives a green light. At locations where there is frequent running of red lights, or where there are repeated crashes from adjacent directions, there may be benefits in increasing the all-red time phase.

This treatment should be used with care as it has been observed to increase red-light-running when drivers become aware that there is more time to enter and clear the intersection on the red signal. It may also reduce the effectiveness of traffic signal as it increases lost time and can increase congestion.

No information on the effectiveness or the treatment life was available for increasing the all-red time.

Refer to *Traffic and road use management, Volume 1 – Guide to traffic management, Part 9: Traffic operations* (TMR 2016e) (https://www.tmr.qld.gov.au/business-industry/Technical-standards-publications/Traffic-and-Road-Use-Management-manual/Volume-1) for technical information.

7.4.5 Fully-controlled Right Turn Phase

Fully controlled right turn phases are provided at intersections to eliminate right turn filtering (Figure 7.5). This treatment significantly reduces through-right turn crashes at intersections and can reduce the severity of crashes throughout the intersection. It can also be used to remove conflict between right turning traffic and pedestrians crossing the road.

Figure 7.5: Right turn signal

Source: Austroads (2015a).

iRAP (2010) indicates that this treatment may reduce the capacity of the intersection; hence, when used, consideration should be given to the introduction of other signal phase changes to improve capacity of the intersection. These may include allowing opposing right turns, parallel pedestrian movements, left turn overlap movements and allowing any unopposed movements.

Reasons for considering the installation of a fully-controlled right turn phase are outlined in Austroads (2015a):

- when new signals are being installed
- when a high number of through-right casualty crashes have occurred over several consecutive years
- where there are two or more lanes turning right at one approach (double right turn)
- where there are two or more right turn lanes on the opposite approach
- when right-turning traffic is opposed by two or more through lanes of traffic
- when there are high operating speeds in two or more opposing through traffic lanes
- when a service road adjacent to the opposing approach continues through the intersection (i.e. not truncated)

- when horizontal or vertical sight distances are restricted.

Chen & Meuleners (2013) evaluated the effectiveness of fully-dedicated right-turn signals at signalised intersections in Perth. The preliminary results found that, after the introduction of the dedicated right-turn signal phase, there was a significant reduction in all reported crashes (24%), right-angle/right-turn through crashes (69%), rear-end crashes (10%) and serious injury crashes (58%).

Sobhani et al (2016) examined four pedestrian treatment types implemented to help reduce pedestrian crashes in Victoria. One of the treatments investigated was a full-time, fully-controlled right turn at signalised intersections. Although crash reduction values for pedestrian crashes were unable to be determined due to insufficient data, they found that the use of 'full-time fully-controlled right turn' treatments resulted in a significant reduction in the total number of casualty and FSI crashes with reduction factors of 52% and 69% respectively.

The following crash reductions were reported in Austroads (2015a):

- 35% for all casualty crashes
- 60% for right-through crashes
- 45% for adjacent-direction crashes
- 10% for partially-controlled right turns.

The treatment life for fully controlled right turn phase is 10 plus years (Austroads 2015a).

Refer to the *Traffic and road use management, Volume 1 – Guide to traffic management, Part 9: Traffic operations* (TMR 2016e) (https://www.tmr.qld.gov.au/business-industry/Technical-standards-publications/Traffic-and-Road-Use-Management-manual/Volume-1) for technical information.

7.4.6 Intersection Turn Lanes (Unsignalised)

Dedicated turn lanes (channelised turn treatments) allow vehicles to decelerate or stop prior to turning without effecting the flow of through traffic behind them, thus reducing the risk of rear-end crashes. It also provides a sheltered location for vehicles to wait for a suitable gap in opposing traffic before turning. A median can provide further separation between vehicles in the turn lanes and opposing traffic. The introduction of turning lanes can improve traffic flow and increase intersection capacity.

Turning lanes require clear delineation and need to have good sight distance and be of suitable length to allow a vehicle time to stop within it. The provision of turning lanes can increase the width of the intersection and cause problems for pedestrians crossing the road. This can be improved by providing a pedestrian refuge island in the median.

Turn lanes are often indented and kerbed in urban areas (Figure 7.6) whereas, in rural areas, they may consist of pavement markings and linemarking in conjunction with sealing the shoulder (Figure 7.7).

Figure 7.6: Right turn lane in urban area

Source: Austroads (2015a).

Figure 7.7: Right turn lane in rural area

Source: ARRB.

Austroads (2015a) indicates a 35% reduction in casualty crashes for right-turn lanes (however, this depends on intersection type and location) and a 20% reduction for left-turn lanes.

The treatment life of turning lanes is 10 plus years (Austroads 2015a).

Refer to the *Road planning and design manual, Volume 3: Supplement to Austroads Guide to road design, Part 4A: Unsignalised and signalised intersections* (TMR 2016c) (https://www.tmr.qld.gov.au/business-industry/Technical-standards-publications/Road-planning-and-design-manual-2nd-edition) and *Traffic and road use management, Volume 1: Guide to traffic management, Part 6: Intersections, interchanges and crossings* (TMR 2017) (https://www.tmr.qld.gov.au/business-industry/Technical-standards-publications/Traffic-and-Road-Use-Management-manual/Volume-1) for technical information.

7.4.7 Splitter Islands

Splitter islands, also known as traffic islands or median islands, are raised structures placed at or near intersections. They are designed to separate opposing traffic movements, channelise traffic to a defined travel path, limit vehicles turning speed by restricting the turning radius, and sometimes to provide a staging point for pedestrians crossing the road (Austroads 2015a).

Figure 7.8: Splitter island with a pedestrian refuge

Source: Austroads (2011b).

Austroads (2015a) indicates a crash reduction of 30% for installing general channelisation or splitter islands.

The treatment life for the installation of splitter islands is 10 plus years (Austroads 2015a).

For technical information, refer to *Road planning and design manual, Volume 3, Supplement to Austroads guide to road design, Part 4A: unsignalised and signalised intersections* (YMR 2014b) (https://www.tmr.qld.gov.au/business-industry/Technical-standards-publications/Road-planning-and-design-manual-2nd-edition).

7.4.8 Turn Bans

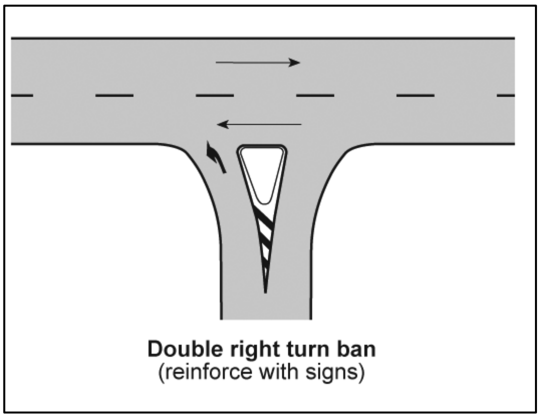
Banning or preventing traffic movements at intersections can be used to remove potential conflicts between through and turning vehicles. Turn bans should be considered when all other less intrusive measures have been exhausted or found to be in appropriate. Consideration should be given to the impacts of the ban on other local streets and surrounding intersections.

Some common situations where turns are banned are outlined in Austroads (2015a), including:

- high right turn crash rate sites
- too many through lanes for the right-turners to filter across (more than two usually)
- construction of a median
- poor sight distance
- lack of turning lanes in high traffic volumes
- property access restriction strategy.

Turn bans usually involve regulatory signage but can also include changes to intersection road geometry such as triangular median islands to discourage right-turn movements to improve compliance.

Figure 7.9: Example of right turn ban layout at T-junction



Source: Austroads (2017).

Turns can be banned during certain times such as during peak hour or they can also be used to restrict certain vehicle types from undertaking a right turn.

Austroads (2015a) suggests a crash reduction of 60% for installing a right-turn ban, or a U-turn and right-turn ban.

The treatment life for the turn bans islands is five to ten years (Austroads 2015a).

