Austroads

Research Report
AP-R542-17

Bicycle Safety at Roundabouts

Bicycle Safety at Roundabouts

Prepared by

Peter Aumann, Kate Pratt and Adrian Papamiltiades

Project Manager

Gemma Kernich

Publisher

Austroads Ltd.
Level 9, 287 Elizabeth Street
Sydney NSW 2000 Australia
Phone: +61 2 8265 3300
austroads@austroads.com.au
www.austroads.com.au

Abstract

This report investigates how the geometric design components of a roundabout may contribute to bicycle crashes.

An Australian and New Zealand crash analysis found that most of the crashes occurred at urban local road roundabouts, in 50 km/h speed limit zones. The crashes predominantly occurred on the circulating lane near the entry for an approach road and were right-adjacent type crashes.

The study included an in-depth investigation of 17 roundabouts across Queensland, New South Wales and Victoria. A geometric analysis identified that the entry geometry of the roundabouts investigated would permit relatively high entry speeds, in excess of the target speed of less than 30 km/h. This target speed was adopted for analysis purposes, however, further investigation to determine an appropriate speed to prevent or minimise fatal and serious injury outcomes for crashes involving motor vehicle and cyclists is needed.

The motor vehicle speeds on the entry and circulating lanes were estimated using the ARNDT crash prediction model, however the model was developed on rural roads and so the application of this model to urban local roads requires verification. For the purposes of this investigation, the ARNDT model was used to assess geometric alignments to achieve lower approach speeds and it was found that a roundabout with a radial-type of alignment, used in countries in Europe, achieved approach and circulating speeds of less than 30 km/h.

Sight distances were examined and it was found that the available sight distance to vehicles approaching from the right did not meet the design requirements. There is some research which indicates that restricting the sight distance on the approach to a roundabout reduces the approach speeds of vehicles, however, this requires further investigation to develop design criteria.

The report recommends further investigation into motor vehicle/cyclist crash outcomes and the effect of restricting sight distance on the approaches to a roundabout, and the development of design guidance for urban local road roundabouts.

About Austroads

Austroads is the peak organisation of Australasian road transport and traffic agencies.

Austroads' purpose is to support our member organisations to deliver an improved Australasian road transport network. To succeed in this task, we undertake leading-edge road and transport research which underpins our input to policy development and published guidance on the design, construction and management of the road network and its associated infrastructure.

Austroads provides a collective approach that delivers value for money, encourages shared knowledge and drives consistency for road users.

Austroads is governed by a Board consisting of senior executive representatives from each of its eleven member organisations:

- Roads and Maritime Services New South Wales
- Roads Corporation Victoria
- Queensland Department of Transport and Main Roads
- Main Roads Western Australia
- Department of Planning, Transport and Infrastructure South Australia
- Department of State Growth Tasmania
- Department of Infrastructure, Planning and Logistics Northern Territory
- Transport Canberra and City Services Directorate, Australian Capital Territory
- Australian Government Department of Infrastructure and Regional Development
- Australian Local Government Association
- New Zealand Transport Agency.

Keywords

Roundabouts, cyclist crashes, geometric design, urban local roads, sight distance, approach speeds, travel path speeds, approach curvature, design speed

ISBN 978-1-925451-66-5

Austroads Project No. TT1967

Austroads Publication No. AP-R542-17

Publication date May 2017

Pages 171

Summary

The objectives of this project are to identify the geometric design factors associated with bicycle crashes at roundabouts and identify design options that may reduce the incidence or severity of these crashes.

A crash analysis was undertaken covering Australia and New Zealand to identify the crash characteristics, which identified that 93% of crashes occurred in speed zones of 60 km/h or less, with 63% occurring on roads with speed zones of 50 km/h or less. The most common type of crash was the adjacent direction crash (entering motor vehicle colliding with a cyclist on the circulating carriageway), accounting for 67% of the crashes followed by vehicles travelling in the same direction crashes comprising 13% of the crashes.

From the crash analysis a representative sample of roundabouts in Queensland, New South Wales and Victoria were identified for detailed investigation to identify contributing factors to the crashes occurring at the roundabouts. Twelve of the roundabouts were on urban local roads (the most common crash location), two on urban arterial roads and three on rural arterial roads and 88% of the crashes occurred on the circulating lane at an entry to the roundabout involving a motor vehicle entering the roundabout, undertaking a turning or straight through movement.

Geometric information was obtained for each of the roundabouts and analysed to assess the affect the geometry may be having on the crashes. This analysis identified that the local road roundabouts typically had entry curve radii ranging between 40 m and 50 m, which would cater for entry speeds greater than 40 km/h, which is greater than the target speed of ≤ 30 km/h for a road space shared by motor vehicles and cyclists. Whilst this target speed has been adopted for this project, further investigation is needed to identify the relationship between motor vehicle speeds and bicycle crash outcomes.

Travel path curvature at the entry was identified as a key characteristic of the roundabout that influences possible vehicle speeds at the roundabout. To estimate the vehicle speeds on the travel path curves, the ARNDT model and the horizontal curve equation were used. Both of these methods have limitations for application to the roundabouts analysed and so the speeds obtained were considered to be indicative only.

Sight distance was examined and it was found that the requirement to meet the sight distance near the holding line was met (Criterion 2), and on the urban local roads the sight distance for drivers approaching the roundabouts (Criterion 3) was not met. Some research has shown that restricting sight distance (Criterion 3) can reduce the approach speeds of motor vehicle but this needs more detailed investigation and development of criteria for application.

Possible treatments were identified, with the entry path curvature being the main component that needed to be increased to slow the entering vehicles. On local roads, with smaller design vehicles, the entry curve radius could be reduced to achieve a speed of ≤ 30 km/h, but on the arterial road roundabouts, reducing the entry speeds was not achievable due to the larger design vehicles on these roads. On the local roads, the alignment of the roundabout to achieve the desired entry speed was similar to the alignment of a radial-type roundabout.

Suggestions are provided to amend the nominated Austroads Guides, however guidance on designing a roundabout, particularly an urban local road roundabout for a specific speed, is a key task for the future.

Contents

Tables

Figures

1. Introduction

1.1 Background

Each year, on average about 37 cyclists were killed and about 5200 hospitalised (Bureau of Infrastructure, Transport and Regional Economics 2015), on roads across Australia. Victorian data for the period 2009 to 2013 has shown that 3.1% of all road crashes occurred at roundabouts, that 12.5% of crashes at roundabouts involved at least one cyclist and that cyclist crashes are over-represented (*Effectiveness of On-road Bicycle Lanes at Roundabouts* (Austroads 2014a)). Based on New Zealand crash data an even more significant proportion of these crashes could be expected to have occurred at roundabouts (Austroads 2014a). The New Zealand crash data (2001–11) revealed that almost 28% of all injury crashes at roundabouts involve cyclists, while at priority controlled intersections and signalised intersections the proportions are 8% and 5.5% respectively.

It is also of major concern that, in 2013, there were 50 cyclists killed in Australia, well above the five-year average. This increase may in part be as a result of an increase in the number of people cycling, or people cycling more often, for whatever trip purpose. Should this trend in increasing cycling continue, and while recognising the ‘Safety in Numbers effect’ (Smeed’s law) that an increase in cycling lowers the crash rate per cyclist, it should be recognised that an increase in cycling may lead to an increase in fatal and serious injury crashes, albeit not at the same rate.

National, state and local government strategies are being developed to get more people cycling for their improved health and other economic and social benefits. Providing more separated, safe and attractive facilities assist in encouraging people to ride bicycles, however there are some treatments, in particular some roundabout layouts and alignments that pose both a real and perceived crash risk to people riding bicycles, deterring people from taking up cycling. Attempts to accommodate or attract cyclists with marked bicycle lanes in the circulatory lanes at roundabouts have been found to be counterproductive in terms of increased crash risk, and therefore methods must be found to better cater for cycling where roundabouts have been or are to be constructed.

1.2 Objectives

The objectives of this project focus on the geometric design components of a roundabout to identify the contribution of these components to bicycle crashes at roundabouts and suggest possible design options that may reduce the incidence or severity of these crashes.

1.3 Methodology

The following method was used for this project.

1.3.1 Establishment of a Project Advisory Group

A project advisory group was established at the commencement of this project with representatives from the Road Design Task Force, Traffic Management Working Group and the Road Safety Task Force and local government.

1.3.2 Literature Review

A limited literature review was undertaken to identify any new research published since the review undertaken for *Effectiveness of On-road Bicycle Lanes at Roundabouts* (Austroads 2014a).

1.3.3 Crash Analysis

Crash analysis was undertaken at roundabouts involving cyclists in Australia and New Zealand. The data was analysed to ascertain any trends in time of crash, crash types, conditions, and demographics. From this crash analysis sites with high cyclist crash numbers in Queensland, New South Wales and Victoria were selected as a representative sample for more detailed investigation.

1.3.4 Investigation of Selected Roundabouts in Queensland, New South Wales and Victoria

The aim of the detailed investigation was to identify the geometric parameters of the roundabouts from available records and a site inspection, in order to confirm the information and identify any local issues that may influence the crash occurrence.

1.3.5 Workshop

A workshop was held with the project advisory group to consider possible options to reduce the occurrence or severity of the crashes. Following the workshop, an options paper was prepared and circulated to the project advisory group for comment.

1.3.6 Final Report

Following the workshop with the project advisory group and consideration of their comments on possible options, this final report has been prepared.

2. Literature Review

This literature review builds upon and expands the literature review conducted in Austroads (2014a) into cyclist crash-risk at roundabouts and compares the practices within Europe and the United States of America with the practices within Australia and New Zealand. The review primarily examines reports that were published after Austroads (2014a) was published and does not aim to be an exhaustive review of all literature.

The literature review was undertaken primarily using the Transport Research International Documentation and Australian Transport Index databases and with a focus on the three-year period from 2012 to 2014.

2.1 Types of Roundabouts

In general the types of roundabouts can be described as:

- Mini-roundabout – a simple arrangement with a central island, which may or may not have approach splitter islands. The central island is either domed with edges that are flush with the circulating lane pavement or simply marked with road markings or a contrasting surface material. The central island is generally between one and four metres in diameter.
- One-lane roundabout – a roundabout having a central island with single-lane entries and exits, with a circulatory carriageway that does not allow two cars to pass one another. The central island can vary greatly in size.
- Multilane roundabout – a roundabout with a central island and multiple entry and exit lanes (most commonly two lanes), with a circulatory carriageway able to accommodate the circulating vehicles alongside one another. The central island can vary greatly in size.
- Signalised roundabout – a roundabout having traffic signals on one or more of the approaches and at the corresponding point on the circulatory carriageway.
- Double roundabout – a junction comprising two roundabouts connected by a short section of road and designed as a single system rather than two separate roundabouts.

2.2 Design Principles

A review of the design principles adopted for the design of roundabouts in Australia and New Zealand, North America, Europe and the United Kingdom was undertaken.

2.2.1 Australia and New Zealand

For Australia and New Zealand the design principles are contained in *Guide to Road Design: Part 4B: Roundabouts* (AGRD Part 4B) (Austroads 2015a):

- The roundabout should be visible from the approach sight distance at the road operating speed, in advance of the roundabout.
- Entering drivers must be able to see circulating traffic and potential conflicting traffic, e.g. vehicles on the approach to the right, in time to avoid a collision.
- Entry speeds should be established after considering the types of users expected to travel through the roundabout, with 50 km/h for arterial roads and 25 to 30 km/h for local roads being suggested on the approaches).
- Entry curvature is used to limit entry speed.
- Exits should enable vehicles to leave the roundabout efficiently.
- The inscribed circle should be large enough to accommodate all entries and exits without overlap.

2.2.2 United Kingdom

The design principles are outlined in the *Design Manual for Roads and Bridges* (Department for Transport 2016):

- Normal roundabouts – entries to be aligned tangentially to central island and have flared entries, i.e. localised widening of the entry, to allow two vehicles to enter the circulating lanes.
- Compact roundabouts – entries aligned more perpendicular to the central island and do not have flared entries, except on roads with speed limits > 65 km/h.
- The roundabout should be visible on the approach for at least stopping sight distance.
- Drivers approaching a holding way line (from 15 m prior to the holding way line) must be able to see the full width of the circulating carriageway ahead (for distances related to the inscribed circle diameter) and to their right.

2.2.3 Netherlands

The design principles for roundabouts in the Netherlands are:

- The roundabout should be visible from the approach stopping sight distance.
- Visibility is required to traffic on the approaching legs and across the central island to oncoming traffic is not necessary.
- Entry curve alignments should be as radial as possible.
- Entry and exit curve radii should be as small as possible.

2.2.4 Germany

Information on the design of roundabouts in Germany is very limited and from the available information a key principle is the radial type-alignment on the approaches.

2.2.5 United States of America

The design principles followed in the United States of America are:

- Entry alignments may be tangential-type or radial-type.
- Entry geometry (curvature) is used to provide a balance between adequate deflection and speed control.
- The roundabout should be visible on the approaches for stopping sight distance.
- Sufficient sight distance is required for drivers approaching a holding way line to vehicles on the circulating lane and to vehicles approaching on the immediate upstream entry to avoid a collision.

2.2.6 Summary

There are some key differences in the design principles between the countries reviewed being:

- Tangential-type of approach alignment used in Australia and New Zealand and the radial-type alignment used in European countries.
- Entry and exit curve radii are kept as small as possible on radial-type alignments.
- European practices limit a sight distance requirement for vehicles approaching from the right to be measured from a point 15 m prior to the holding way line.

2.3 Current Practices for Cyclists at Roundabouts

A review of North American, European and British practices for cyclists at roundabouts was undertaken, with information sourced from national road agencies and state-based or large city-based (e.g. London, United Kingdom) organisations.

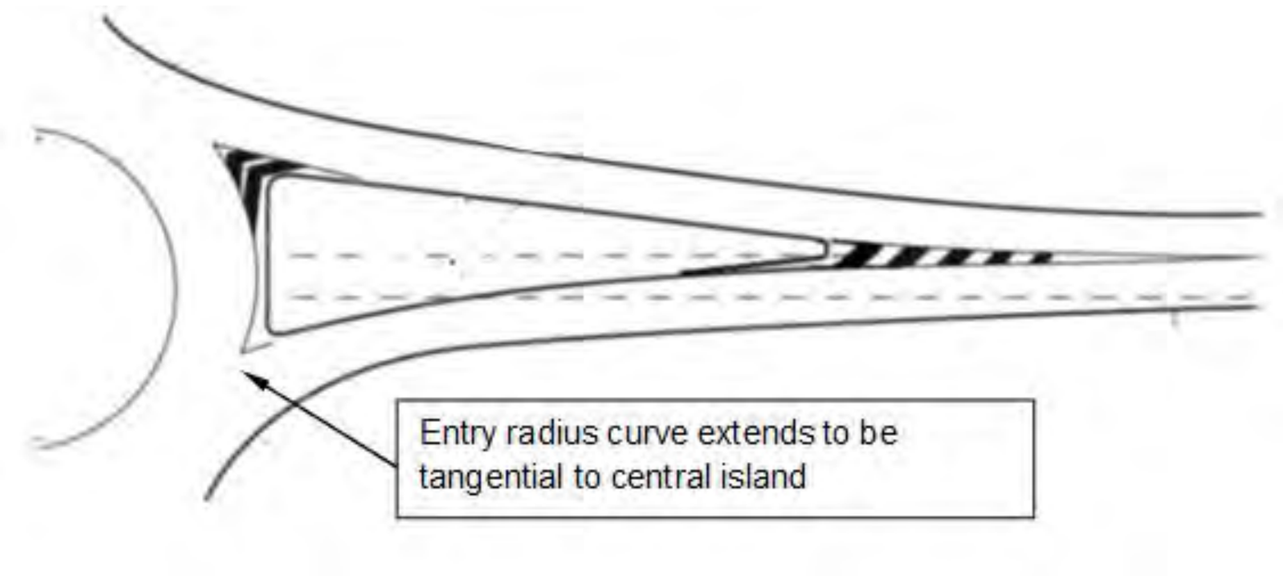
2.3.1 Australia and New Zealand

For Australia and New Zealand guidance is contained in Austroads guides, *Guide to Traffic Management: Part 6: Intersections, Interchanges and Crossings* (AGTM Part 6) (Austroads 2013a), *Guide to Road Design: Part 4B: Roundabouts* (AGRD Part 4B) (Austroads 2015a) and *Cycling Aspects of Austroads Guides* (Austroads 2014b). Note AGTM Part 6 is under review at the time of writing this report and the content relating to bicycles at roundabouts is included in the review of the Guide.

The guidance on roundabout design seeks to control vehicle speeds by providing adequate sight distance for drivers to identify the intersection, observe other vehicles approaching or travelling through the roundabout and identify gaps to enable safe entry onto the circulating lane. The methods of controlling vehicle speeds is through the use of traffic management treatments prior to the roundabout or appropriate approach and entry geometry. Approach speeds are suggested to be 50 km/h for arterial roads and 25 km/h to 30 km/h for local roads.

Minimising entry speeds, which should minimise crashes, is suggested to be achieved by the provision of appropriate vehicle entry path radii on the entry curve or speed reducing measures on the approaches to the roundabout. The vehicle entry path approach typically provides a tangential alignment of the approach legs to the roundabout centre island (Figure 2.1).

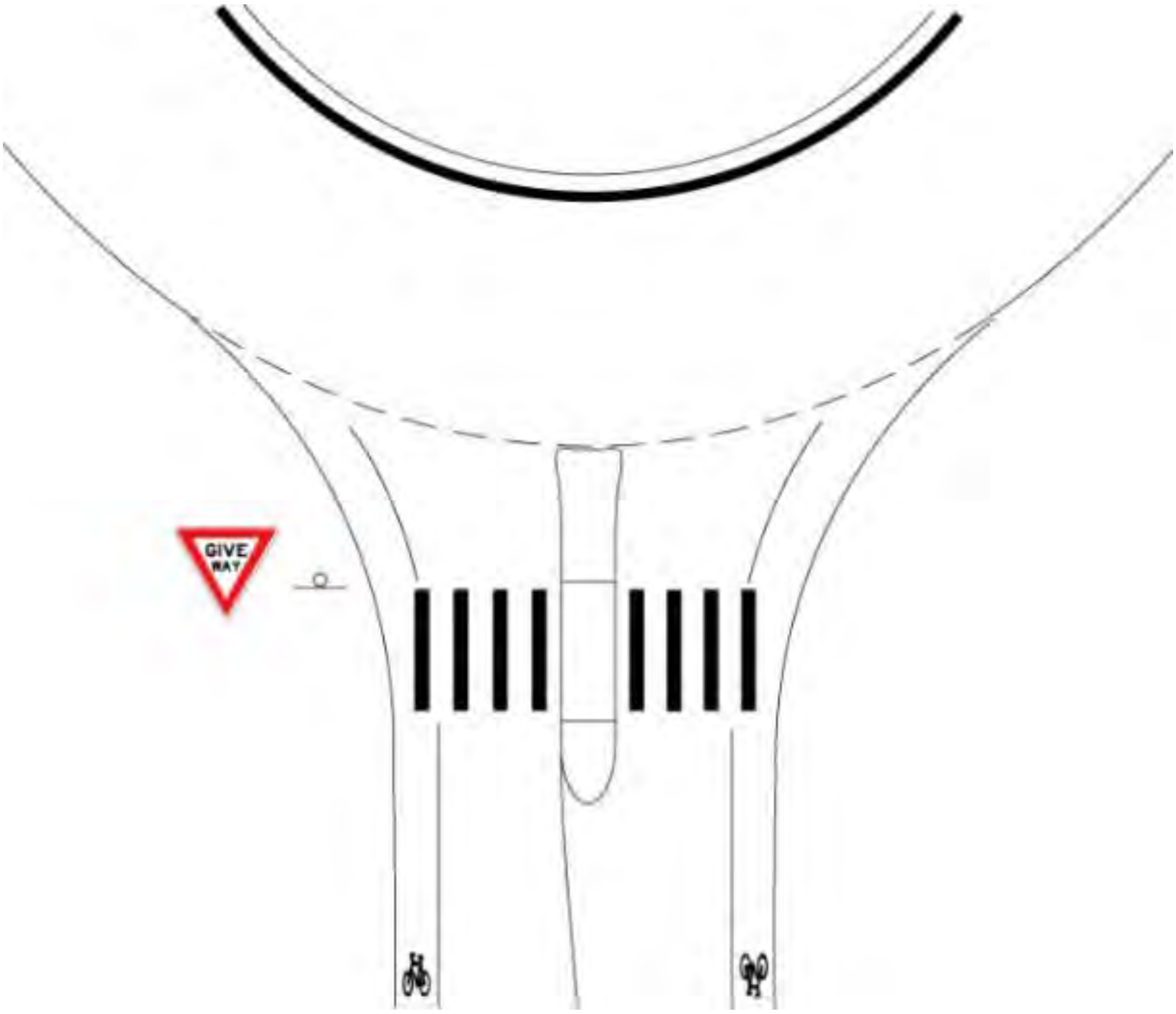
Figure 2.1: Example of a tangential approach to a roundabout



Source: Adapted from Austroads (2015a).

A European type alignment (Figure 2.2) is suggested in AGTM Part 6 (Austroads 2013a) as an alternative approach if a lower entry speed is desirable and practicable and a separated bicycle path is suggested to provide the safest design for inexperienced cyclists. The European alignment provides a radial-type alignment of the approach legs to the roundabout centre island.