7.4.9 Roundabouts

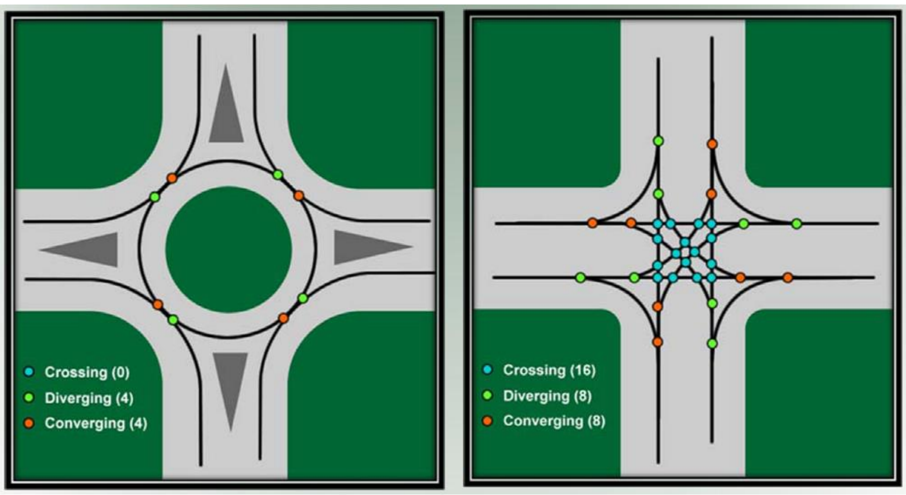
Roundabouts are commonly used to replace intersections to reduce the number of right-angle crashes and crashes related to high speeds, both of which are factors which lead to crashes of a more serious nature. While among the most expensive of intersection crash treatments, roundabouts, whether signalised or unsignalised, have staggering safety advantages over intersections. They are also suitable where other crash treatments have not proven effective. Roundabouts are often viewed as the ideal at-grade intersection option for improved safety outcomes based on the Safe System approach. A typical roundabout in a rural area is shown in Figure 7.10.

Figure 7.10: High speed roundabout on a rural arterial

Source: Austroads (2015a).

A roundabout inherently has fewer conflict points than comparably-sized (i.e. equal number of lanes) intersection as illustrated in Figure 7.11. The geometry and deflection on the approaches of the roundabout forces drivers to reduce their speeds to safely negotiate the roundabout, reducing the risk of serious crashes. However, the number of low-angle impact crashes and rear-end crashes are likely to increase.

Figure 7.11: Signalised intersection vs. roundabout conflict point comparison



Source: FHWA (2009).

Installation of a roundabout is appropriate where there is equal demand on each approach. If the demand is unbalanced, then further analysis should be undertaken to determine whether a roundabout is the best solution for the intersection.

Smaller roundabouts may restrict some larger service vehicles and emergency vehicles and buses unless the central island is mountable. Roundabouts are not suited to locations where large heavy vehicles are likely to be present.

Roundabouts induce a higher number of cyclist-involved crashes. Provisions for cyclists, either by the use of on or off-road facilities, can reduce the risk to cyclists. Pedestrians can be at greater risk at roundabouts; however, as indicated in Austroads (2015a), a well-designed roundabout does not increase the risk to pedestrians.

Austroads (2012a) provides the following crash reduction factors for converting intersections to roundabouts:

- 70% for rural roundabouts
- 55% for urban roundabouts.

The treatment life of a roundabout is 10 plus years (Austroads 2015a).

For technical information, refer to the *Road planning and design manual, Volume 3: Supplement to Austroads guide to road design: Part 4B: Roundabouts* (TMR 2014c) (https://www.tmr.qld.gov.au/business-industry/Technical-standards-publications/Road-planning-and-design-manual-2nd-edition) and *Technical Note 136: Providing for cyclists at roundabouts* (TMR 2015d) (https://www.tmr.qld.gov.au/business-industry/Technical-standards-publications/Technical-Notes/Traffic-engineering).

7.4.10 Signalised Roundabouts

Signalised roundabouts are typically used at existing roundabouts that are poorly performing. Signalising a roundabout removes the potential error in judging and identifying a suitable gap to enter the roundabout. Signalised a roundabout helps to improve capacity, reduce delays, reduce crashes, and address pedestrian and cyclist difficulties (Main Roads Western Australia 2015). Signals assist in regulating the speed of the circulating traffic which improves safety.

The increased numbers of rear-end crashes and crashes involving cyclists, which are inherent in a roundabout, can be controlled by the installation of part-time or full-time traffic signals at the roundabout. When a dominant approach is preventing traffic from another approach entering the roundabout, traffic signals could be installed to aid traffic flow and prevent congestion on the approaches. In rare circumstances where several roundabout approaches are performing poorly for extended periods, and a conventional signalised intersection is inappropriate, a roundabout may be fully signalised (Austroads 2015c).

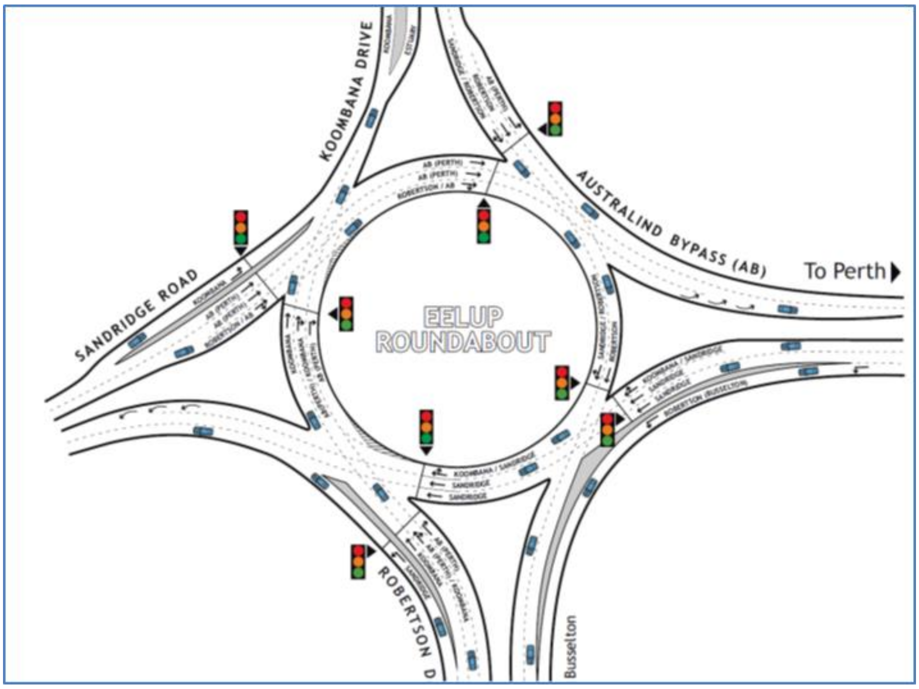
Fully-signalised roundabout

A fully-signalised roundabout has all junctions around its periphery signalised. To be successful the roundabout must be large enough to accommodate any necessary queuing in the circulating roadway and operate on a comparatively short cycle length (preferably 50 to 60 seconds) to limit the internal queue lengths arising from the right turning traffic (Main Roads Western Australia 2015).

A typical fully-controlled signalised roundabout is the Eelup Roundabout in Bunbury, Western Australia. Prior to being signalised this roundabout experienced capacity problems with large queues of vehicles on the approaches roads during peak hours (Main Roads Western Australia 2015). Large multi-combination vehicles struggled to pick a gap in the circulating traffic stream due to the high traffic volumes and high circulating speeds. It had the state's worst crash rate, recording 650 crashes in five years.

A diagram of the signalised Eelup roundabout is shown in Figure 7.12. Review of the treatment indicates a substantial reduction in the number of crashes and congestion during peak periods.

Figure 7.12: As constructed diagram of the Eelup signalised roundabout, Bunbury WA



Source: Main Roads Western Australia (2012).