Figure 2.2: Example of a radial-type approach to a roundabout



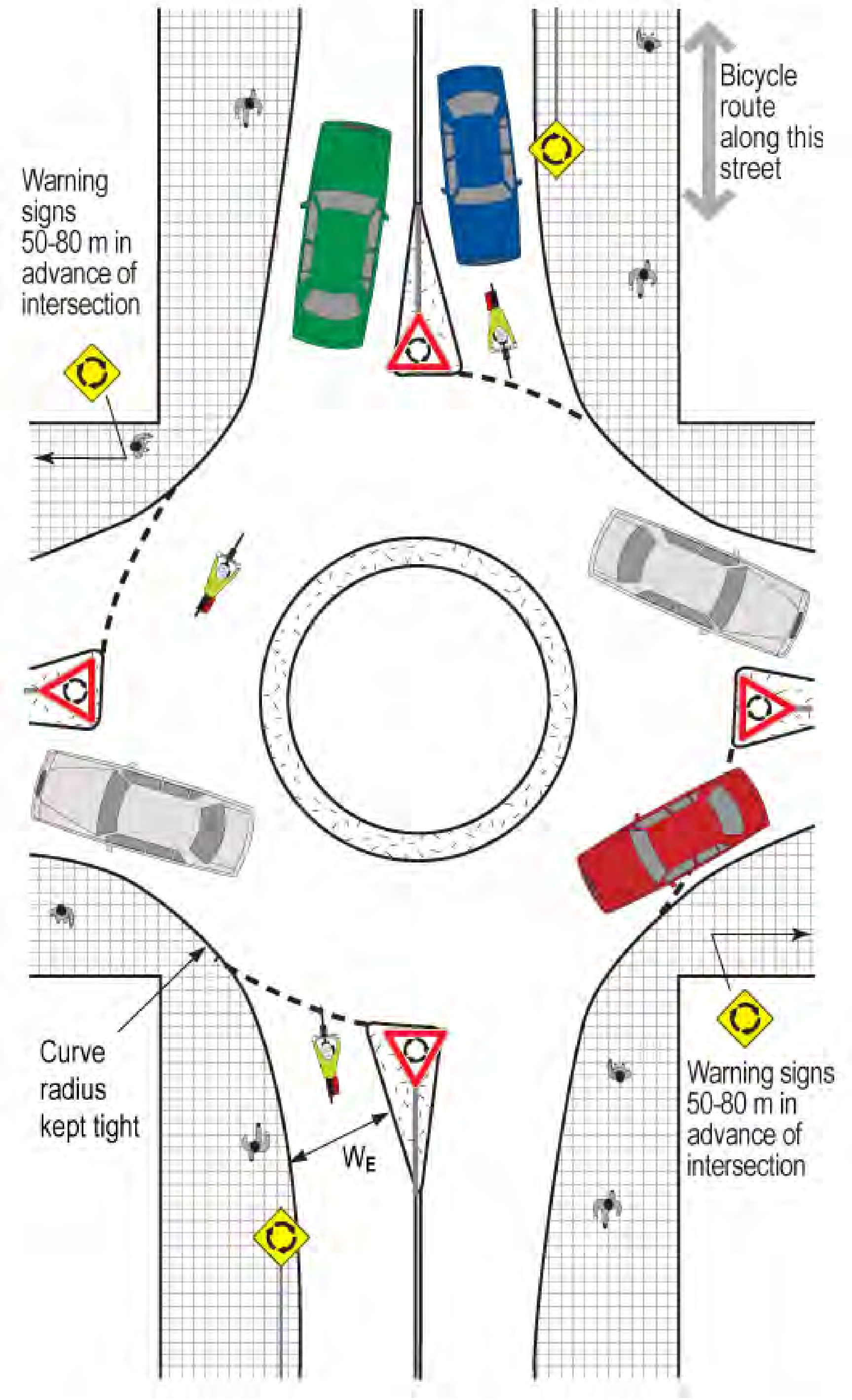
Source: VicRoads (2005).

Single lane roundabouts

For local road intersections, where typically the vehicle speeds are low, i.e. ≤ 50 km/h and volumes are low, i.e. ≤ 3000 vpd, it is suggested in AGTM Part 6 Austroads (2013a) that single-lane roundabouts do not need to be provided with specific bicycle-related treatments. This suggestion is repeated in AGRD Part 4B (Austroads 2015a) with the comment that 'These traffic conditions generally enable cyclists to safely share the road with other traffic.'

An illustration of a local road single-lane roundabout with the cyclist sharing the circulating lane with other vehicles is shown in Figure 2.3.

Figure 2.3: Example of bicycle route through a local road roundabout without marked lanes



Source: Austroads (2015a).

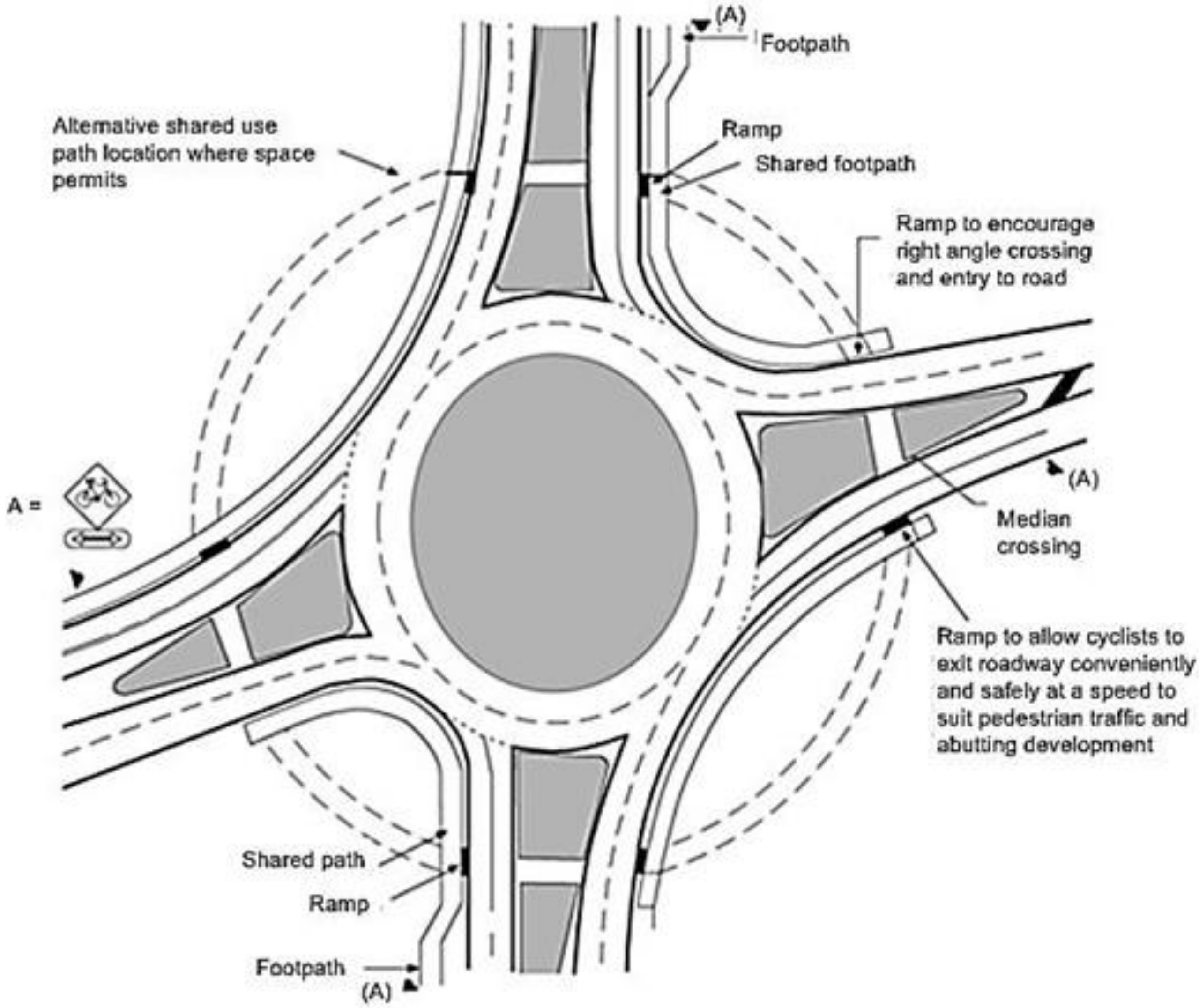
For larger single-lane, or multilane roundabouts AGTM Part 6 suggests:

- an off-road bicycle path around the roundabout (Figure 2.4) with uncontrolled cyclist/pedestrian movement across each leg (some evidence suggests that this is the safest design, at least where traffic flows are high)
- no specific cycle facility (may be acceptable under some circumstances)
- an on-road bicycle lane to provide some separation for cyclists from motor vehicles within the roundabout (Figure 2.5).

It should be noted that the example shown in Figure 2.5 is currently under review, with this guidance being removed from the 2015 edition of AGRD Part 4B (Austroads 2015a). In New Zealand, the practice is to terminate an on-road bicycle lane 30 m in advance of the roundabout holding line.

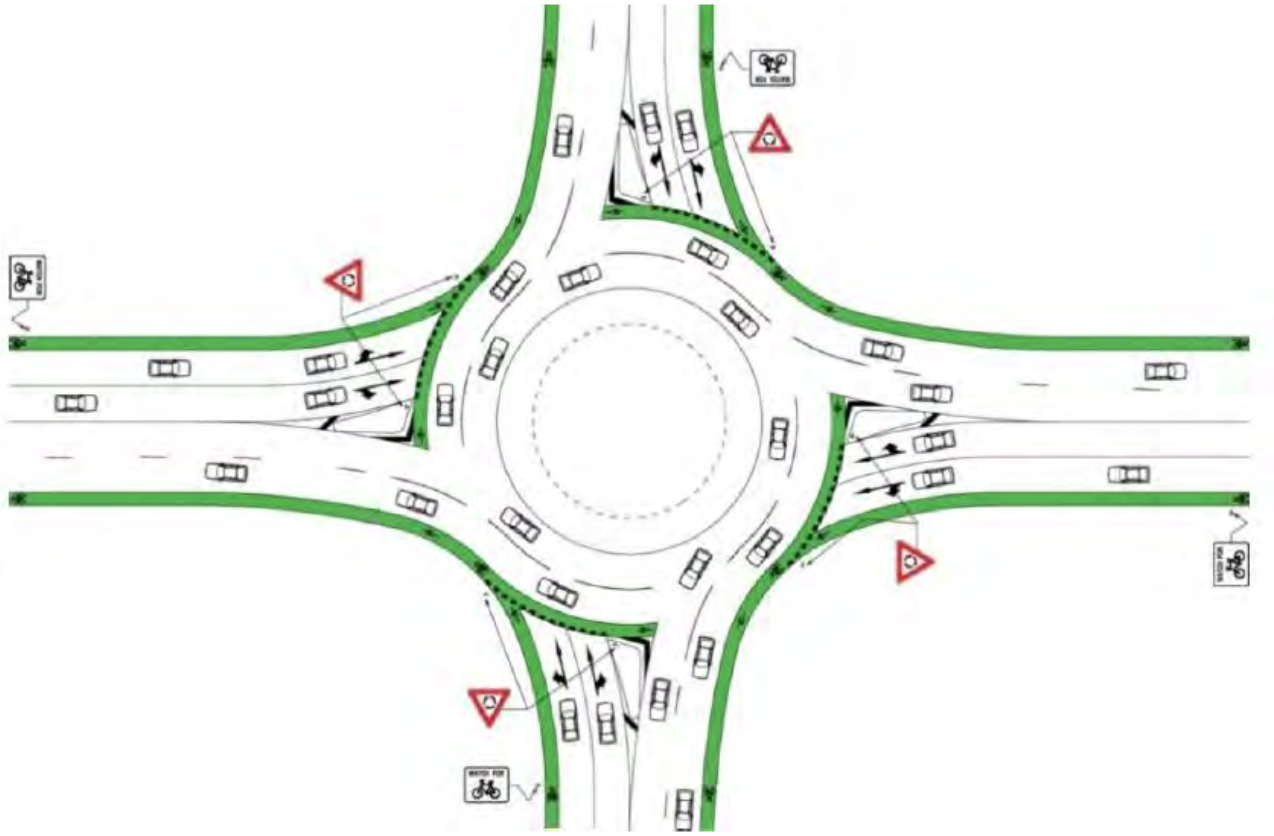
A separated off-road treatment is also suggested in AGRD Part 4B (Austroads 2015a) with uncontrolled cyclist/pedestrian movement across each approach.

Figure 2.4: Paths for cyclists at roundabouts



Source: Austroads (2013a).

Figure 2.5: Bicycle lane with a multilane roundabout



Notes:

Green surfacing is recommended for bicycle lanes within roundabouts to alert motorists to the likely presence of cyclists.

The retention of bicycle lanes within roundabouts as contained in Austroads (2013a) which is currently under review.

Source: VicRoads (2005).

Multilane roundabouts

For dual-lane or multilane roundabouts AGRD Part 4B (Austroads 2015a) does not provide any guidance on the treatments for cyclists and comments that these roundabouts have higher traffic volumes and entry speeds than local roads and therefore create safety problems for cyclists.

AGTM Part 6 (Austroads 2013a) currently provides the same guidance as indicated for larger single-lane roundabouts. It should also be noted that this guidance is under review at the time of writing this report.

One of the issues to be considered when providing bicycle lanes within a roundabout, as shown in Figure 2.5, is the ending of the bicycle lane at the departure of each roundabout, which would require the cyclist to give way to a vehicle leaving the roundabout. This appears to have been developed to be consistent with the *Australian Road Rules*, rule 119 (National Transport Commission 2012), which requires:

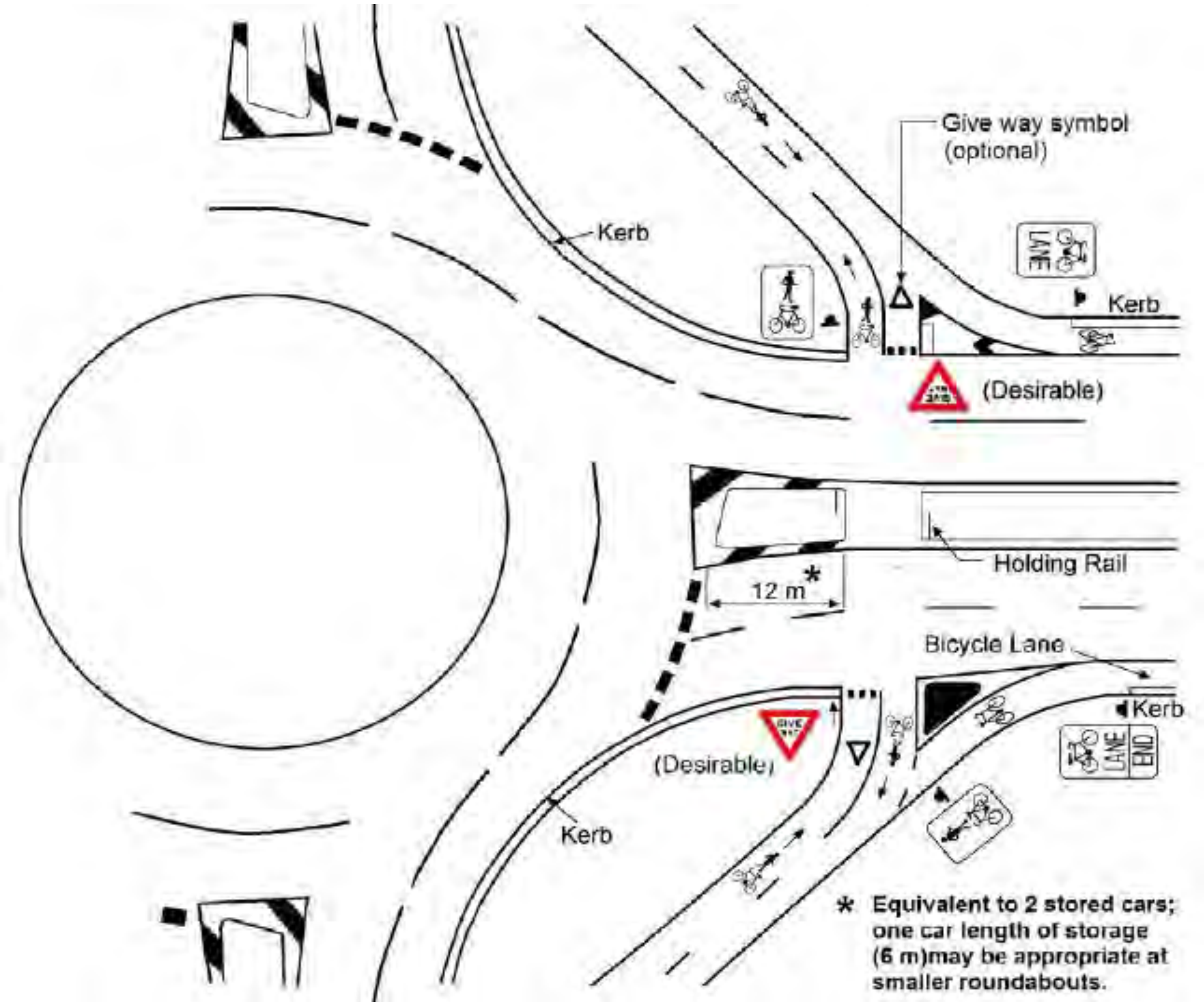
> ***Giving way by the rider of a bicycle or animal to a vehicle leaving a roundabout***
>
> *The rider of a bicycle or animal who is riding in the far left marked lane of a roundabout with two or more marked lanes, or the far left line of traffic in a roundabout with room for two or more lines of traffic (other than motor bikes, bicycles, motorised wheelchairs or animals), must give way to any vehicle leaving the roundabout.*

While this may create difficulties for a cyclist continuing around the roundabout, the main location where cyclist crashes occurred was at the entry to the roundabout (see Section 7).

Crossings

It is suggested in AGTM Part 6 and AGRD Part 4B that where an off-road bicycle path reaches a roundabout, the bicycle path could be directed to a crossing of the legs of the roundabout (Figure 2.6). Cyclists using this type of crossing would not have priority over the vehicles leaving the roundabout which is also the situation for pedestrians crossing at this location.

Figure 2.6: Example of shared crossing path at a multilane roundabout



Source: Austroads (2013a).

2.3.2 United Kingdom

The United Kingdom Department for Transport guide for the geometric design of roundabouts (Department for Transport 2016) contains guidance (Table 2.1) on the selection of the recommended cyclist and pedestrian provision, and the type of roundabout, based on the approach speed zones ('any approach' being a single or dual carriageway), traffic volumes and sufficient demand to justify the treatment.

Table 2.1: Selection of roundabout type in the United Kingdom

Approach carriageways (any approach)	Approach speed zone (km/h) (any approach)	AADT (any approach)	Recommended cyclist provision	Combined cyclist and pedestrian provision	Type of roundabout
Dual	> 65	Any	Signal controlled/ grade separated	Signal controlled/ grade separated	Normal(1)
Single	> 65	> 8 000	Signal controlled/ grade separated	Signal controlled/ grade separated	Normal
Single	> 65	< 8 000	Mix with traffic	–	Compact(2)
Dual	≤ 65	> 25 000	Signal controlled	Signal controlled	Normal
Dual	≤ 65	16 000 to 25 000	Signal controlled	Signal controlled	Normal
Dual	≤ 65	≤ 16 000	No formal control(3)	No formal control	Normal
Single	≤ 65	> 12 000	Signal controlled	Signal controlled	Normal
Single	≤ 65	8 000 to 12 000	No formal control	Either no formal control or single controlled	Normal or compact
Single	≤ 65	< 8000	Mix with traffic	No formal control	Compact

1 *A normal roundabout may have single or dual carriageways, flared entries and exits that allow two or three vehicles to leave the roundabout and a central island at least 4 m in diameter.*
2 *A compact roundabout has single entries and exits and where the speed limit on the approaches is <65 km/h the entries are orientated to be more perpendicular than the normal roundabouts, providing greater entry deflection compared to a normal roundabout.*
3 *For the 'No formal control' situations a separate path is located separately from the circulating lanes of the roundabout.*

Source: Adapted from Department for Transport (2016).

It can be seen from Table 2.1 that the provision for cyclists is guided by the road characteristic, i.e. single or dual carriageway, the approach speeds and traffic volumes. When traffic volumes are less than 8000 vpd, on any approach, cyclists mix with the other traffic travelling through the roundabout. For situations where there are higher approach speeds or volumes, a separate path is suggested, with it being either uncontrolled or signalised crossing. Department for Transport (2016) also suggests that a grade-separation treatment for pedestrians and cyclists is the best option at high speed roundabouts, but may not be cost-effective.

Note: the traffic volumes suggested as suitable for mixing of motor vehicles and cyclists are much higher than the traffic volumes of ≤ 3000 vpd suggested in Austroads (2013a).

Department for Transport (2016) also contains some guidance for compact roundabouts and mini-roundabouts. Mini-roundabouts are 1–4 m in diameter with the central island being installed by using paint or a slight dome. It is recommended that these types of roundabouts only be used on roads with speed zones of 45 km/h or less and have a dry weather 85th percentile speed of less than 45 km/h at least 70 m prior to the give-way line, unless it is installed in combination with speed reducing treatments. Detailed information on compact roundabouts is included in the outline of geometric design practices in Section 3.1.

Department for Transport (2016) also suggests that where a bicycle route contains a roundabout, cyclists can travel through the roundabout, around the outside of the roundabout using a peripheral bicycle track, grade separating the bicycle path or the bicycle route is directed away from the roundabout.

Transport for London have also published a study, *International Cycling Infrastructure Best Practice Study* (Transport for London 2014), which found that continental (or radial) roundabout designs led to slower vehicles, reduced weaving on the circulating carriageway, making it easier for the cyclists to negotiate the roundabout in a more prominent position. Cyclist markings in the centre of the carriageway were also seen to have safety benefits. The report also noted that the use of cycle lanes around the outside of a roundabout may be more suited to countries where cyclists have priority over vehicles leaving the roundabout. Roundabouts with external tracks where cyclists give way to motorists were seen to work well in Nantes, France; the external track with cyclist priority was seen to work well in Malmo, Sweden, Amsterdam and Utrecht in the Netherlands.

2.3.3 Netherlands

In the Netherlands, roundabouts cater for cyclists in different ways, depending on the location and traffic volumes and are outlined in the *Design Manual for Bicycle Traffic* (de Groot 2007).

For lightly trafficked roundabouts, with up to 6000 vpd, passing through the roundabout, cyclist facilities are not required but this is qualified and facilities could be provided if they provide a better fit with the connecting roads. On roundabouts with more than 6000 vpd separate bicycle paths are recommended.

Bicycle lanes are not recommended within roundabouts, i.e. adjacent to the circulating lanes, due to the restricted view to cyclists, particularly from drivers of large vehicles. Some additional issues are to be considered in providing bicycle facilities:

- The bicycle path must provide stimulation for the alertness of the cyclist.
- Crossing points must be clear and conspicuous.
- Cyclists must be visible near the crossing point.

It is important to note that in built-up areas, i.e. urban areas, cyclists on separate paths that travels outside of the circulating lanes, have right of way over vehicles entering or leaving the roundabout. Another important factor to note is that the speed limit in a built-up area varies according to the road function, with a 30 km/h speed limit on roads with an access function and 50 km/h on roads with a distributor function.

Outside of built-up areas, i.e. in rural areas, on roads with a distributor function, cyclists on a separate cycle path do not have right of way over vehicles entering or leaving the roundabout. The speed limit on these roads is typically 80 km/h.

It is important to note that roundabouts are located on roads with speed limits up to 80 km/h (personal communication with John Boender, email 18 December 2015).

At two-lane roundabouts, the preferred treatment is to grade separate the bicycle path from the motor vehicle lanes.

2.3.4 Denmark

In Denmark roundabouts are used to enhance road safety in both urban and rural areas. The roundabout may have one or more lanes in the approach and exit lanes.

Urban areas

In lightly trafficked urban areas, which have speed zones between 30 km/h and 50 km/h, cyclists mix with motor traffic in the one circulating lane. A relatively small central island, approximately 10 m in diameter would be used in these locations.

At larger roundabouts, the central island is typically 15 m to 30 m in diameter with a one-way bicycle path set back from the circulating lanes of the roundabout provided.

At urban roundabouts, vehicles leaving the roundabout have to give way to cyclists continuing around the roundabout.

Rural areas

In rural areas, where the roundabouts are typically larger, 20 m to 40 m in diameter cyclists should not circulate in the roundabout and should be provided with a separate path 10 m to 30 m from the circulating lane(s). When crossing a road on this path, the cyclists do not have priority and must give way to vehicles travelling along the road. This type of path may operate in a two-way manner to minimise the cyclists travel distance around the roundabout.

2.3.5 Germany

Germany has four types of roundabouts:

- compact single-lane roundabouts 26 m to 40 m in diameter
- mini-roundabouts with a traversable island, 13 m to 25 m in diameter
- larger roundabouts 40 m to 60 m in diameter with two-lane approaches
- turbo-roundabouts.

In Germany, bicycle lanes on the edge of the circulating lanes are not permitted due to their being very dangerous to cyclists. At single-lane roundabouts (known as compact roundabouts in Germany) with traffic volumes of 15 000 vpd (total from all approaches), it is considered that the safest treatment is to guide cyclists onto the circulating lane. Above this traffic volume, separate bicycle paths should be provided (Brilon 2014). Where there are bicycle lanes on the approach to a compact roundabout, the bicycle lanes should be terminated at least 10 m prior to the splitter island (ViaStrada 2016).

Where a path is provided around the outside of a roundabout, the path should cross the leg of the roundabout 4 m to 5 m from the circulating lane. In an urban area, cyclists have priority when crossing the legs of a roundabout over the vehicles entering or leaving the circulating lanes. In rural areas, this priority changes and cyclists have to give way to vehicles entering and leaving a roundabout.

2.3.6 United States of America

Guidance from the United States of America shows a preference for cyclists mixing with traffic when it is safe to do so, with roundabouts designed to create vehicular flow at commuter cycle speeds. When this is not possible or for more complicated roundabouts, there should be clear delineation of bicycle and pedestrian pathways with complete separation preferred at multilane roundabouts. When roads approaching the roundabout have bicycle lanes, it is recommended that they terminate at a point that will result in cyclists merging with traffic. Such design will move cyclists away from the edge of the roundabout where they could be hit as vehicles enter and exit (Rodergerdts et al. 2010). Ending bicycle lanes in this fashion is not suggested in current Austroads design guidance.

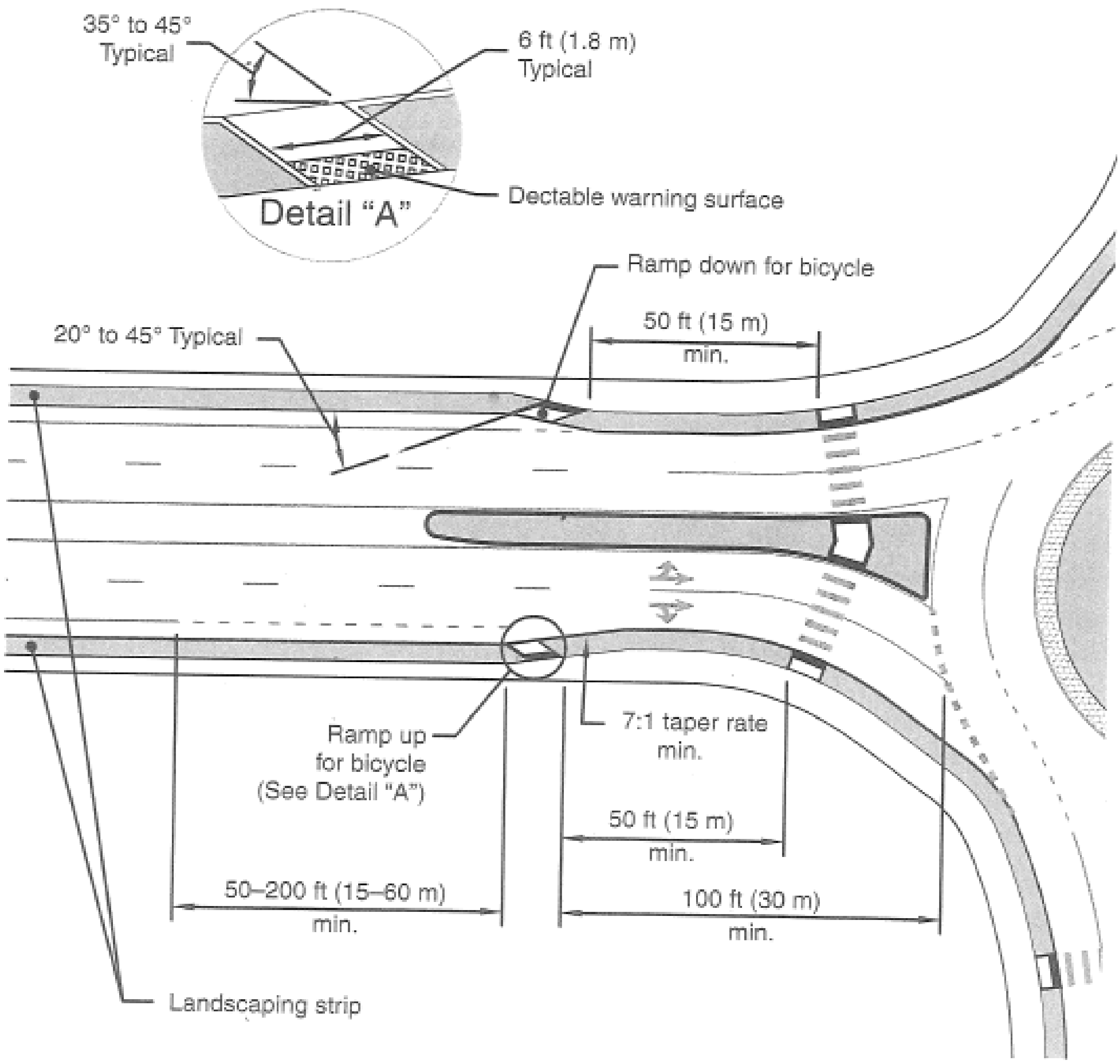
The *Policy on the Geometric Design of Highways and Streets* (American Association of State Highway and Transportation Officials (AASHTO) 2011) provides guidance on bicycles at roundabouts and suggests that:

- Bicycle lanes should be terminated on the approach to the roundabout and not be provided through the roundabout.
- For a single-lane roundabout, cyclists may merge with the other vehicles and travel through the roundabout mixing with these vehicles.

The *Guide for the Development of Bicycle Facilities* (AASHTO 2012) provides further detail and indicates that urban roundabouts should have a design entry speed of 30 km/h to 50 km/h, with single-lane roundabouts at the lower end. Cyclists, who travel in urban traffic generally have the skills to perform this activity and so can manage the single-lane roundabout. Multilane roundabouts are more complex, but many cyclists should be able to travel through these roundabouts (AASHTO 2012).

AASHTO (2012) goes on to suggest that bicycle lanes should be terminated on the approach to a roundabout with provision for the cyclist to leave the traffic lane and utilise the footpath area (Figure 2.7).

Figure 2.7: Example of a bicycle lane termination and re-entry (United States of America)



Source: AASHTO (2012).

2.3.7 Canada

While the Canadian geometric design guide notes that cyclists face increased crash risk at roundabouts, it does not offer specific guidance for their management (Transportation Association of Canada 1999).

2.4 Additional Risk Factors

Silvano, Ma and Koutsopoulos (2015) in a study in Sweden examined the behaviour of motor vehicle drivers to give way, or yield to cyclists crossing the exits of a roundabout[1] to inform the design, planning and policy decisions for roundabouts.

The study examined the speed of vehicles approaching a crossing point when there was a cyclist approaching the same crossing point. The vehicle speeds were found to average 13 km/h whilst the average speed of the vehicles that failed to give way was 22 km/h. The position of the approaching cyclist also influenced the driver behaviour, with a higher rate of vehicles giving way when the cyclist was within 20 m of the crossing point, compared to when the cyclist was further than 20 m from the crossing point.

This study revealed that driver behaviour is influenced by the approach speed of the vehicle and the capability of the driver to observe the cyclist as both approach the same crossing point.

2.5 Summary

In Australia and New Zealand the guidance for the design of roundabouts aims to reduce approach speeds and circulating speeds by using an entry path curve radius that aligns tangentially to the central island.

The guidance in AGRD Part 4B (Austroads 2015a) indicates that bicycle lanes be terminated prior to the roundabout. AGTM Part 6 (Austroads 2013a) currently suggests bicycle lanes to continue from the approach lanes into the roundabout however at the time of writing this report this practice was under review. Some physical separation is suggested on the approach lanes and for a multilane roundabout, the physical separation is suggested also at the exit points of the roundabout. The practice in New Zealand is to terminate on-road bicycle lanes 30 m in advance of the holding lines.

In the United Kingdom, the design guidance suggests that at a compact roundabout for traffic volumes < 8000 vpd (for each approach) with speeds > 65 km/h, bicycles can mix with the other traffic. If the traffic volumes are > 8000 vpd a normal roundabout with a separate path is suggested.

The practices in Europe generally suggest that for low-speed (50 km/h or less), with traffic volumes varying from 6000 vpd in the Netherlands, up to 8000 vpd (on any approach) in the United Kingdom and up to 15 000 vpd (total from all approaches) in Germany, cyclists can mix with other vehicle traffic. Where the vehicle speeds or volumes are higher, it is suggested that separate bicycle facilities are provided. Radial-type roundabouts are also utilised and this alignment has an entry curve radius that is smaller than used for the tangential style of roundabout.

The traffic volume thresholds for the mixing of motor vehicles and cyclists is much higher in the United Kingdom and Europe when compared to the suggested thresholds in Australia and New Zealand.

1 In Sweden, the traffic rules at roundabouts require vehicles leaving a roundabout to give way, or yield to cyclists crossing the exit leg of the roundabout.

3. Geometric Design Practices

An overview of the design of key geometric components of a roundabout in Australia and New Zealand, the United Kingdom, the Netherlands, Germany and the United States of America was undertaken to show the different methods and approaches used in each country.

Generally, the approach to roundabout design is similar in Australia, New Zealand, the United Kingdom and the United States of America, with each following the tangential approach to roundabout layout rather than the radial design approach adopted in the Netherlands. Whilst the general approach is similar, a more detailed examination of the approaches taken in each country has been undertaken.

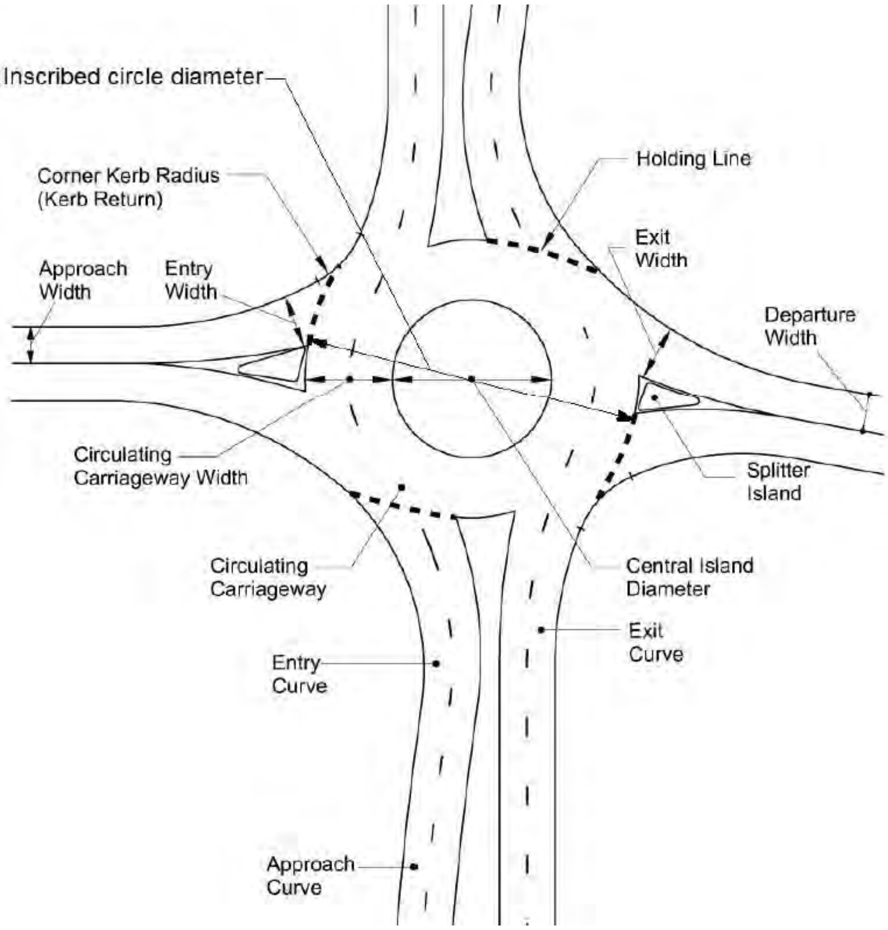
3.1 Geometric Components

The geometric design components (Figure 3.1) are:

- design vehicles – the tracking requirements of the design vehicle has a major influence on the size and shape of intersection layouts
- entry geometry including entry width and the splitter island
- central island and circulating carriageway width
- exit geometry including exit width and departure curve
- sight distance.

Design speed is not a geometric component but it is important to consider as it is related to the vehicle travel path development for achieving the desired entry speed to the roundabout.

Figure 3.1: Example of the roundabout geometric elements



Note: The central island may also include an encroachment area to cater for larger vehicles.

Source: Austroads (2015a).

A comparison of these geometric design components is outlined in the following sections.

3.1.1 Design Vehicles

When comparing the geometric elements of roundabouts in each of the countries, the different design vehicles suggested in each jurisdiction should be recognised.

Australia and New Zealand

The selection of a design vehicle is contained in *Design Vehicles and Turning Path Templates* Guide (Austroads 2013b) and can vary according to the road classification and function. In Australia, the design vehicles for different intersecting road types are shown in Table 3.1.

Table 3.1: Typical design vehicles used in Australia

Australia		
Intersecting road types	**Typical Austroads standard vehicle for design**	**Typical Austroads standard vehicle for checking design**
Arterial/Arterial	Prime mover and semi-trailer (19.0 m)(1) Radius 15 m	Appropriate vehicle e.g.: B-double (25 m)(2) or Prime mover and long semi-trailer (25 m) or Road train(3)
Arterial/Collector	Single unit truck/bus (12.5 m) Radius 12.5 m	Prime mover and semi-trailer (19.0 m) Radius 15 m
Arterial/Local (residential)	Service vehicle (8.8 m) Radius 12.5 m	Single unit truck/bus (12.5 m) Radius 12.5 m
Collector/Collector (industrial)	Prime mover and semi-trailer (19.0 m)(1) Radius 15 m	Prime mover and semi-trailer (19.0 m)(1) Radius 15 m
Collector/Collector (residential)	Single unit truck/bus (12.5 m) Radius 12.5 m	Prime mover and semi-trailer (19 m)(1) Radius 15 m
Collector/Local (residential)	Service vehicle (8.8 m) Radius 9 m	Single unit truck/bus (12.5 m) Radius 12.5 m
Local/Local (industrial)(4)	Prime mover and semi-trailer (19.0 m)(1) Radius 12.5 m(5)	Appropriate vehicle e.g.: B-double (25 m)(2) or Prime mover and long semi-trailer (25 m) or Road train(3)
Local/Local (residential)	Service vehicle (8.8 m) Radius 9 m	Single unit truck/bus (12.5 m) Radius 12.5 m

1 *Select the appropriate vehicle for the design of sites that are frequently used by such vehicles.*
2 *B-double length may vary between jurisdictions.*
3 *Select appropriate road train from the Guide to Road Design: Part 3: Geometric Design (Austroads 2016a) or from relevant jurisdiction guide.*
4 *Also for intersections with industrial land use for collector/local intersections.*
5 *Simulations show that for this radius the maximum steering angle occurs at the exit of the turn and not applied at the crawl speed.*

Source: Austroads (2013b).

In New Zealand, a similar approach is taken albeit with variances in the vehicle length. For example, on an arterial road an 18 m long articulated truck is considered to be an appropriate design vehicle. The New Zealand design vehicles information is contained in *On-road Tracking Curves for Heavy Vehicles* (Land Transport New Zealand 2007).

United Kingdom

The design vehicle suggested in the *Design Manual for Roads and Bridges* (Department for Transport 2016) is a 15.5 m articulated vehicle with a single rear-axle trailer. The manual indicates that this vehicle is not common and its turning requirements are greater than those for other vehicles normally travelling on the roads.

Netherlands

The design vehicles include a 16.5 m truck-trailer combination and an 18.75 m truck and trailer (personal communication with John Boender, CROW, email 18 December 2015).

United States of America

In the United States of America a common design vehicle would be a 21 m to 22 m articulated vehicle. Ultimately, the design vehicle is determined by the designer and the selection should be the largest vehicle using the intersection (Rodergerdts et al. 2010).

3.1.2 Entry Geometry

The purpose of the entry geometry, i.e. entry path and entry width, is to control the speed of vehicles entering the roundabout. It is therefore the most important geometric element as the speed of entering traffic affects the safety performance of the roundabout.

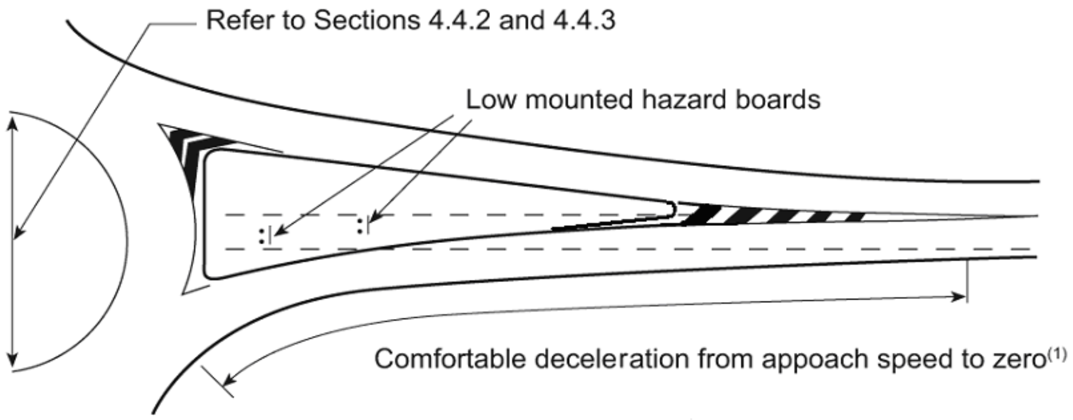
Australia and New Zealand

Austroads (2015a) indicates three methods to achieve good approach geometry for the entry path:

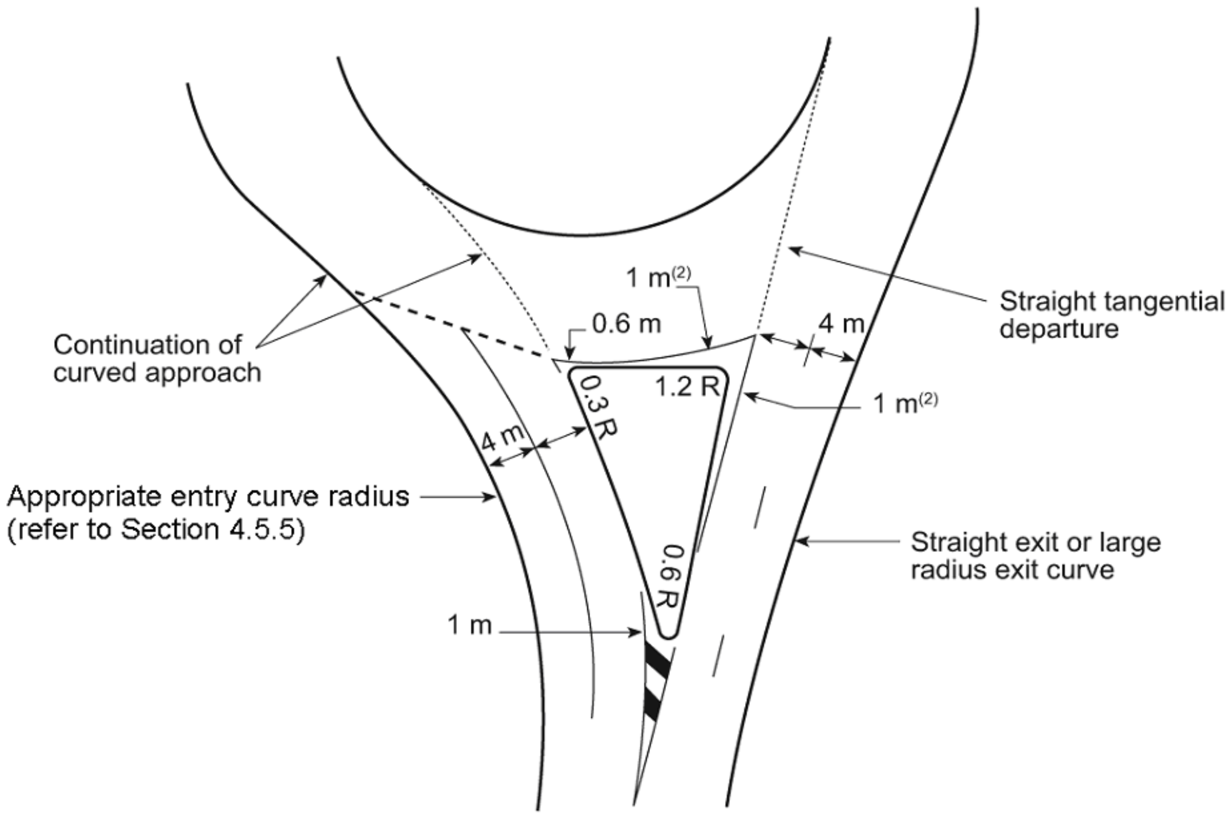
- single entry curve
- reverse curves
- blisters.