Partially-signalised roundabout

Partial signalisation is employed where delays do not occur on all approaches. Studies have indicated that the safety of part-time signalisation is questionable, as drivers can be confused as to whether the signals are in operation or not (County Surveyors Society (1997) cited in Turner and

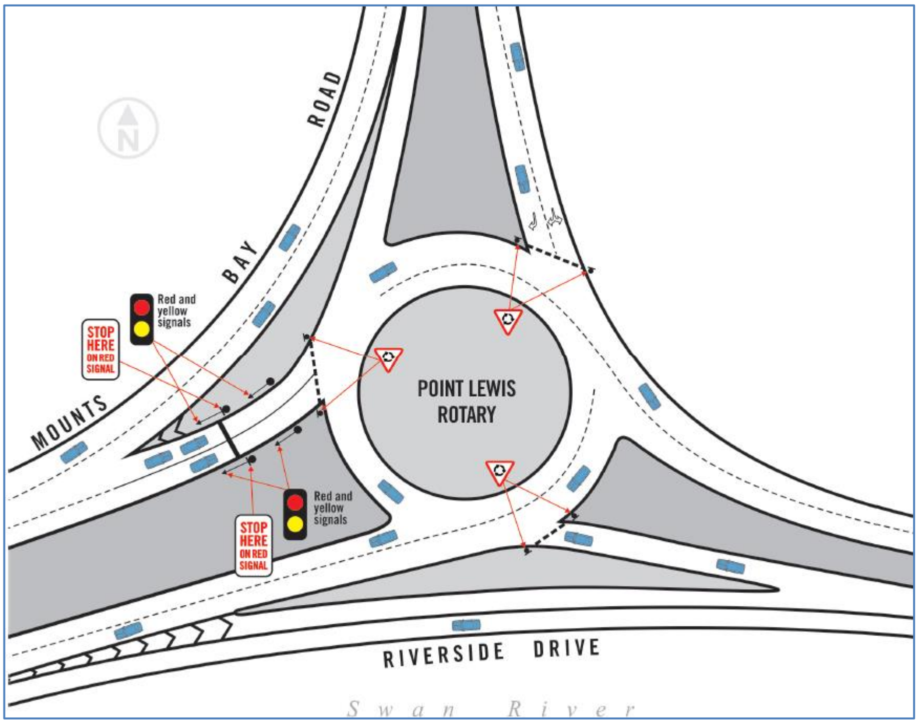
Brown (2013)). Part time signals do not provide for the safety of pedestrians with visual impairments as there is no effective way of indicating in a non-visual way when the signals are not operational.

A typical example of a partial signalised roundabout is the Point Lewis roundabout in Perth, WA. Prior to the metering signals, the roundabout experienced extreme congestion during the peak periods as follows (Main Roads Western Australia 2015):

- during the a.m. peak, traffic on the northern approach (main a.m. peak movement) was blocked by the lesser west-t-o-east traffic flows from the western approach
- during the p.m. peak, traffic on the northern approach was sometimes blocked by the traffic backing up into the roundabout from the eastern downstream exit.

The solution consisted of installing a metering signals on the western approach as shown in Figure 7.12. After the implementation, congestion through the intersection reduced significantly – the a.m. queue length decreased by over 40% and the p.m. peak by approximately 80% (Main Roads Western Australia 2015).

Figure 7.13: As-constructed diagram of Point Lewis Roundabout, Perth WA



Source: Main Roads Western Australia (2013).

There is little research available on the safety effects of signalised roundabouts. County Surveyors Society (1997) (cited in Turner and Brown (2013)) reported the effects of signalised roundabouts to include the following:

- 11% reduction in crashes, and a 44% reduction in crash severity for full-time operation
- 8% crash reduction during part-time operation, 66% increase in off-periods, and no net effect on crash severity.

No information regarding the treatment life of signalised roundabout was available. However, it has been assumed that the treatment life would be 10 plus years based on the treatment life of unsignalised roundabouts and traffic signals at a cross-intersections.

7.4.11 *Staggered T-intersection*

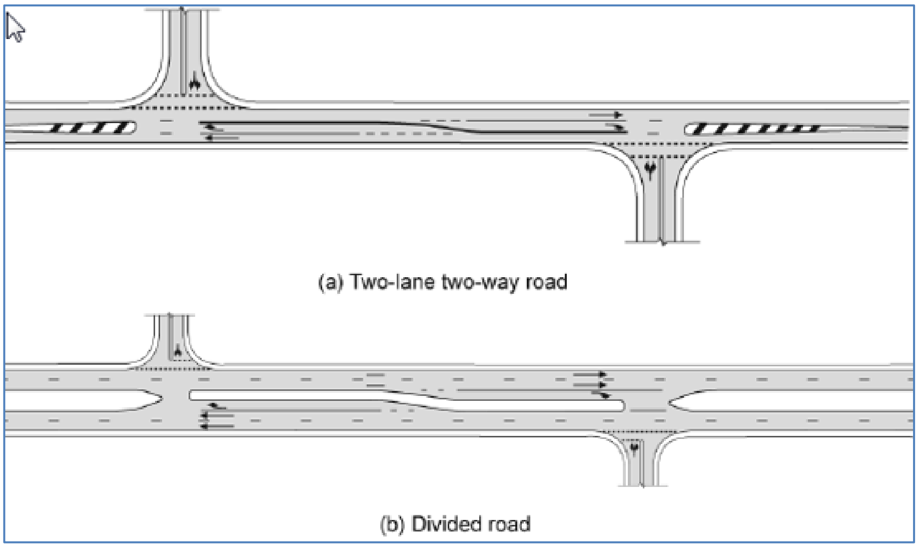
A more involved geometric intersection crash treatment is the conversion of a cross-intersection into a staggered T-intersection, whereby the two minor road approaches to the intersection are offset with respect to each other. This treatment effectively decreases the number of conflict points and encourages slower speeds, which further reduces the likelihood of a serious injury. Staggered T-intersection are very effective in reducing crashes from adjacent directions at low volume unsignalised intersections.

There are two types of staggered T-intersections:

- the left-right stagger, where traffic arriving at the intersection undertakes a left turn followed by a right turn to cross the major road (Figure 7.14)
- the right-left stagger, where traffic takes a right turn followed by a left turn to cross the major road (Figure 7.15).

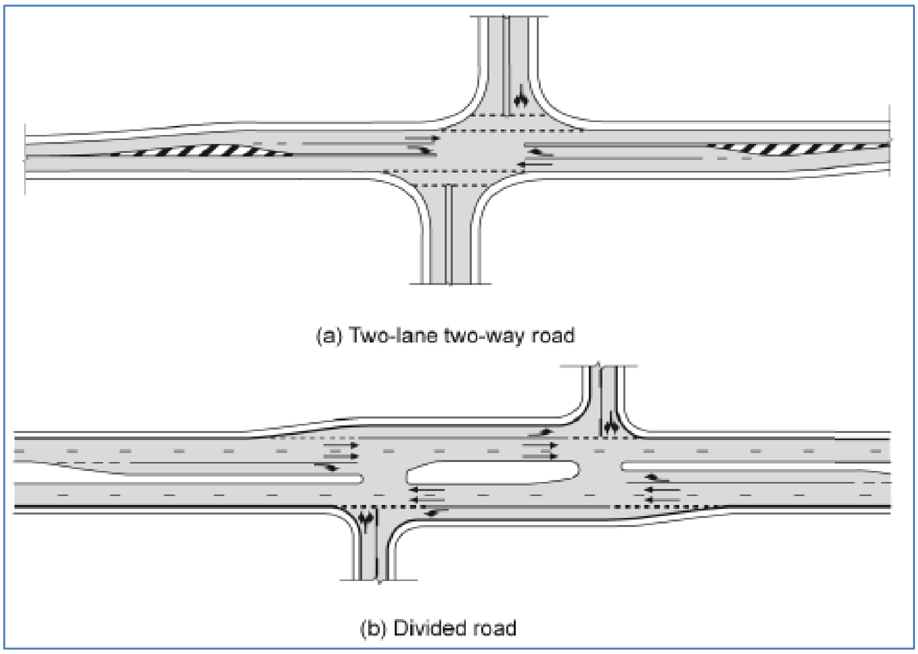
Consideration should be given to the volume of traffic on the minor road undertaking the through movement at the existing cross-intersection. It may be safer for the intersection to remain as it is.

Figure 7.14: Left-right staggered T-intersection



Source: Austroads (2009) – this guide has been superseded by Austroads (2017); however, Figure 7.14 has not been carried over into Austroads (2017).

Figure 7.15: Right-left staggered T-intersection arrangement



Source: Austroads (2009) – this guide has been superseded by Austroads (2017); however, Figure 7.14 has not been carried over into Austroads (2017).

Austroads (2012a) indicates the following crash reduction values for installing a staggered T-intersection:

- 35% reduction where minor road traffic is less than 15% of main road traffic
- 25% reduction where minor road traffic is between 15-30% of main road traffic
- 35% reduction where minor road traffic is greater than 30% on main road traffic.

The treatment life for a staggered T-intersection treatment is 10 plus years (Austroads 2015a).