The 'single entry curve' provides an entry curve on the approach to a roundabout, with a path radius aimed to slow vehicles down before reaching the roundabout. The extension of the kerb line of the splitter island is tangential to the central island (Figure 3.2). It is also suggested that to accommodate heavy vehicle drivers, some road agencies prefer to locate this line tangentially to a design circle offset 1.5 m from the central island.

Figure 3.2: Roundabout with single entry curve on the approach



(a) Typical rural roundabout design (with high speed approach roads)



(b) Typical arterial urban roundabout

Note: References in Figure 3.2 are to sections within Austroads (2015a).

Source: Austroads (2015a).

The reverse curve treatment may be used in high-speed environments in order to provide a physical control on the reduction in the speed of vehicles approaching a roundabout. One or two approach reverse curves are used prior to the entry curve to achieve a speed difference between the successive curves of no more than 20 km/h. This type of treatment is most often used in high speed, i.e. ≥ 80 km/h, approaches.

The use of reverse curves works best on single-lane approaches, but the desired speed reduction can be achieved on two-lane approaches. The reverse curves should be kept as short as possible, but long enough to discourage vehicles from cutting across the lanes and to ensure appropriate development of superelevation throughout the curves.

Austroads (2015a) also indicates that in high-speed environments, the speed on the approaches could be reduced by incorporating other treatments, singly or in combination with each other, such as a long median island and kerb on the left side of the approach to create a perception of the road narrowing, rumble strips, dense roadside plantings (whilst still providing the required sight distances), speed limits, warning signs and lighting.

Entry treatments using blisters (also known as kerb extensions) are used in low-speed urban areas that typically have wide approaches.

Austroads (2015a) does not indicate desirable entry design speeds, relying on the entry path geometry to achieve the entry speed. There is reference to appropriate entry speeds when considering sight distance, i.e. a speed of 50 km/h for arterial roads and 25 km/h to 30 km/h for local roads.

The maximum entry path radius for a single lane entry and a two-lane entry when the vehicles stay within the correct lane and for two-lane entry when vehicles cut across the lanes is shown in Table 3.2.

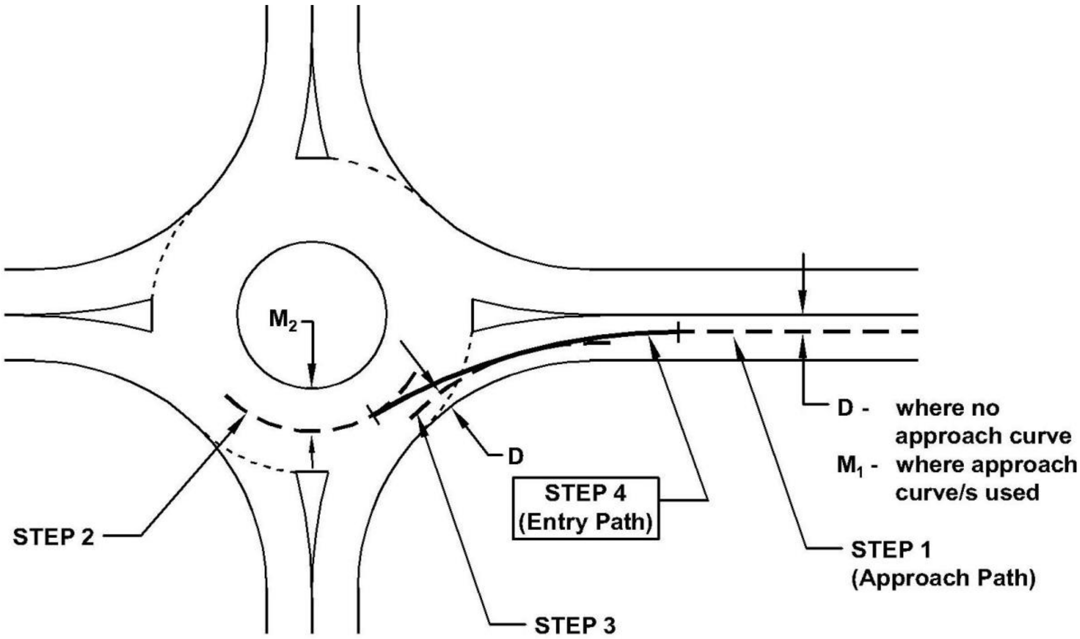
Table 3.2: Maximum entry path radii for one-lane and two-lane roundabouts

Desired driver speed on the leg prior to the roundabout (km/h)	Maximum entry path radius (m)	
	Single-lane entries Two-lane entry – staying in correct lane	Two-lane entry – cutting across lane
≤ 40	≤ 55	1.9 x actual entry path radius when staying in correct lane
50		1.8 x actual entry path radius when staying in correct lane
60		1.6 x actual entry path radius when staying in correct lane
70		1.5 x actual entry path radius when staying in correct lane
80		1.5 x actual entry path radius when staying in correct lane
≥ 90		1.5 x actual entry path radius when staying in correct lane

Source: Austroads (2015a).

For single-lane entries the vehicle path is constructed as shown in Figure 3.3. For this layout the entry path radius must not be greater than the values for the single-lane entries shown in Table 3.2. If the entry path radius is greater than the criteria shown in Table 3.2, this radius should be reduced to the required limit. This could be achieved by relocating the approach leg and/or increasing the roundabout size. Austroads (2015a) also suggests that on local residential streets an approach speed of 25 km/h to 30 km/h is appropriate but there is no guidance on the geometry to achieve these speeds.

Figure 3.3: Entry path for a single-lane entry



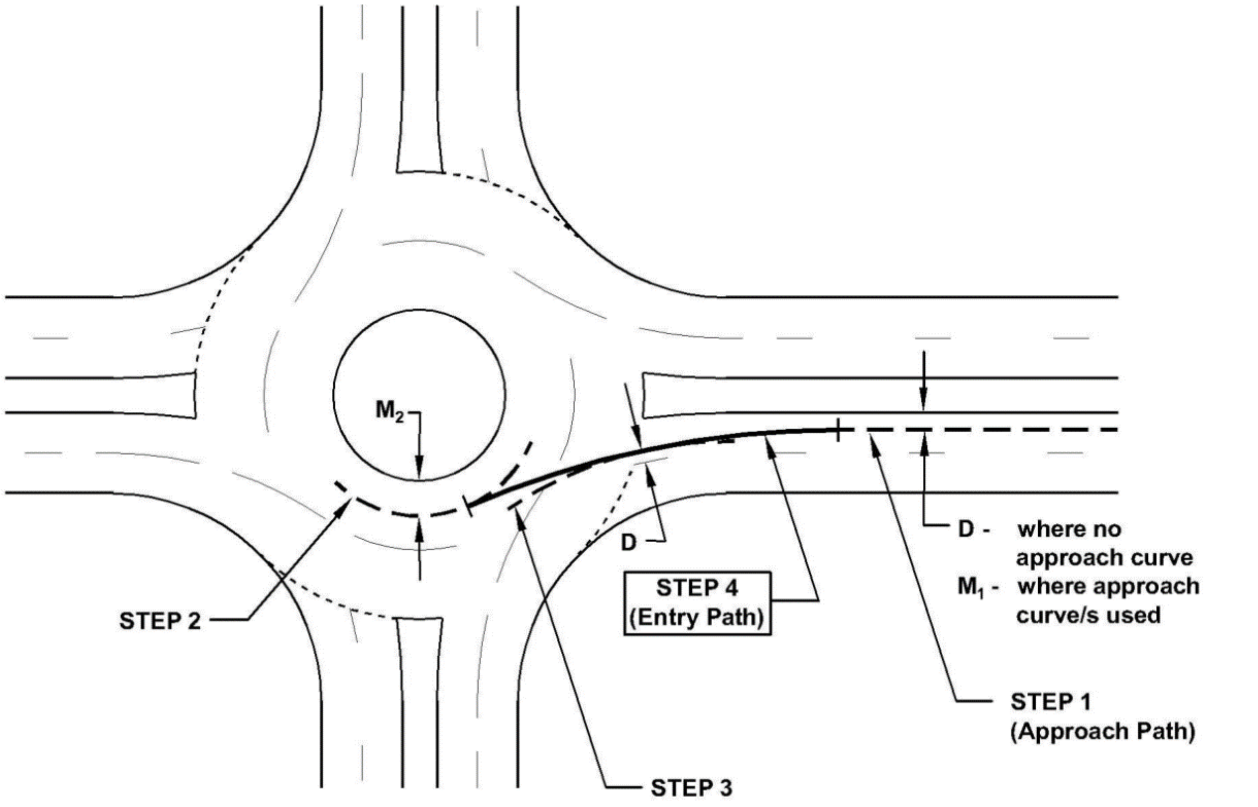
D = 1.5 m when measuring from a road centreline or kerb face, 1.0 m when measuring from an edge line.
M_1 = Half the width of the approach lane.
M_2 = Half of the width of the circulating carriageway.

Note: STEP 1 – STEP 4 show the procedure followed to develop the entry path.

Source: Austroads (2015a).

For a two-lane entry the vehicle path is located from the right entry lane to the inner circulating lane (Figure 3.4). The radius of the entry path should not be greater than the criteria shown in Table 3.2 for a ‘two-lane entry – staying in the correct lane’. If this radius needs to be reduced it is suggested that this could be achieved by relocating the approach leg and/or increasing the roundabout size.

Figure 3.4: Entry path for a two-lane entry – staying in the correct lane



D = 1.5 m when measuring from a road centreline or kerb face, 1.0 m when measuring from an edge line.
M_1 = Half the width of the right approach lane.
M_2 = Half of the width of the inner circulating lane.

Note: STEP 1 – STEP 4 show the procedure followed to develop the entry path.

Source: Austroads (2015a).

For two-lane roundabouts, Austroads (2015a) also indicates a method that caters for vehicles cutting across lanes travelling through the roundabout (Figure 3.5). The entry path starts in the right entry lane and is aimed at the centre of the circulating carriageway width. The entry path radius should not exceed the criteria shown in Table 3.2 for a 'two-lane entry – cutting across lanes'. It is suggested that if this radius needs to be reduced, this could be achieved by relocating the approach leg and/or increasing the roundabout size.

The larger radius in allowing vehicles to cut across the lanes would lead to higher speeds of vehicles travelling through the roundabout.

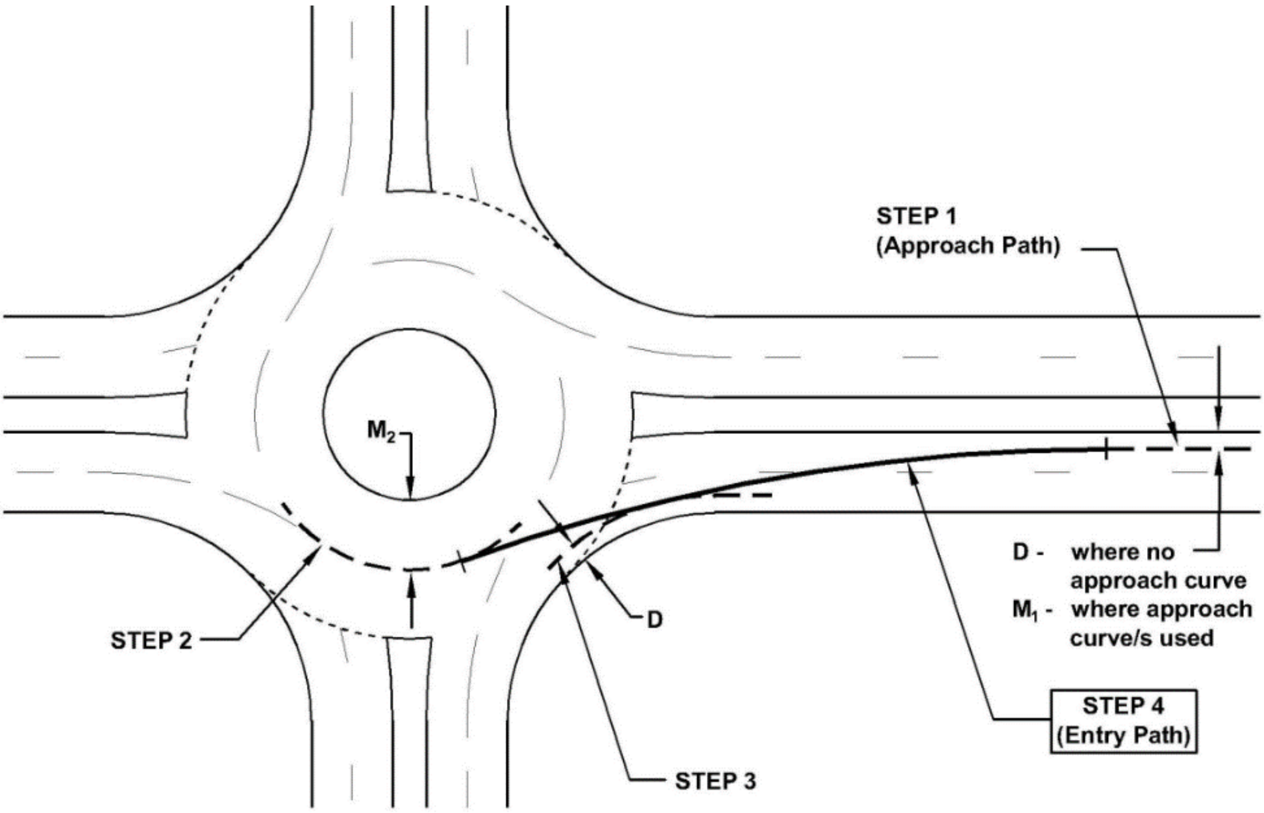
Splitter islands

Splitter islands should be provided to:

- assist in controlling vehicle speeds
- guide vehicles into the roundabout
- deter drivers from turning right, i.e. travelling the wrong way
- provide shelter for pedestrians.

The right side of the splitter island should direct vehicles onto the roundabout to provide a smooth vehicle path but also provides drivers with comfortable sighting of approaching traffic. The entry curve should then be tangential to the central island. In some cases, the right side of the entry curve may be aimed at a point on the central island, when the roundabout is primarily used by cars and cyclists and it is desired to further reduce the entry speeds so that drivers have a better opportunity to scan for cyclists (Austroads 2015a).

Figure 3.5: Entry path for a two-lane entry – cutting across lanes



D	**=**	**1.5 m when measuring from a road centreline or kerb face, 1.0 m when measuring from an edge line.**
M_1	**=**	**Half the width of the right approach lane.**
M_2	**=**	**Half of the width of the circulating carriageway.**

Source: Austroads (2015a).

United Kingdom

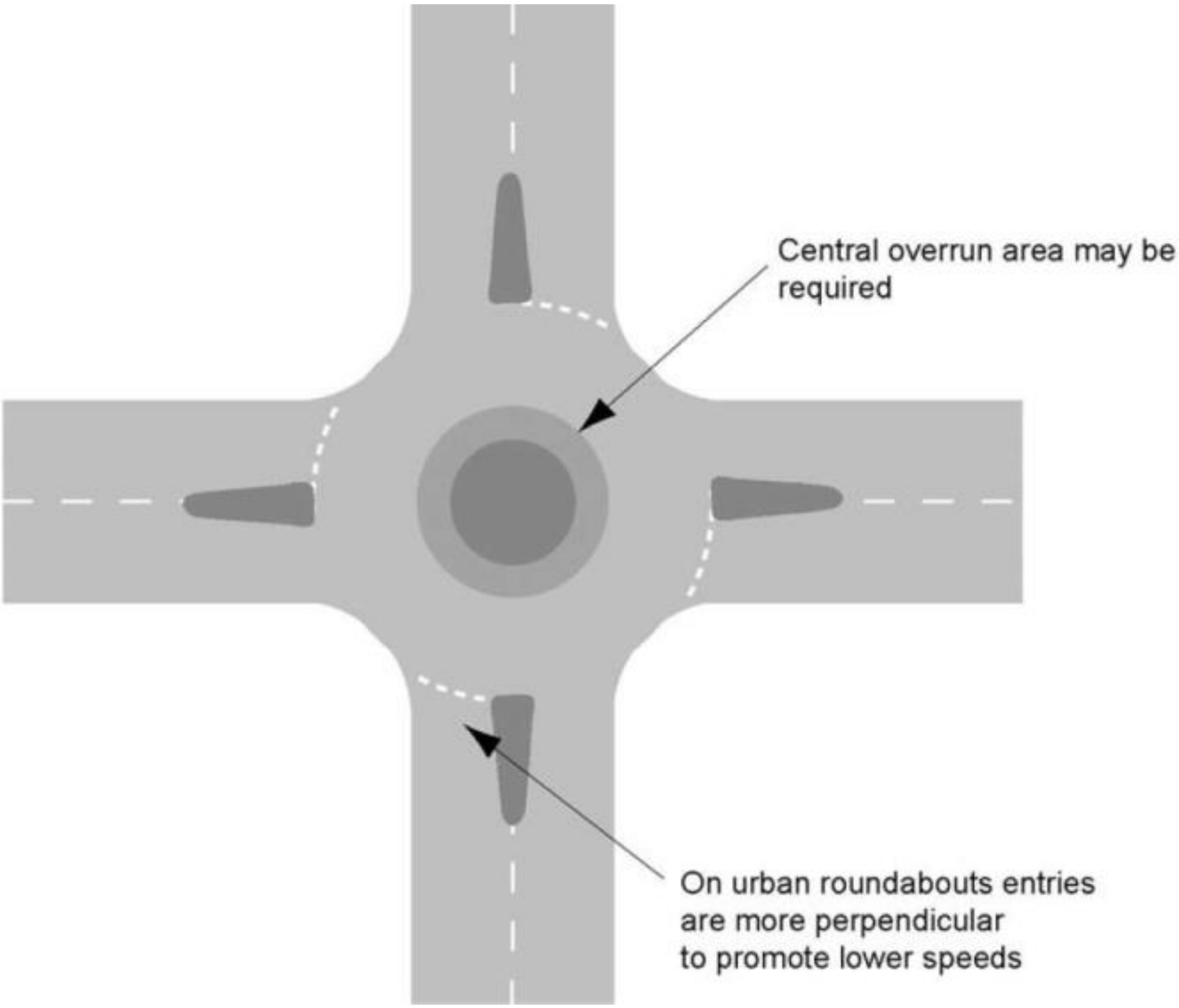
In the United Kingdom a single-lane roundabout may be a compact type or a normal type. A compact type (Figure 3.6) has single-lane, non-flared entries and exits and a normal type may have a single or dual-lane flared entry or exit.

The compact roundabout may have low values of entry and exit radii and high values of deflection. The approach alignment is similar to the radial-type of alignment adopted in the Netherlands.

The capacity of a compact roundabout is less than a normal roundabout but is considered suitable where there is a need to accommodate pedestrians and cyclists. This type of roundabout is utilised on lower speed roads, i.e. < 60 km/h and is similar to the radial-type approach.

The normal type of roundabout with flared entries and exits, provides a greater capacity than a compact roundabout and generally follows the tangential-type approach.

Figure 3.6: Example of a compact roundabout

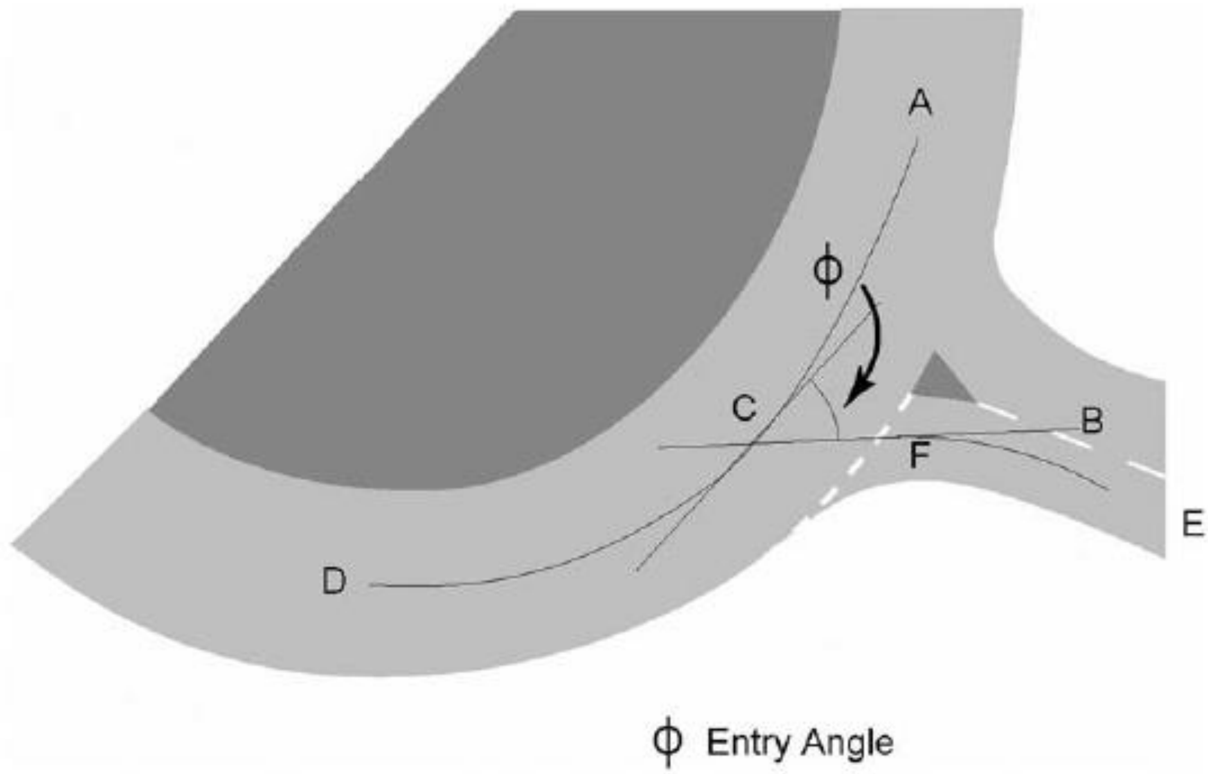


Source: Department for Transport (2016).

For a normal roundabout the approach lane widths at the holding line should not be less than 3 m (appropriate at multilane entries) or more than 4.5 m (at single-lane entries).

For a larger normal type roundabout with approach legs well separated the entry path and entry angle Φ, (Figure 3.7), between the entering vehicle and the circulating vehicle should be between 20° and 60°.

Figure 3.7: Example of the entry angle for a larger roundabout

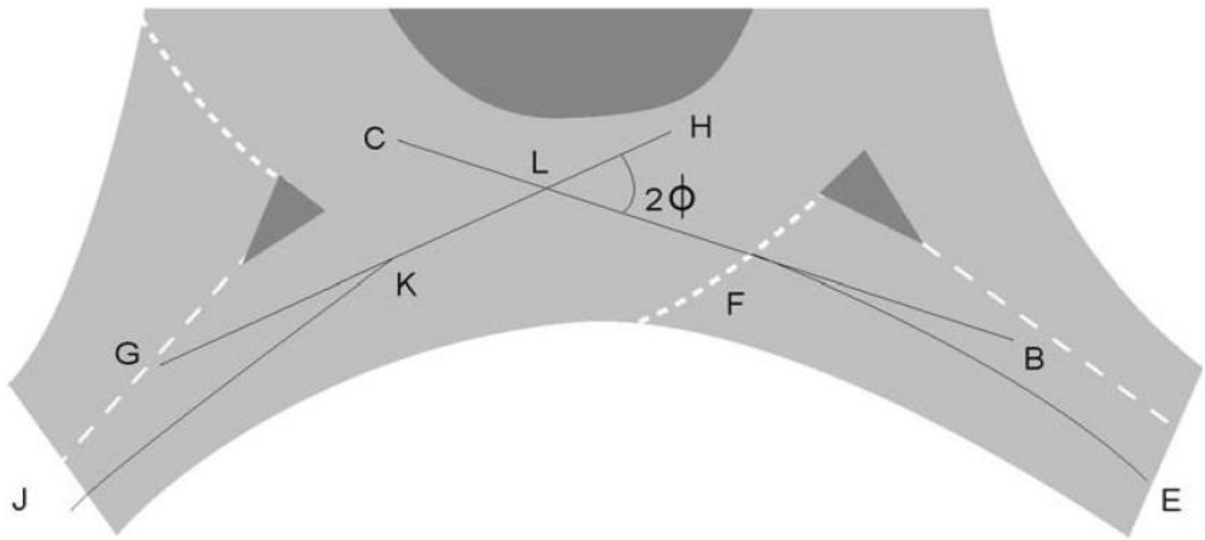


Source: Department for Transport (2016).

For small normal or compact roundabouts, the entry angle is larger (Figure 3.8). This layout is used where there is insufficient separation between the entry and exit to be able to clearly define the circulating vehicle path.

The entry angle Φ should be between 20° and 60°.

Figure 3.8: Example of an entry angle at a smaller or compact roundabout



Source: Department for Transport (2016).

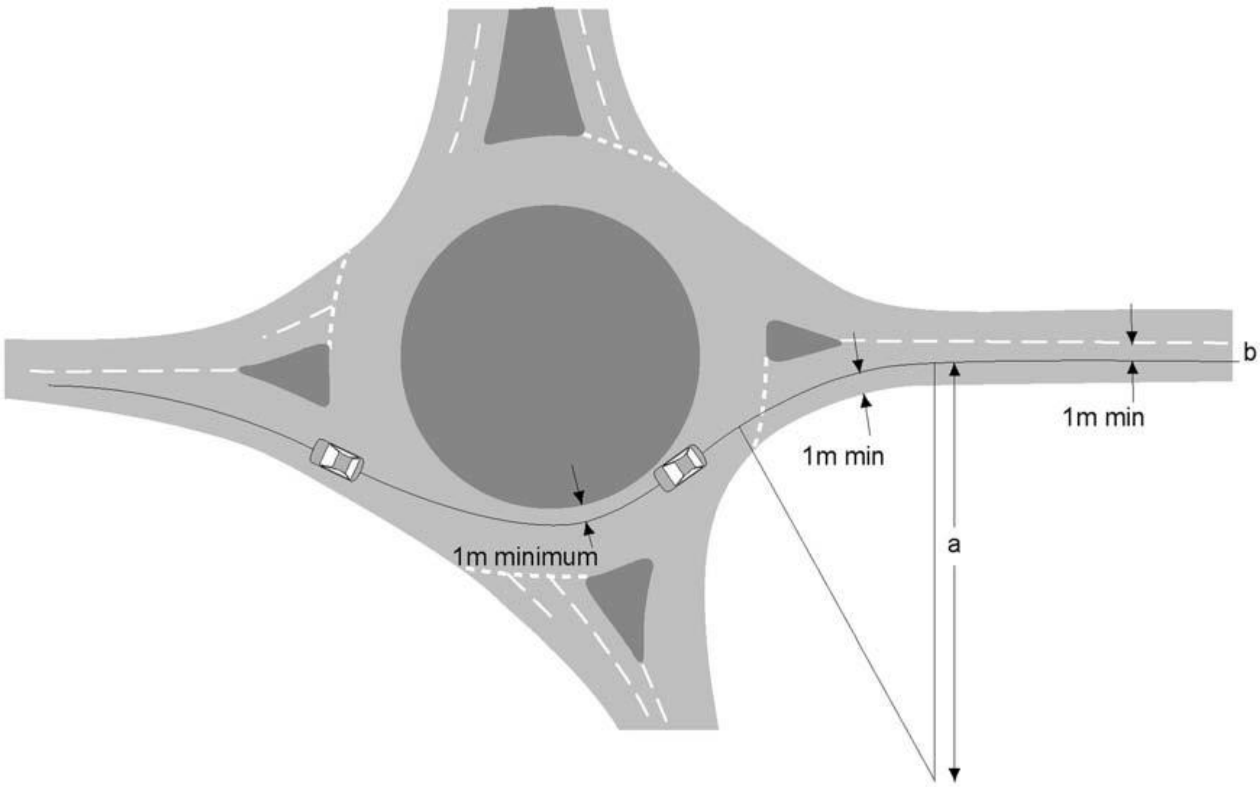
The entry path radius is determined from the fastest path a vehicle can follow through a roundabout. The path is assumed to be 2 m wide and a distance of at least 1 m between the centreline of the path and any kerb or edge. The 1 m applies to the outer edges and the central island as the path travels past these elements. The smallest radius should be at the entry, prior to the circulating lane (Figure 3.9).

The entry path radius must not exceed 70 m at a compact roundabout in urban areas where the speed zone is not greater than 64 km/h (40 mph) and the design speed within 100 m of the holding line on the roundabout is not greater than 70 km/h.

The entry kerb radius should not be less than 10 m, however at compact roundabouts, where large goods vehicles use the intersection, the kerb radius should not be less than 20 m.

The Department for Transport (2016) does not provide any further information on path radii for multilane entry roundabouts.

Figure 3.9: Example of the entry path radius in the United Kingdom

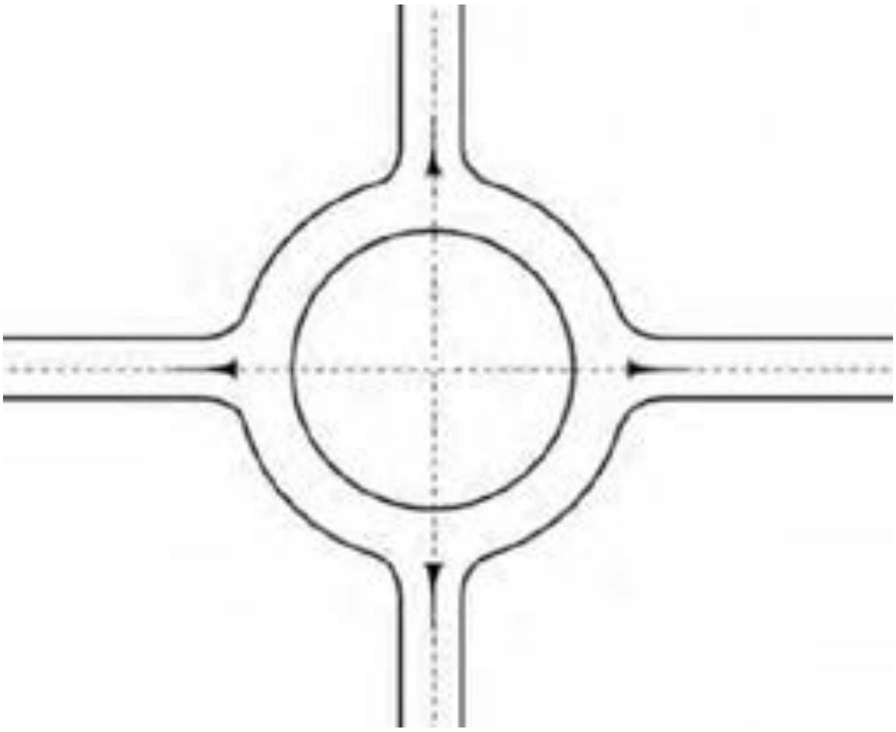


Source: Department for Transport (2016).

Netherlands

Roundabouts follow the radial-type approach which provides a straight approach to the roundabout with the entry lane aligned as much as possible to the middle of the central island. An example of this type of layout is shown in Figure 3.10.

Figure 3.10: Example of a single-lane roundabout with radial-type approaches

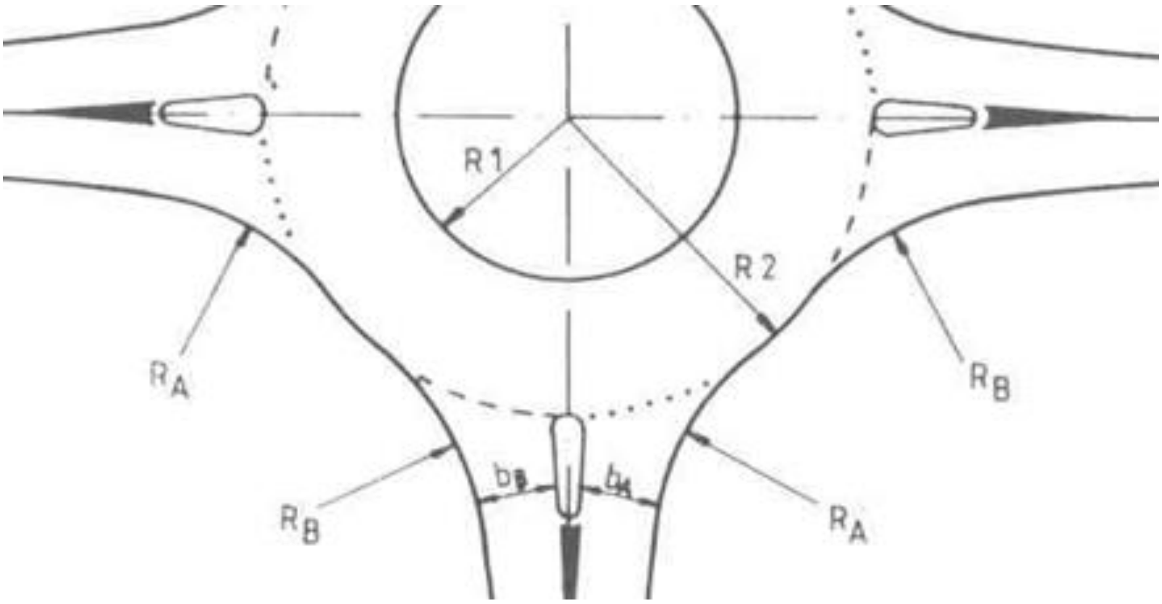


Source: Austroads (2014b).

The entry kerb radius, shown as R_A in Figure 3.11, for both built-up areas and outside of built-up areas ranges between 8 m to 12 m for single-lane roundabouts (personal communication with John Boender, CROW, email 10 September 2015), with the 8.0 m radius used when a splitter island is not provided and 12.0 m radius when a splitter island is provided.

For two-lane roundabouts a 12 m radius (R_A) is used.

Figure 3.11: Example of a radial-type roundabout – geometric elements



Note: Figure 3.11 is taken from material produced for the Netherlands and vehicles travelling on the right side of the road.

Source: Personal communication with John Boender CROW, The Netherlands, email 10 September 2015.

Germany

The roundabouts follow the radial-type alignment with a straight approach and with the section of the splitter island near the circulating lane being curved to follow the entry radius.

For a single-lane roundabout, the entry radius ranges between 10 m to 14 m.

United States of America

Roundabouts may have entry alignments that follow a tangential-type alignment or a radial-type alignment. Rodergerdts et al. (2010) provides information relating to a tangential-type of entry, with very limited information on details of a radial-type alignment.

At a single-lane roundabout, the fastest path is determined on all approaches and movements with the path assumed to be 2 m wide and have a clearance of 0.5 m from the road centreline or concrete kerb. The entry kerb radius is an important factor in determining the speed of vehicles through a roundabout. The selection of the entry kerb radius should be such that it results in the design speed for the fastest path. As in Australia, New Zealand and the United Kingdom, the extension of the splitter island should be tangential to the central island.

Entry path radii are not suggested but Rodergerdts et al. (2010) suggests that for urban single-lane roundabout the entry kerb radii typically range from 15 m to 30 m.

In high-speed locations, usually rural locations, vehicle speeds need to be reduced prior to reaching the roundabout. Rodergerdts et al. (2010) suggests a possible method that is similar to Austroads (2015a) involving the use of reverse curves.

At multilane roundabouts, entry kerb radius should typically be greater than 20 m to encourage vehicles to remain in their lane as they travel through the roundabout. Similarly, the fastest-path radius should preferably be 53 m to 84 m, which results in speeds of 40 km/h to 50 km/h.

The maximum entry speeds recommended are:

- single-lane roundabout – 30 km/h to 40 km/h
- multilane roundabout – 40 km/h to 50 km/h.

Comments on practices in countries considered

The approaches taken by the countries considered above vary with a tangential-type approach generally followed in Australia, New Zealand, the United States of America and the United Kingdom (normal-type roundabouts) and a radial-type approach in the Netherlands and Germany. The United Kingdom also provides guidance for a compact roundabout, used in urban areas where the vehicle speeds and volumes are low, which is a radial-type alignment similar to the alignment adopted in the Netherlands.

In Australia and New Zealand, at single-lane roundabouts, Austroads (2015a) suggests a maximum entry path radius of ≤ 55 m, the United Kingdom guidance for a normal roundabout indicates that the entry path should not exceed 70 m and the United States of America doesn’t suggest an entry path radius but suggests maximum entry speeds.

The maximum entry path radius of ≤ 55 m suggested for a single-lane roundabout caters for desired approach leg speeds ranging from ≤ 40 km/h to ≥ 90 km/h. At the lower speed range, typically found on local road roundabouts, this entry curve is relatively large which may allow a relatively high entry speed. On local residential streets an approach speed of 25 km/h to 30 km/h is suggested, but no guidance is provided on appropriate geometry to achieve these speeds.

For multilane roundabouts, Austroads (2015a) suggests a desirable maximum entry path radius for a vehicle following a lane through the roundabout but also provides guidance for cutting across the lanes, which increases the radius for the 'staying in correct lane' case by between 1.5 for higher speed roads and 1.9 for low-speed roads (Table 3.2).

In the United States of America, the entry path radii provide for speeds of 40 km/h to 50 km/h, with entry path radii preferably 53 m to 84 m.

The Netherlands takes a different approach and follows the radial-type of approach with entry kerb radii on the approach lane being 8 m to 12 m. No information was available on the entry path radius.

3.1.3 Entry Width

The following is a summary of guidance on entry width in the countries reviewed.

Australia and New Zealand

The entry width should be able to accommodate the swept path of the design vehicle, but not be excessively wide as it may be difficult to achieve the desired speed reductions. On arterial roads the entry must be able to accommodate the swept path of the design vehicle within the road pavement with clearance to the edge or kerb. For a single-lane entry the desirable width is at least 5 m between kerbs or the line of kerbs, to enable another vehicle to pass a broken-down vehicle.

On local roads the entry widths should be designed to enable access by the design vehicle, however at small roundabouts it is preferable that the entry width be less than 3.0 m to prevent drivers attempting to enter the roundabout alongside cyclists, forcing them into the kerb.

There is a lack of specific guidance on the entry geometry for the compact-type roundabouts common in the urban local road networks in Austroads (2015a).

United Kingdom

Entry width contributes to the deflection in the travel path through a roundabout. The entry widths should not be less than 3 m or more than 4.5 m with the 4.5 m width appropriate at single-lane entry roundabouts and 3 m to 3.5 m at multilane entry roundabouts.

Netherlands

The entry widths for a single-lane roundabout are between 3.5 m (where there are predominantly passenger cars) and 4.0 m (where there are passenger cars and trucks or buses). For a two-lane roundabout the entry width is the same as the approach lane widths, which may vary according to the road classification (personal communication with John Boender, CROW, email 10 September 2015).

Germany

The entry widths for a single-lane roundabout are between 3.25 m and 3.75 m.

United States of America

The entry width is dependent on the design vehicle and the number of lanes. Entry widths are not suggested but it is indicated that single-lane entries typically range from 4.2 m to 5.5 m. For a two-lane entry the widths typically range from 7.3 m to 9.1 m.

3.1.4 Central Island and Circulating Carriageway

The central island is a key component influencing the operation of a roundabout and there are a variety of roundabout central island sizes depending upon the location, speed environment and vehicle types and volumes.

The inscribed circle diameter is the distance across the outer edge of the circulating carriageway (Figure 3.1).

In conjunction with the central island the inscribed circle diameter (Figure 3.1) influences the operation of a roundabout. This diameter should be large enough to allow separation of the entries and exits without them overlapping, i.e. they must be separated and have geometry in accordance with guidelines.

The widths of the circulating lanes depend on the swept path of the design vehicles and the number of lanes.

Widths for the circulating carriageway are not prescribed in Australia and New Zealand or the United States of America. Austroads (2015a) does however provide some guidance on the initial selection of the circulating carriageway widths.

Australia and New Zealand

The central island is preferably circular to minimise differences in speeds as vehicles travel through and around the roundabout. It should also be large enough for approaching drivers to recognise the intersection treatment.

The size of the island should be large enough to achieve the desired entry path alignment, entry speed and circulating speed. The minimum central island size suggested in Austroads (2015a) indicates that a desirable diameter for a single-lane roundabout varies between 20 m for a low speed, i.e. ≤ 40 km/h on the approach road to 44 m for a high speed, i.e. ≥ 90 km/h approach road. The circulating lane width is determined from the requirements of the design vehicle.

Multilane roundabouts typically have larger central island diameters. The suggested diameters in Table 4.1 of Austroads (2015a) range from 24 m for a low speed, i.e. ≤ 40 km/h, to 48 m for a high speed, i.e. ≥ 90 km/h, approach road. However, many roundabouts on high-speed rural arterial roads have much larger diameters (refer to Table 4.3 and Table 4.4 of Austroads (2015a) that cover single-lane and multilane roundabouts respectively). The diameters range from 10 m to 160 m and the relationship between the diameter and the circulating carriageway width should be noted as it may provide flexibility in the choice of diameter. Tables 4.3 and Table 4.4 include criteria that cover several design vehicles.