7.4.12 Give Way and Stop Signs

Give way and stop signs are regulatory signs used at unsignalised intersections to control traffic movements. These signs are accompanied by prescribed linemarking in the form of appropriate holding lines (broken for give way signs and continuous for stop signs).

Give way and stop signs can assist in defining the priority at intersections, improve compliance with the road rules, and improve the conspicuity of the intersection. An example of a stop sign is shown in Figure 7.16.

Figure 7.16: Stop signs at a T-junction

Source: Austroads (2015a).

Austroads (2015a) indicates the following crash reductions:

- 25% for give way signs
- 60% for four way stop sign at cross-intersection
- 15% for a stop sign at T-intersection
- 30% for a stop sign at cross-intersection.

The treatment life of give way and stop signs is five to ten years (Austroads 2015a).

For technical information, refer to the *Traffic and road use management, Volume 3: Guide to pavement markings, Part 2: Pavement marking usage, Chapter 4: Treatment at intersections/roundabouts/interchanges* (TMR 2015b) (https://www.tmr.qld.gov.au/business-industry/Technical-standards-publications/Traffic-and-Road-Use-Management-manual/Volume-3).

7.4.13 Sight Distance Improvements

Adequate sight distance is essential to enable approaching drivers to be able to (Austroads 2017):

- recognise the presence of an intersection in time to slow down or stop in a controlled and comfortable manner
- see vehicles approaching in conflicting traffic streams and give way where required by law or avoid a crash in the event of a potential conflict.

Types of sight distances required at intersections include safe intersection sight distance and approach sight distance. Sight distance may be obstructed by road furniture, vegetation, parked vehicles, the road geometry, batters, signs, etc. An example of limited sight distance due to the intersection being on the inside of curve, and by vegetation, is shown in Figure 7.17.

Figure 7.17: Sight distance limited due to intersection being on inside of curve and by vegetation

Source: FHWA (2016).

Some low-cost solutions to improve sight distance include:

- remove or cut back vegetation
- relocate structures, signs, roadside furniture impeding sight distance
- ban or indent parking
- bring forward stop line (if safe to do so)
- install traffic mirror (low volume, low speed location only).

More expensive solutions may include redesigning or reconstructing the intersection i.e. increasing curve radii, flattening crests, flattening embankments etc.

The effectiveness of sight distance improvement is a 30% reduction in casualty crashes (Austroads 2015a).

The treatment life for improved sight distance at intersection is five to ten years (Austroads 2015a).

For technical information, refer to the *Road planning and design manual, Volume 3: Supplement to Austroads guide to road design, Part 4A: Unsignalised and signalised intersections* (TMR 2014b) (https://www.tmr.qld.gov.au/business-industry/Technical-standards-publications/Road-planning-and-design-manual-2nd-edition).

7.4.14 Skid Resistance

Skid resistance is a very important factor especially, on the approach to intersections where breaking commonly occurs. This is exacerbated when the road is wet or where poor surface drainage exists.

The road surface can deteriorate over time due to the action of traffic wearing the surface and polishing the aggregate. A build-up of debris and oil can also impact on the skid resistance of the road surface.

Two methods available to treat pavements with low skid resistance: retexturing, which involves mechanical reworking of the existing surface to improve friction properties, and resurfacing of the pavement.

Skid resistance improvements can reduce rear-end and run-off road crashes. Austroads (2015a) indicates a 35% reduction in casualty crashes for general skid resistance improvements in urban areas, and expected reduction smaller in rural areas.

The treatment life for improved skid resistance is one to five years (Austroads 2015a).

For further information regarding skid resistance refer to TMR's *Skid resistance management plan* (TMR 2016b) (https://www.tmr.qld.gov.au/business-industry/Technical-standards-publications/Skid-Resistance-Management-Plan).

7.4.15 Speed Management

Reduced vehicles speeds on the approach to and through intersections can reduce the risk of crashes and make them less severe when they do occur. There are a number of speed management treatments, including perceptual treatments, vehicles activated signs and pavement treatments, aimed at reducing vehicle speeds at intersections. These are now discussed.

Traverse linemarking

Transverse and peripheral linemarking is where painted bars or lines are placed perpendicular to or across the flow of traffic to alert drivers to reduce their speeds on the approach to an intersection as shown in Figure 7.18 and Figure 7.19, respectively.

Figure 7.18: Transverse linemarking on approach to rural intersection

Source: Department of Planning, Transport and Infrastructure South Australia (n.d.)

Figure 7.19: Peripheral bars on approach to intersection

Source: Transportation Research Board (2008).

Transverse chevrons, which are painted geometric arrows that converge, can also be used to give the illusion of speed on the approaches to intersections.

Martindale & Urlich (2010) trialled the use of transverse markings on the approach to an intersection and bridge in New Zealand. They found the main benefit to be a reduction in vehicle speeds at the start of the treatment, with a reduction in mean speed of 4-12 km/h and 85th percentile speed of 3 km/h, indicating that it is does have alerting properties. Charlton and Baas (2006) found the transverse lines to be effective in reducing vehicle speeds by 8-14% on approaches to hazards.

Although, the trials in New Zealand did indicate some success in speed reduction, there is uncertainty as to their effectiveness over time. Also, the layout of the linemarking, such as the length prior to the intersection, needs to be adjusted and further evaluated. Transverse linemarking is being trialled by the Department of Planning, Transport and Infrastructure in South Australia.

A treatment life of five years has been adopted for transverse linemarking based on other linemarking treatments.

Transverse rumble strips

Transverse rumble strips are raised or grooved lines across the travel lane on the approach to an intersection (refer Figure 7.20). They provide a visual and audible warning to alert drivers of an upcoming need to act such as to slow down at an intersection.

While rumble strips warn drivers that some action may be necessary, they do not identify what action is appropriate. The driver must use visual cues to decide what type of action is appropriate. Thus, rumble strips serve only to supplement, or call attention to, information that reaches the driver visually. In many cases, the objective of a transverse rumble strip is to call attention to a specific traffic control device, such as a ‘STOP AHEAD’ sign (Transportation Research Board, 2008).

Transverse rumble strips are most commonly used on the approach to unsignalised intersections, but have been used on approaches to signalised intersections, particularly where there are unexpected isolated signals.

Rumble strips can be noisy and consideration needs to be given to their location relative to pedestrians, residence and other land use types located close by. Transverse rumble strips can be hazardous to motorcyclists and cyclists.

Figure 7.20: Transverse rumble strips

Source: Transportation Research Board (2008).

Srinivasan, Baek & Council (2012) examined the safety effects of transverse rumble strips on the approaches to stop-controlled rural intersections (Figure 7.21). They found that, for three- and four-leg intersections in Iowa and Minnesota, there was an approximately 21% reduction in all injury crashes and a 39% reduction in fatal and serious injury crashes. However, the trade-off was an increase in property-damage-only crashes.

Figure 7.21: Transverse rumble strip on approach to stop-controlled intersection

Source: Srinivasan et al (2012).

iRAP (2010) indicates a casualty crash reduction of 10-25% for general use of rumble strips.

The treatment life for transverse rumble strips is five to ten years (Austroads 2015a).

For technical information, refer to the *Traffic and road use management, Volume 1 – Guide to traffic management, Part 10: Traffic control and communication devices* (TMR 2016d) (https://www.tmr.qld.gov.au/business-industry/Technical-standards-publications/Traffic-and-Road-Use-Management-manual/Volume-1) and *Traffic and road use management, Volume 2 – Guide to road safety, Part 5: Road safety for rural and remote areas* (TMR 2015c) (https://www.tmr.qld.gov.au/business-industry/Technical-standards-publications/Traffic-and-Road-Use-Management-manual/Volume-2).

Vehicle-activated signs (VAS)

VAS are signs which only target selected drivers. Sensors detect approaching vehicles and if a vehicle exceeds a pre-set trigger (for instance speed), the sign is activated. The objective of VAS is to reduce the risk and the severity of crashes by reducing the speed of vehicles and enhancing driver awareness of a hazard, such as an intersection ahead.

They can be used in different situations, including as speed control measure and to improve safety at intersections, railway crossings, and horizontal curves. They are used in advance to an intersection to alert drivers they are approaching an intersection, or to alert vehicles on a major road that vehicles are approaching an upcoming intersection from the minor road (Figure 7.22). This can reduce the incidence of crashes involving vehicles from adjacent approaches, opposing vehicles turning, or vehicles entering the roadway.