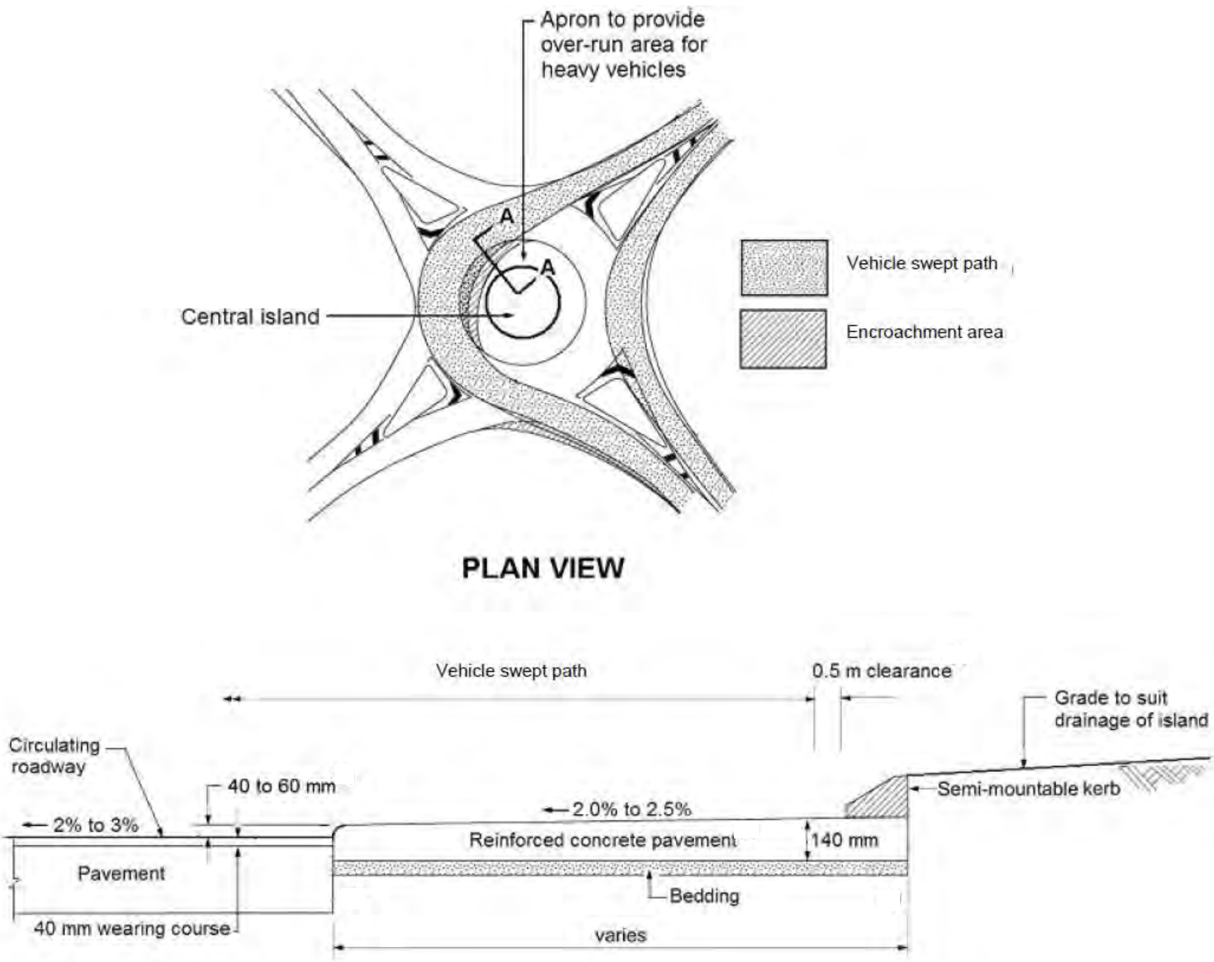
A further consideration is the relationship between the entry speed and the circulating speed with the maximum decrease suggested to be 20 km/h.

Austroads (2015a) provides an initial guide to the circulating carriageway for single-lane and two-lane roundabouts (Table 4.3 and Table 4.4) and the central island diameter (Table 4.1) that can be used as starting points for a design. These are refined, as necessary, through the design process and through tasks such as checking the design vehicle's swept path on the assumed travel path for the key turning movements.

The central island may incorporate an encroachment area (Figure 3.12), which is provided to cater for the swept path of the design vehicle, allow a smaller width of the circulating carriageway instead of widening the carriageway to cater for the larger vehicle and enabling the circulating carriageway to be kept narrow to control the speed of smaller vehicles. The design vehicle should not track on the encroachment area but larger vehicles, such as a design checking vehicle may travel across the encroachment area.

Austroads (2015a) also suggest that on a bus route in constrained locations the encroachment may be used with fully mountable kerbing.

Figure 3.12: Example of an encroachment area



Source: Austroads (2015a).

The width of the encroachment area can vary to suit the particular situation and may have a lip of 40 mm to 60 mm as shown in Figure 3.12.

United Kingdom

The minimum inscribed circle is indicated to be not less than 28 m (Department for Transport 2016), which accommodates the design vehicle, refer to Section 3.1.1. A maximum size of 100 m diameter is suggested for the inscribed circle, as larger diameters can result in high circulating speeds.

For a single-lane roundabout the circulating lane width should not exceed 1.0 to 1.2 times the entry width with a further requirement of not exceeding 6 m for a compact roundabout or 15 m for a multilane roundabout.

Based on these dimensions the central island for a normal or compact roundabout has a minimum diameter of 16 m.

The Department for Transport (2016) also suggests that the minimum diameter for a central island is 4 m. The 4 m diameter excludes the encroachment area that may be utilised to enable the design vehicle to negotiate the roundabout.

Over-run or encroachment areas are used to cater for larger vehicles while providing sufficient deflection of smaller vehicles. The encroachment area should not prevent cyclists crossing it safely and have a bullnose kerb 15 mm high (maximum) with a 16 mm to19 mm radius.

Netherlands

The central island for a single-lane may vary between 13.0 m to 30.0 m in diameter for both inside and outside of a built-up areas and may be provided with an over-run (encroachment) area to cater for the larger vehicles. Circulating lanes range between 5 m and 6 m for a single-lane roundabout and 8 m to 10 m for a two-lane roundabout.

The width of an over-run area depends on the design vehicle adopted for the location, and typically a 4.0 m width may be adopted for a 27.0 m design vehicle, a 3.0 m width adopted for a 22.0 m design vehicle and a 1.5 m width adopted if the design vehicle is shorter (Boender 2000).

For a two-lane roundabout the central island size is between 20 m and 60 m (personal communication, with John Boender, CROW, email 10 September 2015).

Germany

The central island is located close to the centrelines of the approach roads and for a single-lane roundabout has an inscribed circle diameter between 30 m and 35 m, which may be varied to range from 26 m to 40 m. The circulating lane width can vary between 4 m to 6 m.

Encroachment areas are used in urban areas to accommodate the design vehicle and are between 40 mm and 50 mm high with a semi-mountable apron. Travel across the area is permitted only if the size of the vehicle requires this area to negotiate the roundabout.

United States of America

The central island is mainly non-traversable but may include an apron to allow occasional larger trucks to travel through the roundabout by encroaching on the apron. Central island sizes are not suggested as the size depends on the inscribed circle diameter and the width of the circulating lanes.

The size of the inscribed circle is not prescribed but to give an indication of some typical sizes Rodergerdts et al. (2010) indicate that the inscribed circle diameter for a single-lane roundabout would be in the range of 36 m to 43 m and for two-lane roundabouts 46 m to 55 m.

3.1.5 Exit Geometry

Exit geometry relating to the radius and width of exits for the countries considered is presented below.

Australia and New Zealand

Austroads (2015a) indicates that ‘the exit from the roundabout should be as easy as practicable’ and ‘drivers should be able to accelerate from the circulating roadway through the exit.’ To accommodate this approach the exit is designed to be tangential to the central island or have a large radius (Figure 3.2b). Where there are a large number of pedestrians crossing the exit, or there is parking activity on the road beyond the exit, the exit speed should be limited to maximise the safety for pedestrians. There is no specific guidance on the exit speed appropriate for these situations but commentary is included that where there are significant numbers of pedestrians crossing the exit or there is parking activity on the road beyond the exit, the exit speed should be limited by providing a smaller radius on the exit curve.

Exit widths should be designed to enable vehicles to leave the roundabout as ‘efficiently as possible’ (Austroads 2015a). The width is based on the number of traffic lanes, including the necessary clearances to kerbs or road edges.

United Kingdom

The exit is governed by the exit kerb radius which, should exceed the entry kerb radius and provide a smooth path past the splitter island.

The preferred exit kerb radius for a single-lane roundabout is between 15 m and 20 m, whilst at larger roundabouts the exit kerb radius should be 40 m to limit the exit speed. Where there are large numbers of cyclists using the roundabout or there are pedestrian crossing facilities immediately downstream, high exit speeds are not appropriate. No indication is provided of an appropriate exit speed for these circumstances.

The exit width is similar or slightly less than the entry width, and with the exception of compact roundabouts the exit width, where possible, should provide one more traffic lane than is present on the downstream road. The width is tapered down to a minimum of 6 m, which allows traffic to pass a broken down vehicle.

Netherlands

For a single-lane roundabout the exit curves follow the radial alignment as do the entry curves but have a larger radius of 12 m to 15 m. The exit width is suggested to be 4.0 m where there is predominantly passenger cars to 4.5 m, where there is passenger cars, trucks and buses.

For a two-lane roundabout the exit curve is nominated at 15 m and the exit width is the same as the continuing roadway (personal communication with John Boender, CROW, email 10 September 2015).

Germany

For single-lane roundabouts the exit curves follow the radial-type alignment in a similar manner to the entry curves, but have a larger radius of 12 m to 16 m. The exit width is suggested to be between 3.5 m and 4.0 m.

United States of America

The exit curves are typically used to promote a good path alignment, with the radius of the curve larger than the entry curve radius. Where a pedestrian crossing has been provided at the exit, the exit speeds should be kept low. There is no guidance on an appropriate speed for this situation.

The exit widths are based on the requirements for the design vehicle, with no specific widths suggested.

Where pedestrians are expected, the exits should be designed to achieve slow exit speeds to maximise the safety of pedestrians.

3.1.6 Sight Distance

The provision of adequate sight distance is a key component for the safe operation of a roundabout. In each of the countries being examined, the sight distance to allow drivers to identify the presence of a roundabout, approach sight distance (stopping sight distance in the United Kingdom and the United States of America) is required. The application of some other sight distance matters within the respective countries is outlined below.

Australia and New Zealand

There are three sight distance criteria to be considered at roundabouts (Figure 3.13):

Criterion 1 considers the approach sight distance to the holding line on the roundabout (similar to stopping sight distance in the United Kingdom and the United States of America). The distance is based on the speed prior to the entry curve.

Criterion 2 considers an entering driver having adequate sight distance to two possible conflicts, vehicles entering from the approach to the right and vehicles travelling on the circulating lane.

On the approach to the right, a driver stopped at the holding line should have a clear line of sight to a vehicle approaching from the right, for at least a distance equal to the travel time equivalent to the critical acceptance gap. It is measured from the driver eye height to the height of a vehicle indicator. A critical gap of four to five seconds is used in calculating this distance.

On the circulating lane, the sight distance to circulating vehicles is also checked.

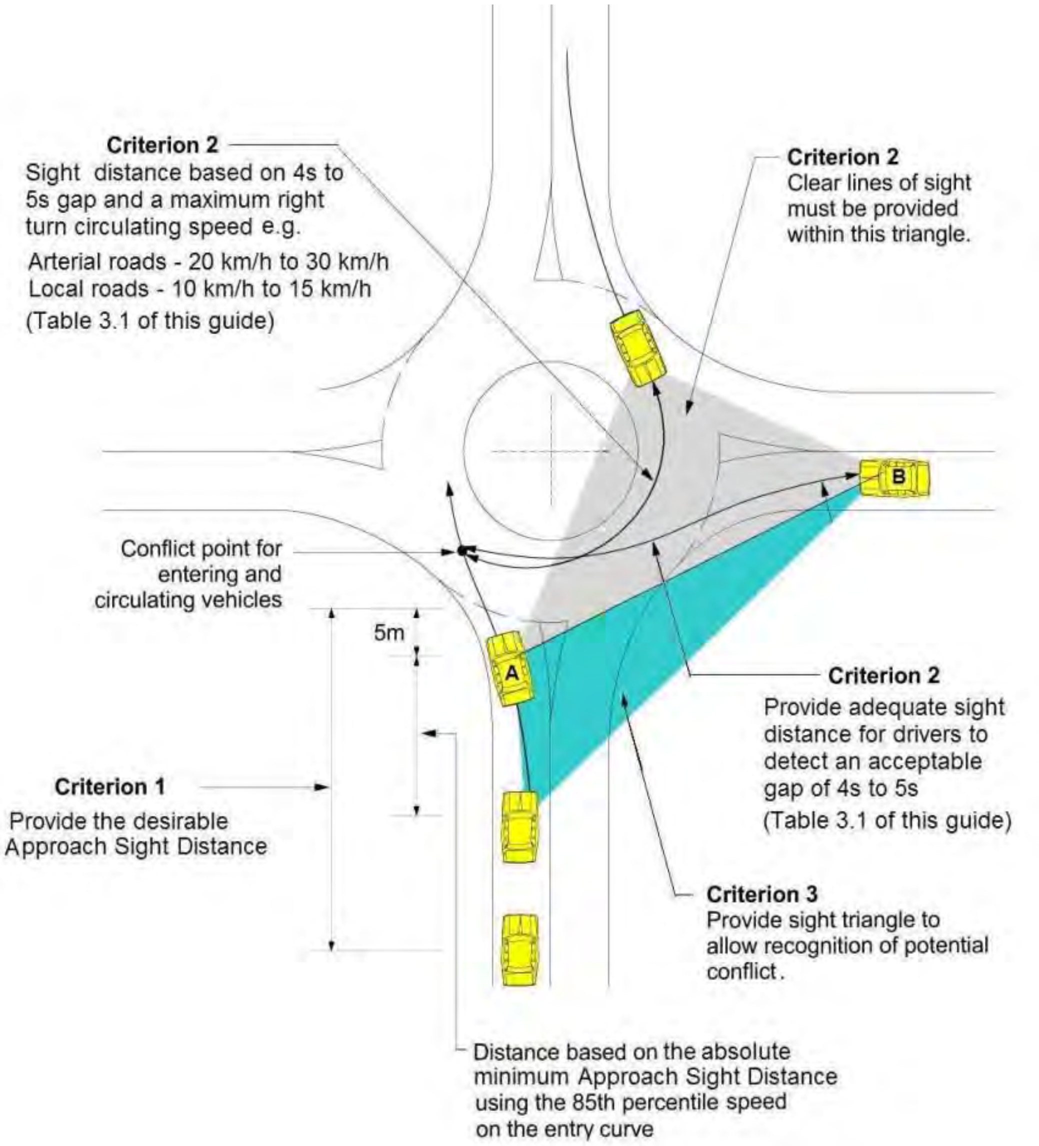
Criterion 3 considers a driver approaching the roundabout being able to observe other vehicles approaching or travelling through the roundabout in time to avoid that vehicle.

The vehicle speeds adopted for this assessment for an appropriately designed roundabout are suggested to be 50 km/h for an arterial road and 25–30 km/h for a local residential street. Alternatively, the ARNDT model (Section 7.1) may be used to determine likely 85th percentile speeds for any horizontal geometric element of the roundabout (Austroads 2015a).

Criteria 1 and 2 are both mandatory requirements whereas Criterion 3 is not mandatory. However, Austroads (2015a) suggests that Criterion 3 is desirable, but also notes the concern in some jurisdictions that a larger sight triangle may lead to higher entry speeds.

Criterion 3 is determined using an absolute minimum approach sight distance, with the guidance contained with AGRD Part 4A (Austroads 2010). For the assessment of the absolute minimum approach sight distance a minimum reaction time of 1.5 seconds and a coefficient of deceleration of 0.46 is suggested.

Figure 3.13: Sight distance criteria in Australia and New Zealand



Note: Values for Approach Sight Distance are provided in Table 3.1 of the Guide to Road Design – Part 4A: Unsignalised and Signalised Intersections

Source: Austroads (2015a).

United Kingdom

The sight distances required to be determined in the United Kingdom are stopping sight distance on the approach and sight distance, for drivers approaching the holding line, to their right (Figure 3.15).

The sight distance to the right is measured from two locations:

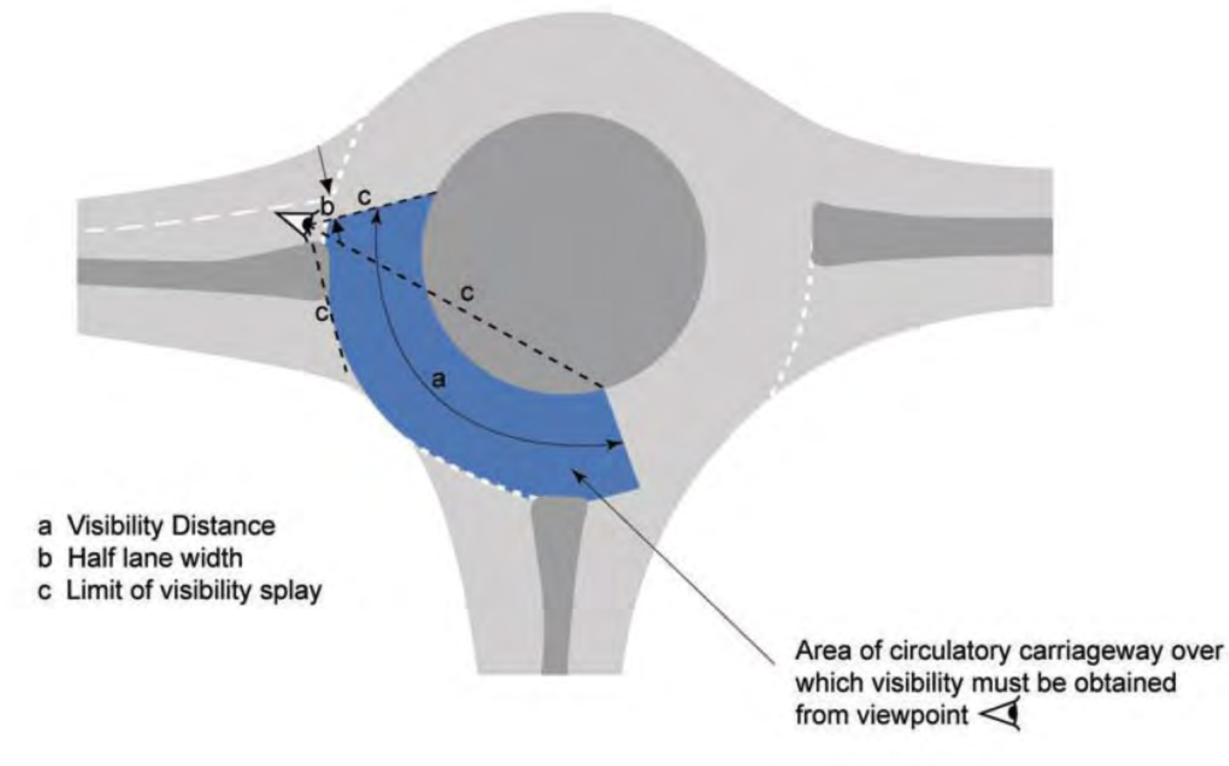
1. at or near the holding line (Figure 3.14)
   For drivers at or near the holding line, sight distance must be available to full width of the circulatory lanes to the right from the centre of the approach lane at the holding line
2. a point 15 m prior to the holding line (Figure 3.15).
   The sight distance to the full width of the circulatory lanes only is required.

For the approach sight distance, minimum stopping sight distance for the design speed of the road is required. This sight distance is determined from the driver eye height to an object height of 0.26 m. This differs from the Austroads practice of having the approach sight distance measured from the driver eye height to zero (i.e. pavement level) so that pavements markings are visible to approaching drivers.

The limited sight distance to the right is suggested by the Department for Transport (2016) as excessive sight distance can result in high entry speeds.

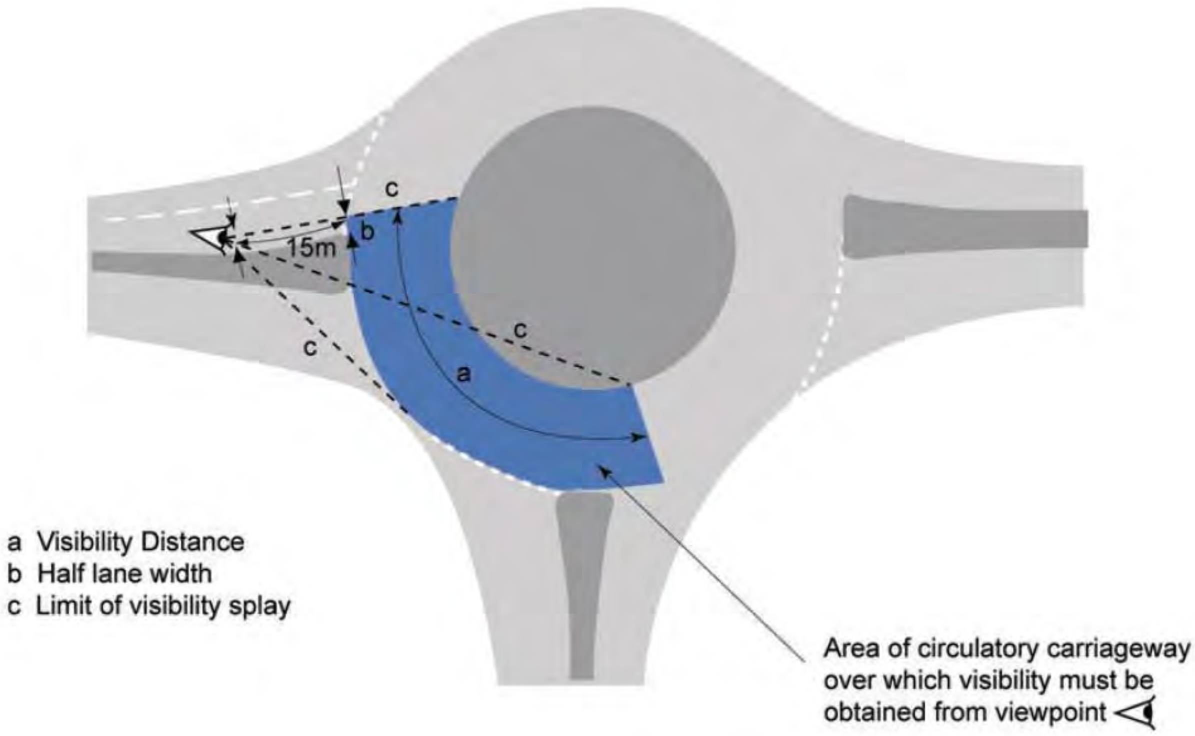
The sight distance to the right requirements are similar in application to Criterion 2 in Austroads (2015a) except for the sight distance being limited to the circulatory lanes. The assessment of the sight distance from a point 15 m prior to the holding line, in concept is similar to Criterion 3, but the point at which it is measured is closer to the holding line and also measured to the edge of the circulating lane.

Figure 3.14: Sight distance near the holding line at a United Kingdom roundabout



Source: Department for Transport (2016).

Figure 3.15: Sight distance in advance of the holding line at United Kingdom roundabout



Source: Department for Transport (2016).

Department for Transport (2016) also indicates that 'excessive visibility to the right can result in high entry speeds, potentially leading to accidents. On dual carriageway approaches where the speed limit is greater than 40 mph (64 km/h), limiting visibility to the right by screening until the vehicle is within 15 metres of the holding line can be helpful in reducing excessive approach speeds' (Figure 3.15). The screening is suggested to be at least 2 m high to block the view of all road users.

On high-speed single carriageways roads screening is also suggested on the flared approaches where there is a long splitter island.

Netherlands

The sight distance requirements were not available.

United States of America

Two types of sight distance are required – stopping sight distance and intersection sight distance. Stopping sight distance should be provided at every point within the roundabout. Intersection sight distance is the same as Criterion 2 in Australia and New Zealand.

When determining the intersection sight distance the distance back from the holding line is suggested to be limited to 15 m. This is intended to limit the sight distance and as a result vehicles will slow down prior to entering the roundabout.

3.1.7 Summary

The geometric design criteria used across the non-European countries considered is very similar with the adoption of the tangential entry alignment being common to all.

Entry speeds are controlled by the entry path radius and this varies across the countries. In Australia and New Zealand have a maximum radius of 55 m for both single-lane and multilane roundabouts. The entry alignment follows a tangential-type alignment.

The United Kingdom has an entry path radius of less than 70 m for a compact roundabout and less than 100 m for other roundabouts. A compact roundabout follows a radial-type alignment, while the normal roundabout follows a tangential-type alignment.

In the United States of America, a maximum entry speed of 30 km/h to 40 km/h for a single-lane roundabout and 40 km/h to 50 km/h for a multilane is recommended, with entry path radii determined form the speed adopted. Rodergerdts et al. (2010) does suggest however for an urban single-lane roundabout entry kerb radii are typically 15 m to 30 m.

The Netherlands have adopted a radial alignment for their roundabouts and for a single-lane roundabout provide an entry curve radius of 8 m to 12 m and exit curve radius of 12 m to 15 m. The central island diameter is generally between 13 m and 30 m. The entry/exit curve geometry is not significantly different between the single-lane and two-lane roundabouts, however the central island could be much larger, up to 60 m in diameter, compared to the 30 m diameter for a single-lane roundabout. Circulating lanes are between 5 m and 6 m for a single-lane roundabout and 8 m to 10 m for a two-lane roundabout.

The German guidance follows the radial-type alignment and for a single-lane roundabout provides entry curve radius between 10 m and 14 m and an exit curve radius between 12 m and 16 m. The central island diameter ranges between 18 m and 27 m with circulating lanes between 4 m and 6 m.

The entry widths in Australia and New Zealand, are guided by the swept path of the design vehicle and for a single-lane roundabout are desirably be at least 5.0 m and on local roads may be 3.0 m. Entry radii are less than 55 m for speeds on the approach leg ranging from ≥ 90 km/h to ≤ 40 km/h.

In the United States, a single-lane roundabout entry width may be between 4.2 m and 5.5 m.

The United Kingdom guidance indicates entry widths should be between 2.0 m and 4.5 m for single-lane roundabouts and for a multilane roundabout 3 m to 3.5 m.

The guidance in the Netherlands and Germany is similar, with a single-lane roundabout entry in the Netherlands ranging from 3.5 m to 4.0 m and in Germany the range is from 3.25 m to 3.75 m.

The sight distance guidance in Australia and New Zealand is based on stopping sight distances and gap acceptance. A driver at a holding line needs to be provided with sufficient stopping sight distance to observe approaching vehicles, either on the circulating lane of the approach to the right. A non-mandatory sight distance is suggested to provide a driver approaching a roundabout to be able to observe other vehicles approaching the roundabout sufficient distance to avoid a collision.

The United Kingdom has adopted a different approach for sight distance, particularly for sight distance to the right of an approaching vehicle. The sight distance from either at or near the holding line or 15 m prior to the holding line is to the circulating lanes of the roundabout, which by comparison to Criterion 2 and Criterion 3 in Austroads (2015a) suggests a shorter sight distance requirement.

4. Crashes at Roundabouts

Crash information reported in Austroads (2014a) has been summarised and is outlined below together with some more recent information which provides a trend in the crash types and locations.

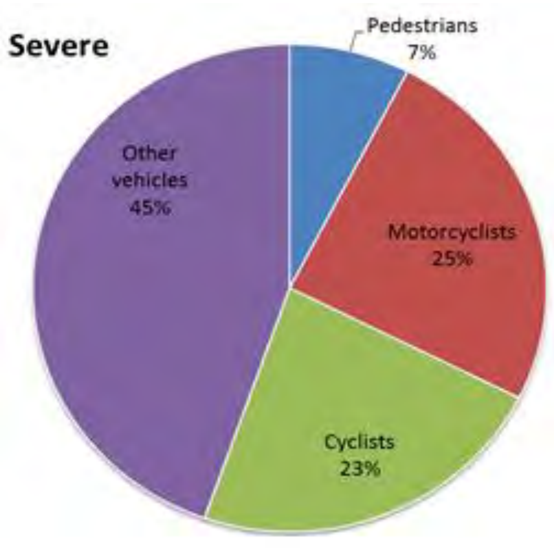
In reviewing the crash rates, it should be noted that variations in practice in the countries presented are relevant in comparing the crash rates for the following reasons:

- the different style of roundabout (i.e. a tangential layout in Australia and New Zealand, United Kingdom (normal-type) and the United States of America and a radial layout in the United Kingdom (compact roundabouts) and European countries)
- road rules applicable for each country, i.e. in the Netherlands and Sweden, a cyclist crossing an exit may have right of way over motorists leaving a roundabout.

4.1 Australia and New Zealand

Austroads (2013c) undertook some crash analysis of roundabouts in Victoria, covering the period 2007–11. Crashes from 1281 sites, involving 2089 crashes were analysed. From the analysis it was found that 55% of the severe crashes involved vulnerable road users, principally motorcyclists (25%), cyclists (23%) and pedestrians (7%) (Figure 4.1).

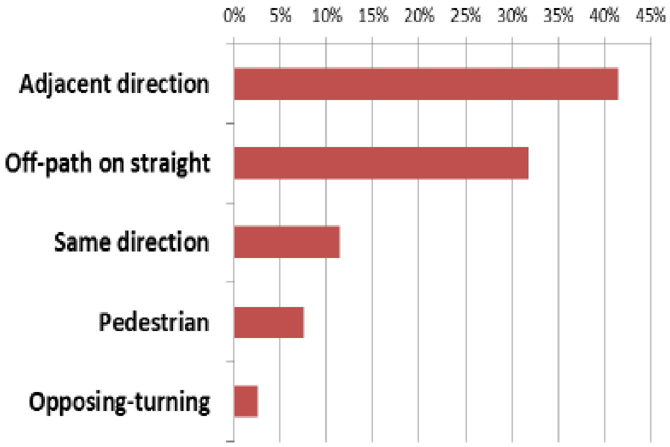
Figure 4.1: Severe crashes at roundabouts



Source: Austroads (2013c).

A more detailed analysis of the types of crashes showed that the predominant crashes were adjacent direction and off-path on straight (Figure 4.2). The most common crashes for cyclists were the adjacent direction (occurring at the entry to the circulating carriageway) and the same-direction – occurring on the approach/entry and in the middle of the roundabout (Austroads 2015b).

Figure 4.2: Crash types at roundabouts



Source: Austroads (2013c).

Whilst this data was only for Victoria, it demonstrates the likely issues found at roundabouts and serves as a guide to areas for improvement.

Austroads (2014a) also provided some aggregated Australian and New Zealand crash data for cyclists at roundabouts, finding that cyclists were overrepresented for fatal and serious injury crashes compared to other road users and other types of intersection control. Table 4.1 and Table 4.2 show the number of crash locations.

Table 4.1: Crash locations in Victoria 2006–10

	Crash severity			
	Fatal	Serious	Other	Total
All mode crashes				
All locations	1 269	25 177	35 152	61 598
Roundabouts	11	597	1 316	1 924
Cyclist crashes				
All locations	22	1 092	2 040	3 154
Roundabouts	1	71	169	241

Source: Austroads (2014a).

Table 4.2: New Zealand crash data, disaggregated by junction and intersection control

Proportion of cyclist involvement in crashes at:	1996–2000		2001–2011		
	All injury	Non-injury	All injury	Fatal	Fatal & serious
All locations	7.5%	1.1%	5.6%	1.4%	4.4%
All intersections	16.1%	2.4%	14.9%	7.3%	14.6%
Roundabouts	27.5%	2.8%	27.8%	15.8%	32.8%
Priority controls	12.8%	1.6%	8.1%	1.9%	7.2%
Signalised intersections	6.3%	1.0%	5.5%	3.8%	6.7%

Source: Austroads (2014a).

The most common crash type reported to police in Auckland at multilane roundabouts was 'entering vehicle versus circulating cyclist'. This crash type was seen in 69% of all cyclist injury crashes and is consistent with results from other studies. In order to mitigate this effect the C-roundabout (cyclist friendly) concept was developed and recommended for trial (Campbell, Jurisich & Dunn 2006). Asmus, Campbell and Dunn (2012) found that this design forced lower vehicle entry speeds through multilane roundabouts, increasing safety and the likelihood of survival for cyclists involved in collisions.

4.2 Denmark

Jensen (2013) undertook a study in Denmark of 332 intersections that had been converted to a roundabout, finding that converting intersections to roundabouts led to a 65% increase in bicycle crashes and a 40% increase in cyclist injuries. The roundabouts contained a range of different treatments.

A summary of the analysis of the various treatments used for bicycle movements is contained in Table 4.3.

Table 4.3: Safety effects at converted intersections

Type of Facility	Estimated expected crashes	Actual crashes	Percentage difference (%)
No facility	14	20	+45
Bicycle lane within the roundabout	35	75	+113
Coloured bicycle lane within the roundabout	11	38	+246
Bicycle track, priority to cyclists crossing the roundabout legs	15	18	+18
Bicycle track with coloured crossings across the roundabout legs	5	10	+82 (1)
Bicycle paths, without priority to cyclists crossing the roundabout legs	15	3	–81

1 *Figure is contained in Jensen (2013) but appears to be an error.*

Note: In Denmark a bicycle track is physically separated from the other circulatory lanes.

Source: Jensen (2013).

This study found that a roundabout with bicycle paths outside of the roundabout had the best safety outcomes, while roundabouts with bicycle lanes within the roundabout had the worst safety outcomes.

Jensen (2013) also found that along arterial roads where reductions in speed may be undesirable, signalised roundabouts also provide safety benefits for cyclists with studies showing that adding signals to roundabouts can lead to an 80% reduction in cyclist crashes while the presence of signals was also noted to lead to an 18% reduction in injuries (Jensen 2013).

4.3 Germany

Schreiber, Ortlepp and Bakaba (2014) reported on the outcomes of research projects on cycling safety at intersections and roundabouts, undertaken by German Insurers Accident Research, Berlin.

An analysis of crashes was undertaken and at 100 urban roundabouts in Germany, where 1015 collisions had occurred. The roundabouts were in different urban-type locations (e.g. town centre, village, residential, commercial areas) and catered for cyclists in the following ways:

- 44 roundabouts had cyclists mix with traffic on the circulating lanes
- 41 roundabouts had separated bicycle paths or shared bicycle/pedestrian paths with cyclists/pedestrians having priority
- 15 roundabouts had separated bicycle paths with cyclists not having priority.

The analysis found that separated bicycle paths with priority for cyclists at the legs of the roundabout proved to be the least safe for cyclists. A comparison of crash cost rates indicated that roundabouts provided with separate bicycle paths which had priority in crossing the legs of the roundabout resulted in the highest rate of crash costs compared with roundabouts where the crossing did not have priority or the cyclists mixed with traffic on the circulating lane.

Based on these results it was suggested that cyclists mixing with traffic or riding along a path that requires them to give way to vehicles would be a safer alternative. This was thought to result in more cautious cyclist behaviour and an improvement in communication between cyclists and drivers (Schreiber, Ortlepp & Bakaba 2014). This finding is consistent with the Jensen (2013) study discussed in Section 4.2.

5. Crash Data Analysis

Crash data, for fatal and serious injury involving cyclists at roundabouts between 2009 and 2013 was collected from all Australian states and territories and New Zealand. Each set of data was analysed to ascertain any trends in time of crash, crash types, conditions, and demographics. However, the available data did not identify whether the roads were divided or undivided, or the details of horizontal and vertical geometry on the approaches to the roundabouts and so it has not been possible to include this information in the analysis.

5.1 Crashes by Year, Month, Day and Time

Between 2009 and 2013, Australia and New Zealand experienced a combined total of 2766 cyclist crashes at roundabouts, with an average of 553 crashes per year. Figure 5.1 shows the number of crashes recorded each year broken down by jurisdiction. As can be seen in Figure 5.1, New South Wales and Victoria consistently have the highest recorded values. It is also important to note that in Queensland the number of cyclist crashes at roundabouts has recently been halved, with 101 annual crashes in 2011 and 54 in 2013. This is discussed further in Section 5.7.1.

Figure 5.1: Bicycle crashes at roundabouts – by year

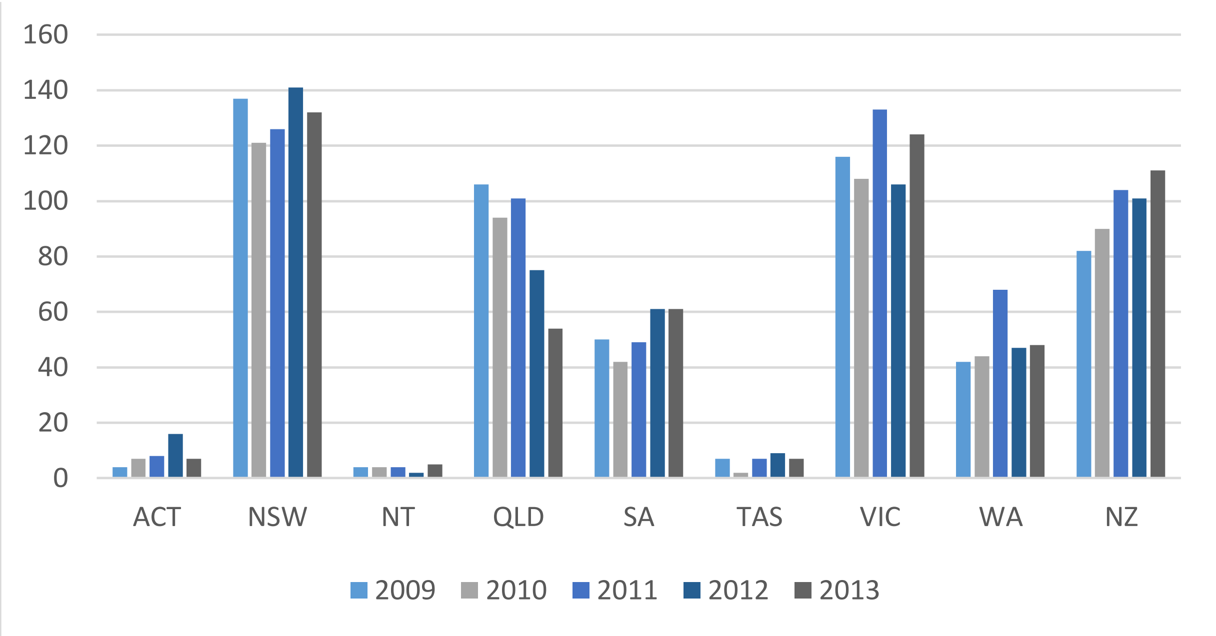


Figure 5.2 shows the breakdown of crashes by month and jurisdiction (i.e. state, territory or country). The number of crashes has some variation across the year, with a greater number of crashes occurring during the January – May period. These variances are possibly due to seasonal influences on cycling populations.

Figure 5.2: Bicycle crashes at roundabouts – by month

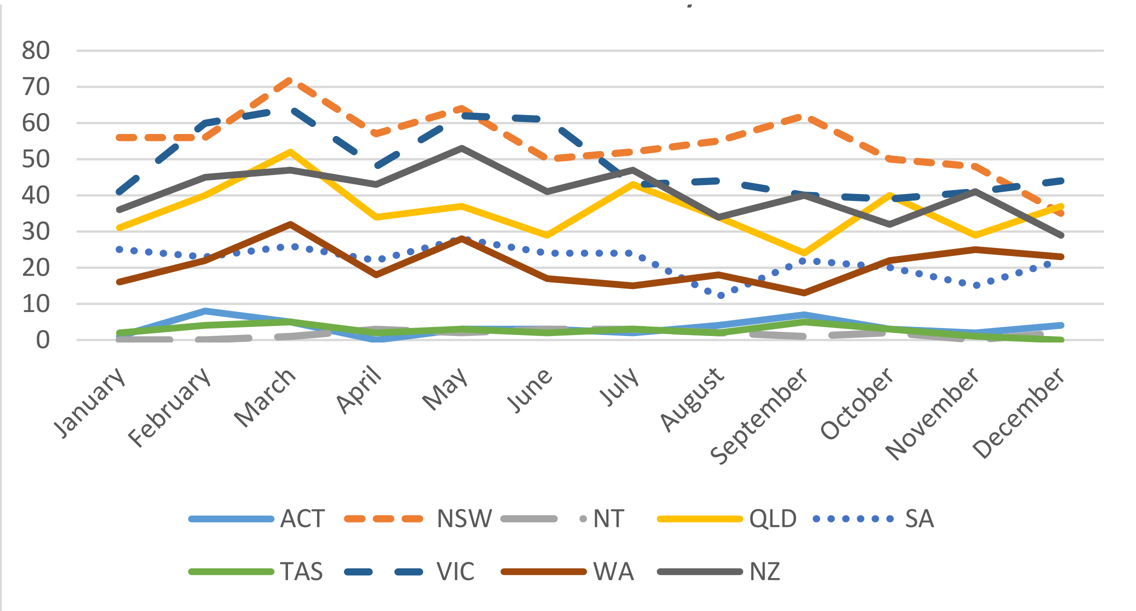


Figure 5.3 shows the distribution of crashes over days of the week. As can be seen, there are more crashes during the week compared to weekends. This is possibly because the majority of crashes (approximately two-thirds) occurred during peak hours of travel (between 7 am and 10 am, or 3 pm and 7 pm as shown in Figure 5.4) and are therefore possibly commuter-related crashes. It should be noted that during these times there are likely to be more motor vehicles present and therefore a greater chance of interaction between the motor vehicles and cyclists.

Figure 5.3: Percentage of bicycle crashes at roundabouts – by day of week

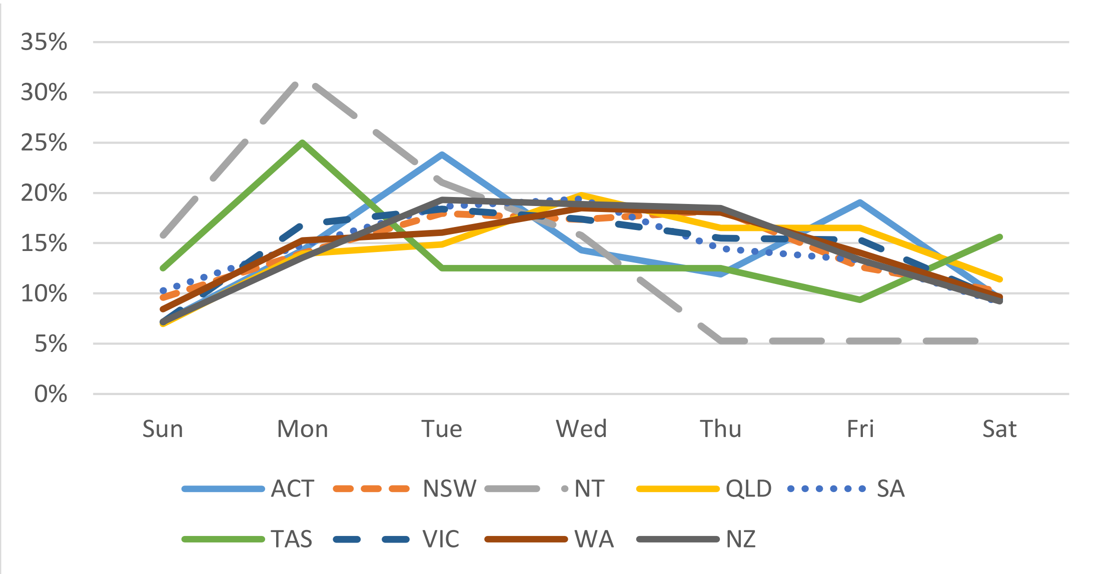
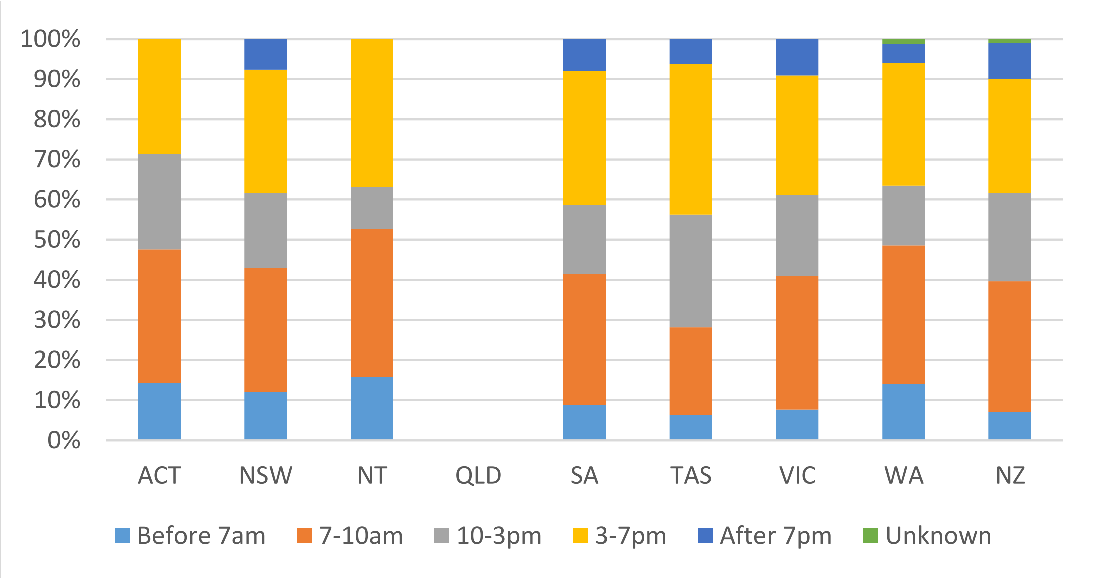


Figure 5.4: Cumulative percentage of bicycle crashes at roundabouts – by time of day



5.2 Crashes by Type and Severity

Figure 5.5 shows the distribution of major crash group types recorded for bicycle crashes at roundabouts for each jurisdiction. Crash groups that had fairly low numbers of crashes were not included in the graph for purposes of clarity only, thus the illustrated crash distributions do not reach 100%. The top four crash types shown account for over 85% of crashes in each jurisdiction, with the exception of South Australia and Northern Territory where there were a number of crashes where the crash group was not recorded (for South Australia this was the case for over 50% of the recorded crashes). The top four crash group types were:

- adjacent direction (intersection) – on average 67% of crashes
- same direction – on average 13% of crashes
- opposing direction – on average 5% of crashes
- manoeuvring – on average 3% of crashes.