Figure 7.22: VAS on the approach to an intersection

Source: Bradshaw, Bui & Jurewicz (2013).

VAS are effective in reducing vehicle speeds on the approach to rural intersections and estimated to reduce fatal crashes by 18% and serious injury crashes by 12% on average (Bradshaw et al. 2013). Austroads (2015a) indicates that the use of VAS in general have a casualty crash reduction of 35%.

The treatment life for VAS is five to ten years.

For technical information, refer to Technical Note TN160 – *Vehicle-activated signs* (TMR 2016a) (https://www.tmr.qld.gov.au/business-industry/Technical-standards-publications/Technical-Notes/Traffic-engineering).

Vertical deflection

Vertical deflections on intersection approaches utilise protrusions from the intersection surface to promote lower approach speeds (Corben et al. 2010). These can be in the form of (Candappa, Colobong & Bui 2016):

- raised stop lines or raised platforms – mild elevations in the vicinity of the stop line that induce speed reduction through the intersection (Figure 7.23)
- raised intersection – identical to raised stop lines but in this case the entire intersection is raised (Figure 7.24).

Figure 7.23: Images of speed humps on European Roads (raised stop line or platform)

Source: Corben et al 2010.

Figure 7.24: Example of an intersection that has been raised and paved a different colour

Source: Austroads (2011b).

While these treatments do not affect the number of conflict points at an intersection, the speed reduction potential could be sufficiently large leading to substantial safety improvements. Vertical deflection devices are typically used on lower speed roads. They do have the potential to affect emergency vehicle response times and can be expensive and may have noise concerns. However, the raised section can facilitate pedestrian movements.

Raised platforms at intersection have been successfully implemented in The Netherlands. Van der Dussen (2002) studied the effectiveness of ten raised platforms at intersections in The Netherlands with traffic volumes ranging from 3 000 to 6 000 vehicles/day, and reported a reduction in casualty crashes of 80%.

A raised intersection was trialled at a T-intersection in Hamilton, New Zealand. It was found to reduce the 85th percentile speed by 1.1 km/h (Austroads 2011b). Watkins (2000) studied raised intersections at two sites in Cambridge, Massachusetts USA and found a reduction in 85th percentile speeds of 4 and 5 km/h.

Although these treatments had been widely applied overseas and to a lesser extent in Australia and New Zealand, it their effectiveness in mixed use environments and high volume roads in Australia is unclear. Makwasha and Turner (2017), examined speed and crash data from ten raised intersection treatment sites and found no statistically significant change in casualty crashes. This may be due to the small sample size and number of crashes at the study sites. However, they found that the 85th percentile speeds were reduced by 7.5 km/h across the sites. The study also highlighted the need for further trials of raised intersections in Australia and New Zealand.

A raised platform is being trialled at the signalised T-intersection of Kidman Avenue and the Surf Coast Highway in Belmont, Victoria. This intersection has a higher than average crash rate, carries high traffic volume and 70 km/h speed limit on Surf Coast Highway. Preliminary results of the trial from a combined treatment of signals, reduced speed limits and a raised platform indicated lower speeds at the trial site compared to the control intersections. Due to the combination of treatments, the direct effect of the raised platform on the lowered speed is not as clear (Candappa et al. 2016). They also noted that about 20% of the drivers encroached on the stop line when stopping at red signal, suggesting some level of driver confusion and uncertainty as to where they are required to stop.

It was reported in Austroads (2011b) that speed humps, a common form of vertical deflection, were effective in reducing the 85th percentile speed in the order of 5-10 km/h. It is intuitive that this would lead to less severe crashes. iRAP (2010) indicate 25 - 40% crash reduction for traffic calming in general which includes vertical deflection treatments.

A treatment life of five to ten years has been adopted for vertical deflection at intersections based on the treatment life for traffic calming provided by Austroads (2015a).

7.4.16 Roadside Furniture and Hazards

Roadside furniture at intersections, such as utility poles, trees, and sign posts, are potential hazards if they are not located at an appropriate distance from the edge lanes or are not adequately protected (Figure 7.25).

A collision with a roadside hazard such as a pole can have severe consequences. Where possible, hazardous roadside furniture should be removed from intersections and edge lanes without impacting on sight distance; otherwise, vehicles should be protected from the hazard.

Figure 7.25: Example of roadside hazards at intersection

Source: ARRB.

Though it is difficult to quantify the effectiveness of removing roadside hazards, iRAP (2010) indicates a 25-40% crash reduction for the relocation of roadside hazards, noting that this value is not specific to intersections.

The treatment life for roadside hazard removal is five to ten years (iRAP 2010).

For technical information, refer to *Road planning and design manual, Edition 2, Volume 3: Supplement to Austroads guide to road design, Part 6: Roadside design, safety and barriers* (2014a) (https://www.tmr.qld.gov.au/business-industry/Technical-standards-publications/Road-planning-and-design-manual-2nd-edition.aspx).

7.4.17 Railway Level Crossings

Vehicle and train collisions at railway level crossings are the most severe crashes, and are more likely to result in fatal or serious injury.

At-grade railway crossings on intersection approaches have potential safety problems if:

- vehicles queue across railway tracks
- the sight distance to signals or to approaching trains is poor
- traffic control is inadequate
- there is a lack of pedestrian facilities
- the pavement is not maintained
- signalling equipment is located too close to the road.

Level crossings can be controlled using ‘passive’ or ‘active’ systems. Passive systems warn the road user of the presence of the level crossing through the use of signs and linemarking. However, they do not react to the presence of an oncoming train. Active systems warn road users of approaching trains. This is achieved by flashing lights, combined with signs and audio devices, which are activated when a train passes over a detector (Figure 7.26). There is also physical separation of vehicles and pedestrians from trains by the use of pedestrian gates and vehicle boom barriers.

At uncontrolled rail crossings the road may be realigned to improve sight distance.

Upgrading level crossings from passive to active control or introduction of physical separation can dramatically reduce the incidence of crashes. However, rail crossing upgrades are expensive due to the number and complexity of rail hardware systems involved. Austroads (2015a) indicate the following crash reductions:

- 25% from nothing to signage
- 50% from signage to lights and bells
- 45% from lights to bells and barriers
- 70% from signage to barriers
- 45% for improved sight distance.

The treatment life for improvements 10 plus years (Austroads 2015a).

Figure 7.26: Rural railway level crossing with flashing lights

Source: Austroads (2015a).

7.4.18 Improved Pedestrian Intersection Treatments

Pedestrian crossing treatments at intersections can be used to eliminate or minimise the risk of crashes involving vehicles and pedestrians. These include improvements to signal timing and the use of raised intersections and platforms.

Raised intersection and platforms

Raised intersections and platforms are a speed management device typically used on local roads. Raised intersections is where the whole intersection is raised and acts as a speed hump across the intersection, alternatively raised stop lines or platforms can be used in advanced of the intersection to reduce vehicle speeds. They can facilitate pedestrian movements. No information was available regarding the effectiveness of raised intersection and platforms in reducing pedestrian crashes. However, casualty crash reductions and speed reductions obtained from the use of these treatments are provided in Section 7.4.15.

Pedestrian signal timing

Pedestrian safety can be improved at signalised intersections by the installation of pedestrian signal phases, the introduction of fully controlled left and right turn phases (which removes the conflict between turning vehicles and pedestrians), improvements to pedestrian signal timing and the use of rest on red (in situations where pedestrian priority is required, the traffic signal can dwell on the pedestrian walk green until a vehicle is detected).

Austroads (2012a) indicated a pedestrian crash reduction of 50% for adding a pedestrian phase at signals, a 35% pedestrian crash reduction for improved signal timing.

The treatment life for improving pedestrian signal phasing is 10 plus years (Austroads 2015a).

7.4.19 Red Light Cameras

Red light cameras, and signs informing the public of their presence, are a common treatment at signalised intersections with a high frequency of right-angle crashes attributed to drivers who intentionally disobey red lights. An example is shown in Figure 7.27.

Figure 7.27: Red light camera, Fortitude Valley

Source: The Quest Community News (2015).

While red-light cameras have the potential to decrease right-angle crashes, they can also increase rear-end crashes due to the abrupt stopping of leading vehicles and the following vehicles not having enough time to act accordingly.

Transport NSW (2015) analysed the performance of their red-light speed camera program and reported the following crash reductions due to changes in driver behaviour:

- 34% reduction in casualty crashes
- 39% reduction in total casualties
- 55% reduction in fatalities
- 32% reduction in serious injuries
- 45% reduction in moderate injuries
- 36% reduction in minor/other injuries
- 44% reduction in pedestrian casualties.

A treatment life for the installation of red light cameras of five to ten years has been adopted based on the treatment life used for speed cameras provided by Austroads (2015a).

7.4.20 Emerging Treatments and Innovative Designs

Other emerging treatments that may warrant further development or research are provided in the following section.

Design innovations at signalised intersections

There are design innovations which are aimed at managing the speeds at which road users approach intersections. These designs include the following:

- Cut-through roundabout and squircle: cut-through roundabouts consist of a central island within a signalised intersection (Figure 7.28). Right-turn movement are directed through cuts within this central island. A squircle operates on the same principle as shown in Figure 7.29.

Figure 7.28: Example of a cut-through roundabout

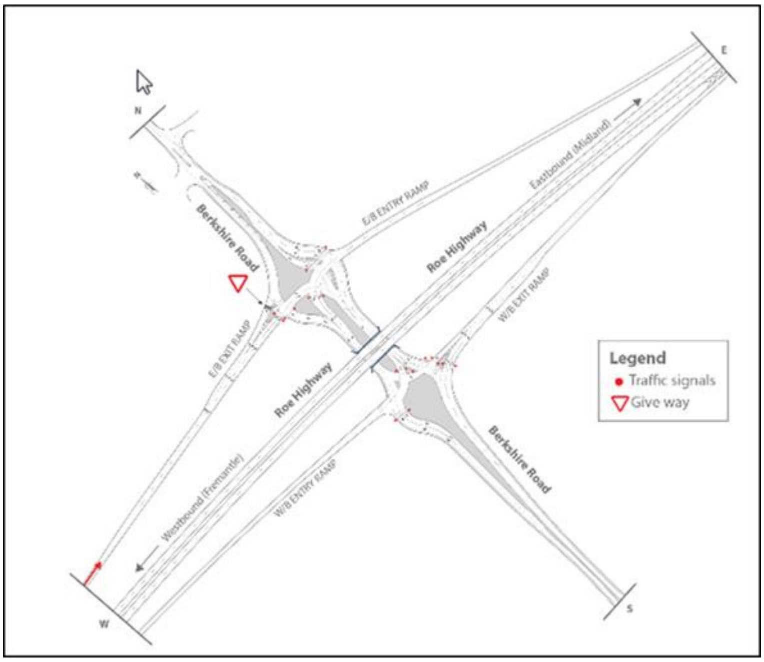
Source: Corben et al. (2010).

Figure 7.29: Example of a squircle

Source: Corben et al. (2010).

- Deflection at approaches to signalised intersections: this involves modifying signalised intersections based on roundabout principles. This reduces both the vehicle approach speed and the angle between converging vehicles. This could be used as an alternative to signalised roundabouts. An example on a tennis ball configuration which uses deflection on the approaches to the intersection is shown in Figure 7.30.

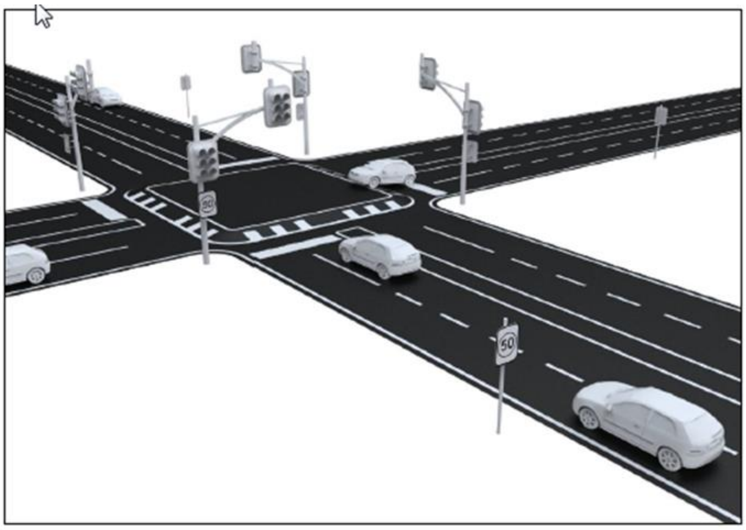
Figure 7.30: Tennis ball configuration at Roe Highway / Berkshire Road intersection, Perth



Source: MRWA (2017).

- Signalised raised platforms intersections and raised stop lines: this involves the use of a raised platforms or raised stop lines at signalised intersection to reduce vehicle speeds on the approaches to and through the intersection (Figure 7.31). This is more suited to low-volume intersections.

Figure 7.31: Signalised raised platform



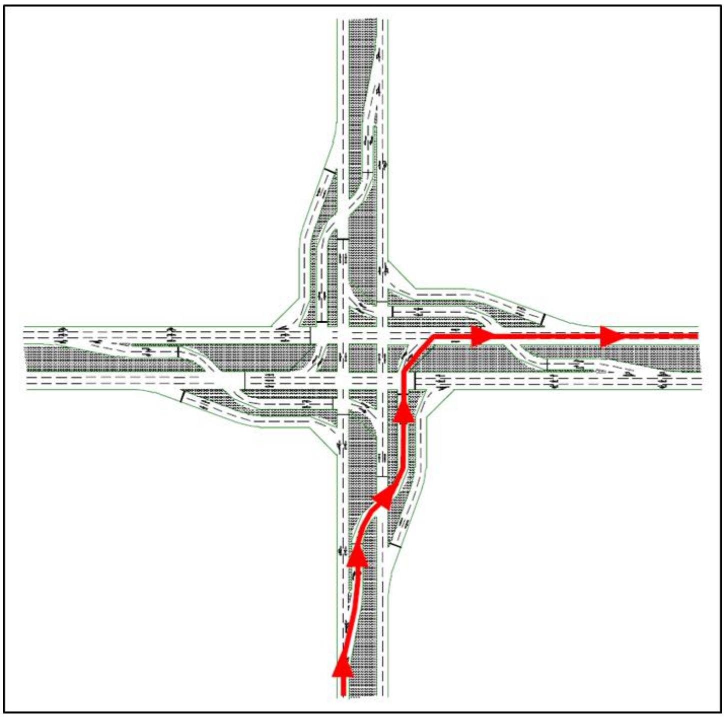
Source: Corben et al. (2010).

Reduced conflict points at intersections

There are other innovative intersection designs which have the objective of reducing the number of conflict points at the intersection. Many of these are high cost and require a large area. These include:

- Displaced right turn (DRT): A displaced right turn removes the right-turn phase at an intersection by directing right-turning movement to the other side of the opposing roadway as illustrated in Figure 7.32. Traffic signals are placed at conflict points of the intersection. This can be used on one approach or all approaches of the intersection (Austroads 2015d).

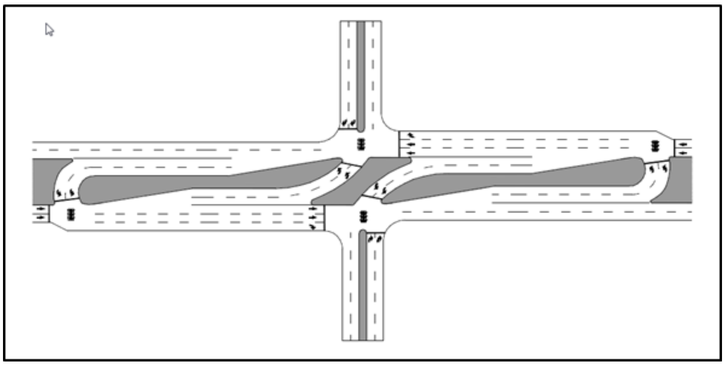
Figure 7.32: Example of a displaced right turn intersection



Source: Simmonite & Chick (2003).

- Signalised restricted crossing U-turn Intersection (RCUT): this design redirects right turn and through movements from the minor street approaches to make a U-turn downstream as shown in Figure 7.33 . When signals are used, only two phases are required instead of four at a conventional four leg intersection.

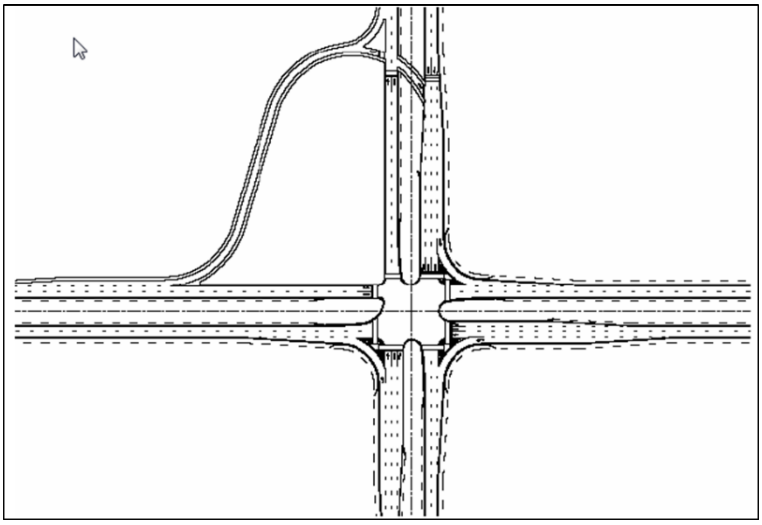
Figure 7.33: Example of RCUT intersection (right hand drive version)



Source: Federal Highway Administration (2014a).

- Jughandle intersection: this design involves the right-turning vehicle movement from an intersection using a one-way path on the left approach to an intersection as shown in Figure 7.34.

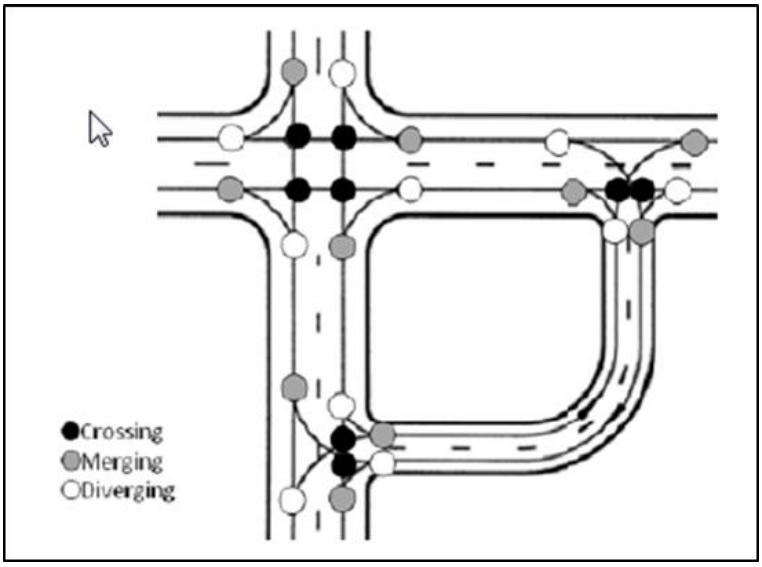
Figure 7.34: Jughandle intersection



Source: Pyke, Sampson and Schmid (2006)

- Quadrant roadway intersection (QR): the quadrant roadway intersection takes the jughandle design further by removing all right-turn movements from the intersection by rerouting them through the addition of a connector roadway as shown in Figure 7.35.

Figure 7.35: Quadrant roadway showing conflict points



Source: Federal Highway Administration (2010).

8 CONCLUSION

A review of historical crash data revealed that the three key crash types which occur on Queensland roads are intersection, run-off-road and head-on crashes. TMR commissioned ARRB to examine these crash types to identify treatment options to reduce the occurrence and severity of these crashes.

The first two years of the project involved the review of head-on, run-off road and intersection crashes on Queensland roads, with Year 1 focussing on head-on and run-off road crashes, and Year 2 focussing on intersection crashes.

For each of the crash types the following was undertaken:

- a review of the literature to identify available treatments and their effectiveness in reducing the likelihood and severity of that crash
- a comprehensive analysis of crash data from 2007 to 2011 to determine any trends, key road features and other factors contributing to the occurrence and severity of these crash types for both local and state-controlled roads in Queensland.

Based on the review of literature and the findings from the crash analysis, recommended engineering treatments to reduce head-on, run-off-road and intersection crashes have been incorporated into a series of Technical Notes which describe and provide guidance on the available treatment options, including their effectiveness and crash reduction potential.

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APPENDIX A SUMMARY OF DOCUMENTS, POLICIES AND GUIDELINES

A.1 TMR Documents

The following documents were provided by TMR for review of existing guidance:

- Crash investigation policy 2013
- CRFs matrix Feb. 2014
- Fact sheet – wet weather vehicle activated signs
- Road safety audit policy supporting guidelines
- RSA audit policy 2009
- Safety advice note for wide centre line treatment (WCLT)
- TRUM – Volume 1: Warrant calculation for use of coloured surface treatment for bicycle lanes
- TRUM – Volume 2: Guide to road safety
- TRUM – Volume 2 Part 3: Speed limits and speed management
- TRUM – Volume 2 Part 4: Local government and community road safety
- TRUM – Volume 2 Part 5: Road safety for rural and remote areas
- TRUM – Volume 2 Part 6: Road safety audit
- TRUM – Volume 3 Part 1: Introduction – guide to pavement markings
- TRUM – Volume 3 Part 2: Pavement marking usage
- TRUM – Volume 3 Part 2 Chapter 4: Pavement marking usage – treatment at intersections/roundabouts/interchanges
- TRUM – Volume 3 Part 3: Application of markings
- TRUM – Volume 3 Part 4: Materials and equipment
- Appendix B: Bicycle crash prediction tool for QLD roundabouts
- Guidelines for road design on brownfield sites
- Design Guide for Roadside Signs
- Rest area guidelines – rest areas and stopping places – location, design and facilities
- RPDM Supp. Vol. 3 Part 6: Supplement to Austroads guide to road design – roadside design, safety and barriers
- RPDM Supp. Vol. 3 Part 6B: Supplement to Austroads guide to road design – roadside environment
- TN18 – Design criteria for motor grids
- TN108 (1) – Midblock bicycle lane termination treatments
- TN128 – Selection and design of cycle tracks
- TN128_Appendix B_Drawings
- TN130 – Speed management on shared paths
- TN131 – Speed path and bicycle path termination treatments

- TN132 – Maintenance minimisation guidelines for walking and cycling facilities
- TN133 – Guidance on the widths of shared paths and separated bicycle paths
- TN136 – Providing for cyclists at roundabouts
- TN137 – Bicycle Activated Warning Signs
- TN138 Verge parking and indented parking
- TN139 – Use of on-street space (kerbside road space) for safer cycling)
- TN147 – Recommended interim treatment for crash-damaged public domain steel beam guardrail infrastructure
- TN155 – Wide centreline treatment – interim advice
- TN160 – Vehicle activated signs
- Technical guidelines screening structures.

A.2 Austroads Guides and Australian Standards

The following Austroads Guides and Australian Standards provide guidance for treatments for head-on, run-off road and intersection crashes:

- Australian Standard AS1742 – *Manual of Uniform Traffic Control Devices* (MUTCD)
- Austroads Guide to Road Design: Part 3 – Geometric design
- Austroads Guide to Road Design Part 4 – Intersections and crossings - general
- Austroads Guide to Road Design Part 4A – Unsignalised and signalised intersections
- Austroads Guide to Road Design Part 4B – Roundabouts
- Austroads Guide to Road Design Part 4C – Interchanges
- Austroads Guide to Road Design Part 6 – Roadside design, safety and barriers
- Austroads Guide to Road Design Part 6A – Pedestrian and cyclist paths
- Austroads Guide to Road Design Part 6B – Roadside environment
- Austroads Guide to Road Safety Part 3 – Speed Limits and Speed Management
- Austroads Guide to Road Safety Part 5 – Road safety for rural and remote areas
- Austroads Guide to Road Safety Part 8 – Treatment of crash locations
- Austroads Guide to Road Safety Part 9 – Roadside hazard management
- Austroads Guide to Traffic Management Part 5 – Road management
- Austroads Guide to Traffic Management Part 6 – Intersections, interchanges
- Austroads Guide to Traffic Management Part 8 – Local area traffic management
- Austroads Guide to Traffic Management Part 9 – Traffic operations
- Austroads Guide to Traffic Management Part 10 – Traffic control and communication devices.

APPENDIX B SUMMARY OF TREATMENTS AND GUIDANCE

Table B 1: Summary of treatments and guidance

Recommended Treatment	Description	Crash type	Existing TMR Guidance
Median Safety barriers – wire rope	▪ Provision of wire rope barrier in the central median	Head-on	▪ Safety Advice Note for wide Centre Line Treatment (WCLT) ▪ The Department's Road Planning and Design Manual Edition 2: Volume 3, Supplement to Austroads Guide to Road Design Part 6: Roadside Design, Safety and Barriers
Two plus one (2 +1) lane (with wire rope)	▪ A 2+1 lane treatment is used on two-way roads, and allows overtaking to occur where there is an overtaking lane (2nd lane) occurring swapping sides every few kilometres for traffic in both directions of travel	Head-on	▪ Guidelines for Road Design on Brownfield Sites
Centreline treatments and painted medians	▪ Provision of wide centreline treatments, central hatching and profiled centreline marking	Head-on	▪ Safety Advice Note for wide Centre Line Treatment (WCLT) ▪ TMR Guidelines for Road Design on Brownfield Sites ▪ TRUM Vol 2 – Guide to Road Safety Part 5: Road Safety for Rural and Remote Areas (2006)
Adequate sealed shoulder	▪ Provision of a sealed shoulder particularly where none existed previously	Run-off-road & Head-on	
Shoulder rumble strip	▪ Installation of profiled edge lining including rumble strips and audio tactile edge lines	Run-off-road	▪ TRUM Vol 2 – Guide to Road Safety Part 5: Road Safety for Rural and Remote Areas (2006)
Roadside hazard treatment	▪ Provision of a clear zone – removal of roadside hazards, particularly on curves ▪ Replacement of non-frangible poles with frangible ones ▪ Hazard protection through the use of safety barriers ▪ Batter slopes management Application of impact attenuators ▪ Consider motorcycle friendly barrier on motorcycle routes	Run-off-road	▪ The Department's Road Planning and Design Manual Edition 2: Volume 3, Supplement to Austroads Guide to Road Design Part 6: Roadside Design, Safety and Barriers ▪ Design Guide for Roadside Signs
Curve treatments	▪ Installation of curve widening ▪ Provision of advanced warning signs ▪ Installation of CAMS ▪ Installation of speed advisory signs	Run-off-road & head-on	▪ Guidelines for Road Design on Brownfield Sites ▪ Road Planning and Design Manual Edition 2: Volume 3, Supplement to Austroads Guide to Road Design Part 3: Geometric Design ▪ TRUM Vol 2 – Guide to Road Safety Part 5: Road Safety for Rural and Remote Areas (2006) ▪ Design Guide for Road Signs
Speed management	▪ Provision of Vehicle Activate Signs (VAS)	Run-off-road & head-on	▪ TN160 Vehicle Activated Signs ▪ Fact sheet wet weather VAS
	▪ The use of transverse rumble strips	Run-off-road & head-on	▪ TRUM - Volume 3: Part 2 Pavement Marking Usage ▪ TRUM Vol 2 – Guide to Road Safety Part 5: Road Safety for Rural and Remote Areas (2006)

Recommended Treatment	Description	Crash type	Existing TMR Guidance
			▪ TRUM - Volume 1: Part 10 Traffic Control and Communication Devices
	▪ Consistent application of curve design and treatments along routes	Run-off-road & head-on	
	▪ Perceptual countermeasures, e.g. road pavement markings, additional marker posts	Run-off-road & head-on	▪ TRUM - Volume 3: Part 2 Pavement Marking Usage ▪ TRUM - Volume 3: Part 3 Application of Markings ▪ TRUM - Volume 3: Part 4 Material and Equipment
Overtaking Lanes	▪ Provision of regular overtaking lanes to allow motorists to overtake slower-moving vehicles without moving into the opposing traffic lane	Head-on	
Provision for motorcycles on motorcycle routes		Run-off-road & head-on	
Provision for heavy vehicles on HV routes		Run-off-road & head-on	
Good delineation and consistent and predictable road alignment		Run-off-road & head-on	
Good shoulder and road drainage with good skid resistance, particularly on curves		Run-off-road & head-on	
Regular maintenance of edge break	▪ Ensure regular maintenance of pavement edge to prevent edge break and drop off	Run-off-road & head-on	
Traffic signalised treatments	▪ Installation of traffic lights at T-junctions and cross-intersections	Intersection	▪ TRUM Volume 1 – Guide to Traffic Management Part 9: Traffic Operations
	▪ Increase right turn phase intervals at existing traffic lights	Intersection	▪ TRUM Volume 1 – Guide to Traffic Management Part 9: Traffic Operations
	▪ Increase clearance phase (all-red) at existing traffic lights	Intersection	▪ TRUM Volume 1 – Guide to Traffic Management Part 9: Traffic Operations
	▪ Add dedicated right turn phase at existing traffic lights	Intersection	▪ TRUM Volume 1 – Guide to Traffic Management Part 9: Traffic Operations
	▪ Left turn on red	Intersection	
Left turn lane treatments	▪ Provision of dedicated left turn lanes	Intersection	▪ RPDM – Volume 3 Supplement to Austroads Guide to Road Design Part 4A: Unsignalised and Signalised Intersections ▪ TRUM - Volume 1 Guide to Traffic Management: Part 6: Intersections, Interchanges and Crossings
Right turn lane treatments	▪ Provision of dedicated right turn lanes	Intersection	▪ RPDM – Volume 3 Supplement to Austroads Guide to Road Design Part 4A: Unsignalised and Signalised Intersections ▪ TRUM - Volume 1 Guide to Traffic Management: Part 6: Intersections, Interchanges and Crossings
Intersection conflict point reduction	▪ Install staggered-t and roundabouts in place of cross intersections	Intersection	▪ RPDM - Volume 3 Supplement to Austroads Guide to Road Design: Part 4B: Roundabouts ▪ TN136: Providing for Cyclists at Roundabouts

Recommended Treatment	Description	Crash type	Existing TMR Guidance
Signalise existing roundabouts	▪ Installation of signals at existing roundabouts	Intersection	▪ TN136: Providing for Cyclists at Roundabouts
Pedestrian and cyclist facilities at roundabouts	▪ Provide pedestrian and cyclist facilities at roundabouts	Intersection	▪ TN136: Providing for Cyclists at Roundabouts
Increase delineation at intersections	▪ Linemarking, signage, street lighting, traffic islands, stop signs at T-junctions	Intersection	▪ TRUM - Volume 3: Part 2 Pavement Marking Usage ▪ TRUM - Volume 3: Part 2 - Chapter 4 Pavement Marking Usage - treatment at intersections/roundabouts/interchanges ▪ TN130 - corner protective islands for cyclists
Ensure adequate sight distance to intersections		Intersection	▪ RPDM – Volume 3 Supplement to Austroads Guide to Road Design Part 4A: Unsignalised and Signalised Intersections
Install red light cameras and signs		Intersection	
Median openings	▪ Limit median openings where possible and place give way signs, or place give way signs or stop signs at frequently trafficked median openings	Intersection	
Improved skid resistance	▪ Resurface pavement to improve skid resistance	Intersection	
Railway crossing	▪ In addition to flashing lights, install barriers, bells, boom gates and signage at railway crossings to notify drivers	Intersection	▪ TRUM - Volume 3: Part 2 Pavement Marking Usage
Hazardous roadside furniture	▪ Remove hazardous roadside furniture away from intersections and edge lanes ▪ Install barrier to protect drivers	Intersection	▪ RPDM Volume 3, Supplement to Austroads Guide to Road Design Part 6: Roadside Design, Safety and Barriers (2014).
Pedestrian visibility improvements	▪ Enhanced crossing signs with flashing overhead lights, provision of in-roadway warning lights at unsignalised pedestrian crossings where there is an issue with vehicles stopping compliance	Intersection	
Improved pedestrian safety & speed management	▪ Provision of perceptual countermeasures such as transverse or peripheral line larking, converging chevron pavement markings, pavement marking to reduce lane widths, and alternate guide post spacing and heights	Intersection	▪ TRUM - Volume 3: Part 2 Pavement Marking Usage
Pedestrian treatments at signalised intersections	▪ Installation of signal phases, improvement to pedestrian signal timing and use of rest on red	Intersection	