This data confirms the relatively high vulnerability of cyclists around roundabouts regardless of the type of layout. Full details on the number of crashes in each crash group type can be found in Appendix A.

Figure 5.5: Cumulative percentage of crash type groupings

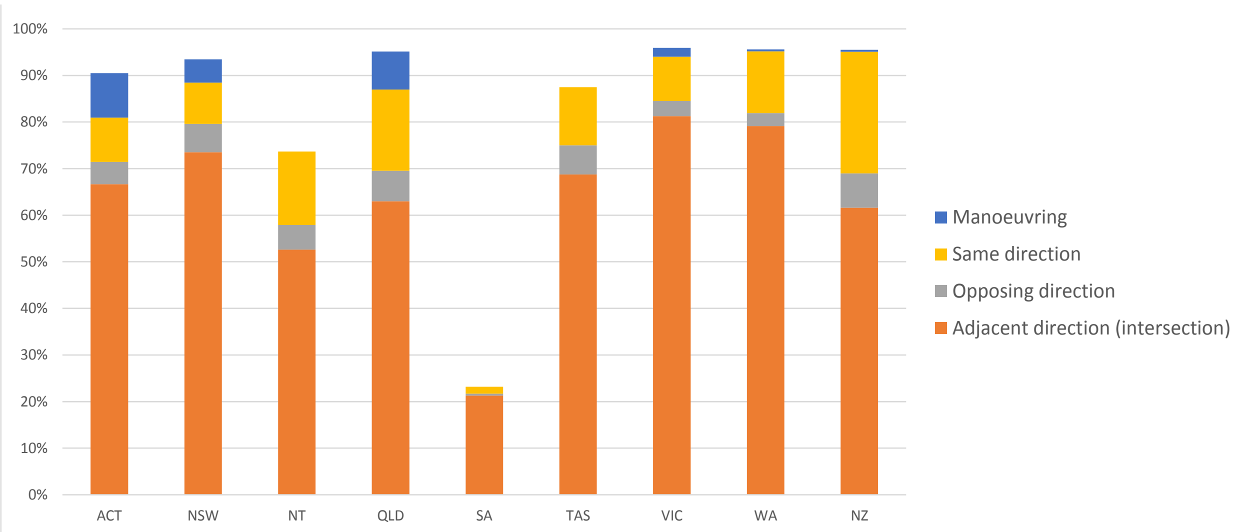


Figure 5.6 and Figure 5.7 show the breakdown of the top four crash types within the 'adjacent direction' and 'same direction' crash groupings respectively. The column heights relate back to Figure 5.5 and show the percentage of all crashes for a location. It should be noted that the crash type details for the Northern Territory were not provided and that New Zealand has a significantly different crash coding system to Australia. Therefore these two locations were not included in Figure 5.6 and Figure 5.7.

Figure 5.6: Cumulative percentage of crash types under the 'adjacent direction' crash group

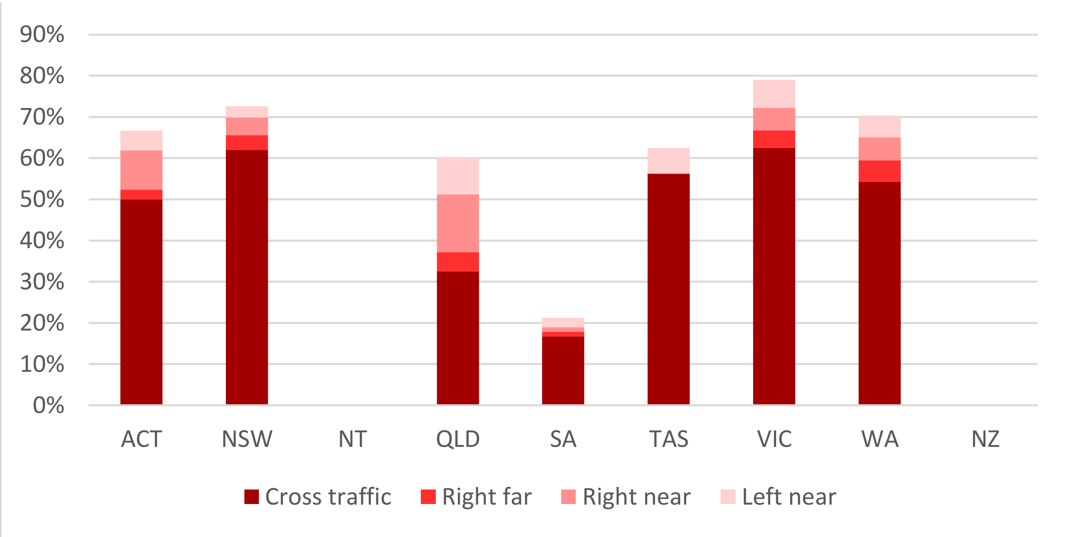
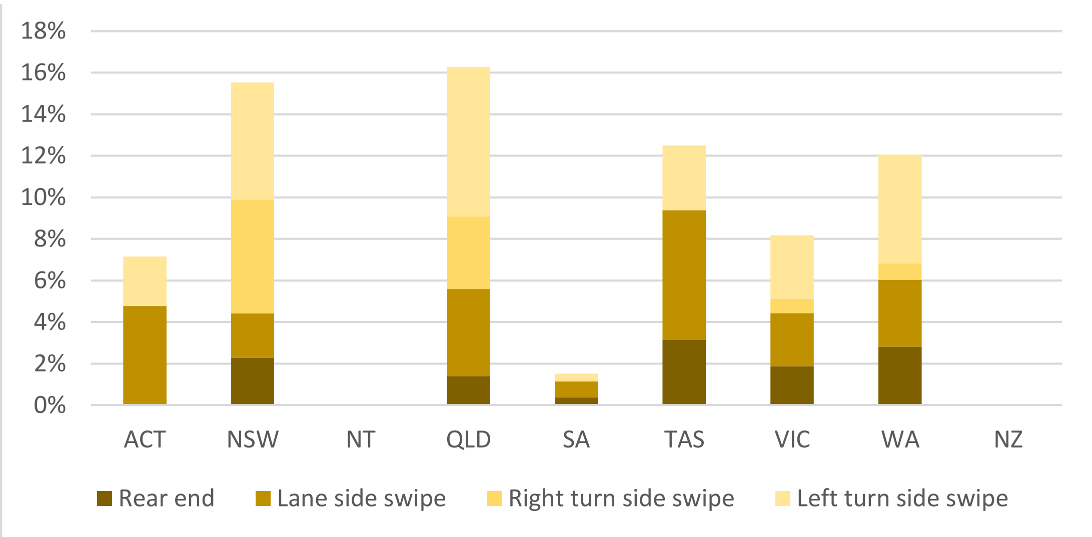
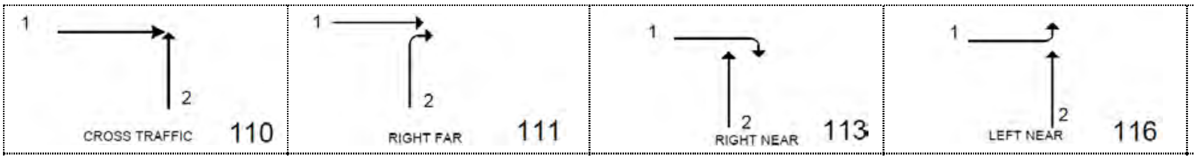


Figure 5.7: Cumulative percentage of crash types under the 'same direction' crash group



The most frequent crash type in the 'adjacent direction' crash group was 'cross traffic', which on average comprise 77% of the 'adjacent direction' crashes, and 41% of all crashes in a jurisdiction. The second most frequent crash type in this group was 'right near' crashes, which on average comprised 10% of the 'adjacent direction' crashes and 5% of all crashes in a jurisdiction. Definitions of the four top crash types for the 'adjacent direction' crash group are shown in Figure 5.8

Figure 5.8: Crash definitions of top 'adjacent direction' crash types

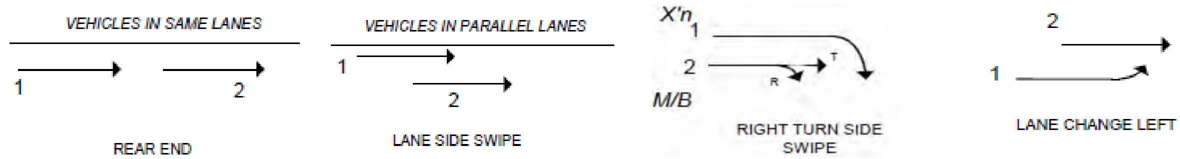


Source: Adapted from VicRoads (2013).

There was no dominant crash type in the 'same direction' crash group. 'Rear end', 'lane sideswipe' and 'left turn side swipe' were slightly more frequent (comprising 23–30% of 'same direction' crashes each, and 3–4% of all crashes each in a location).

Definitions of the four top crash types for the 'same direction' crash group are shown in Figure 5.9.

Figure 5.9: Crash definitions of top 'same direction' crash types



Source: Adapted from VicRoads (2013).

The following set of figures show the crash group breakdown for each jurisdiction by crash severity. As can be seen from the individual graphs, 'adjacent direction' crashes were the most common grouping across the different crash severity levels. The crash data does not have a consistent classification method and these differences are reflected in the figures. Property damage only (PDO) crashes have been included where data was provided as, although this type of crash is not the prime focus of a Safe System, it is a good indication of where and what type of problems are occurring.

More details on crash severity by location can be found in Appendix A.

The crash severities by location are outlined in Figure 5.10 to Figure 5.18. From these figures, the predominant crash type in all of the locations is the 'adjacent direction' type.

Figure 5.10: Crash groups by crash severity for ACT

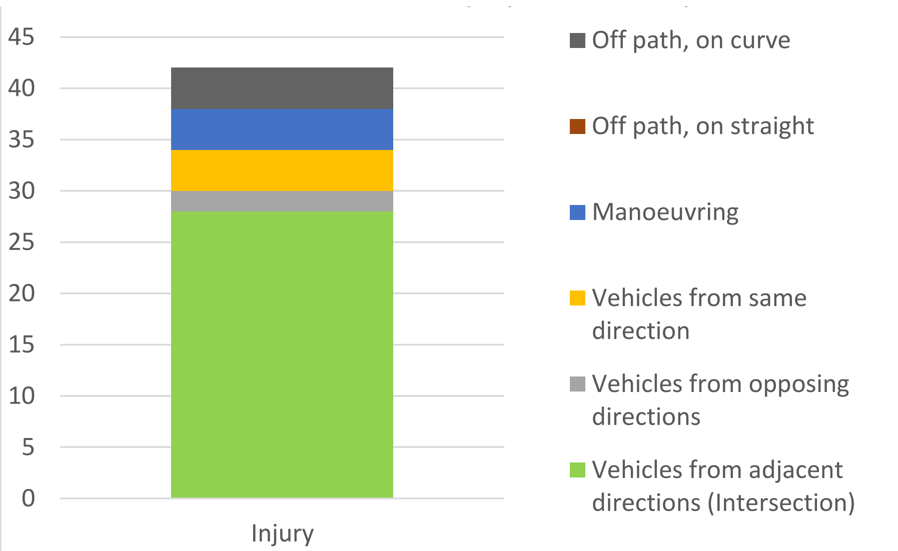


Figure 5.11: Crash groups by crash severity for NSW

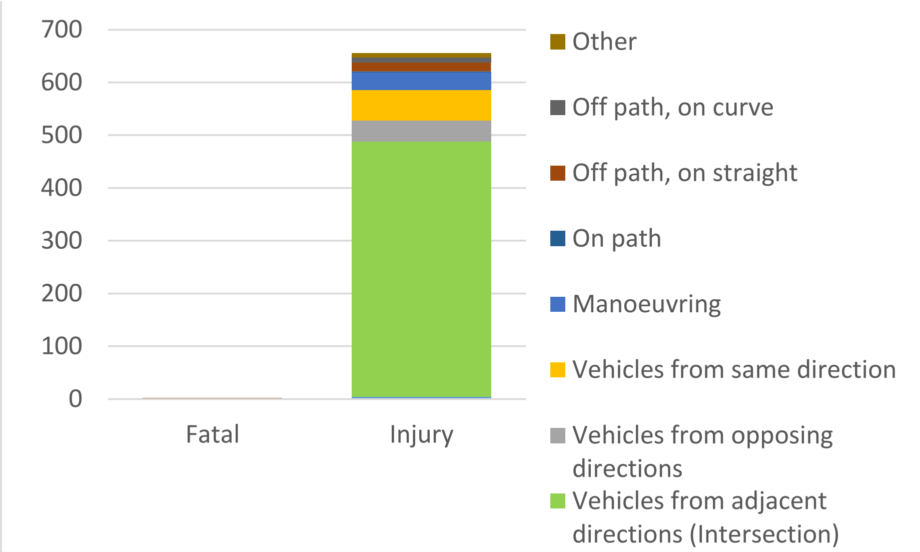
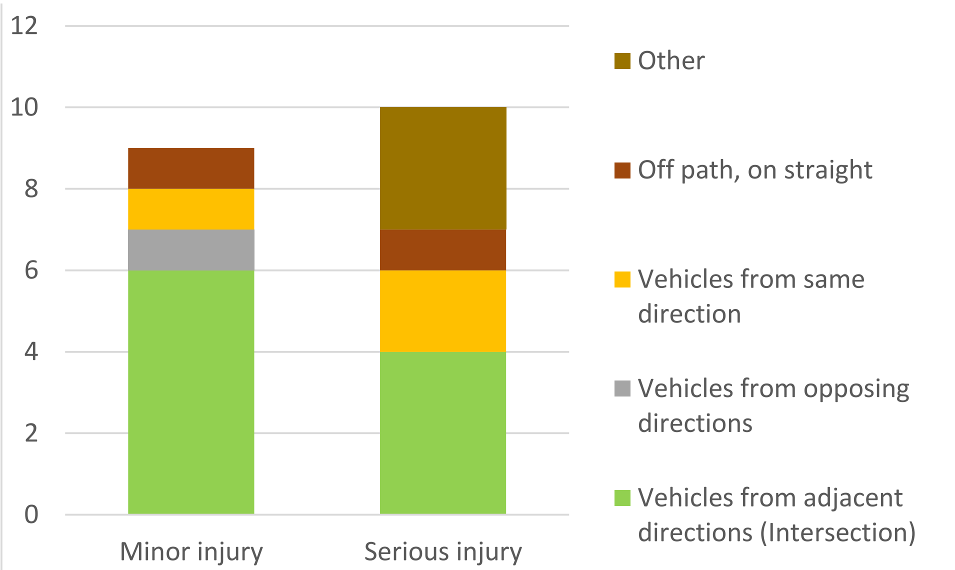


Figure 5.12: Crash groups by crash severity for NT



Note: The 'Other' category contains crashes where the DCA was unknown.

Figure 5.13: Crash groups by crash severity for QLD

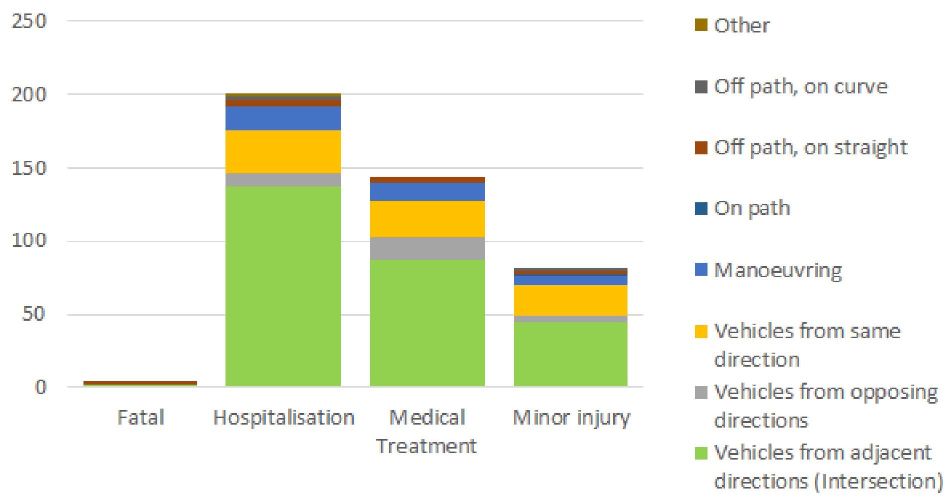


Figure 5.14: Crash groups by crash severity for SA

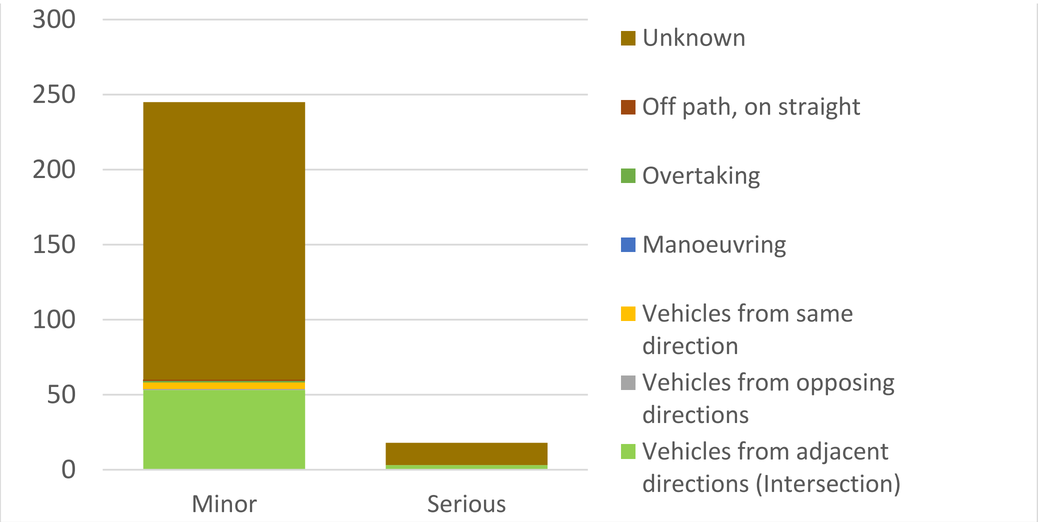


Figure 5.15: Crash groups by crash severity for TAS

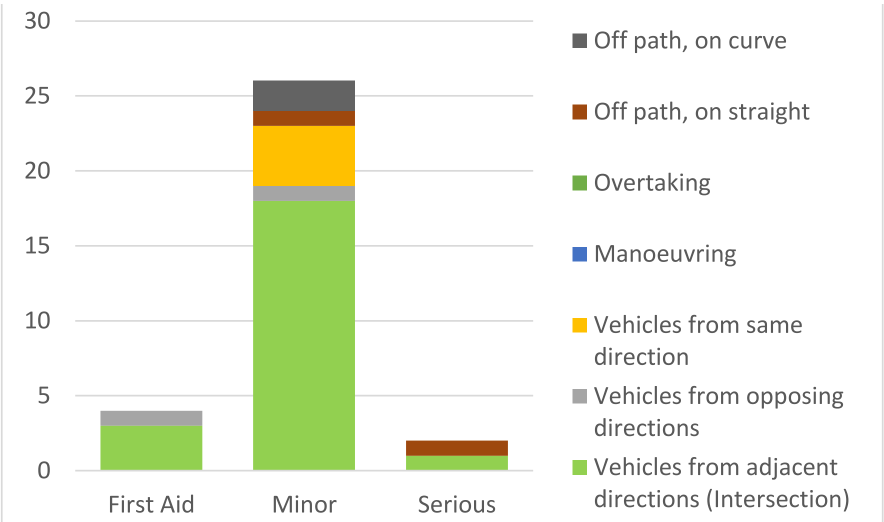
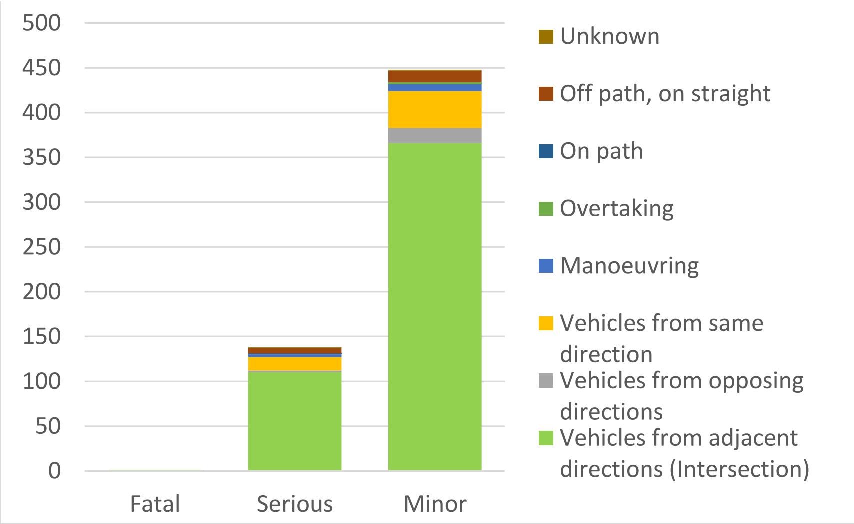


Figure 5.16: Crash groups by crash severity for VIC



Note: One fatality occurred in Victoria during 2009–13.

Figure 5.17: Crash groups by crash severity for WA

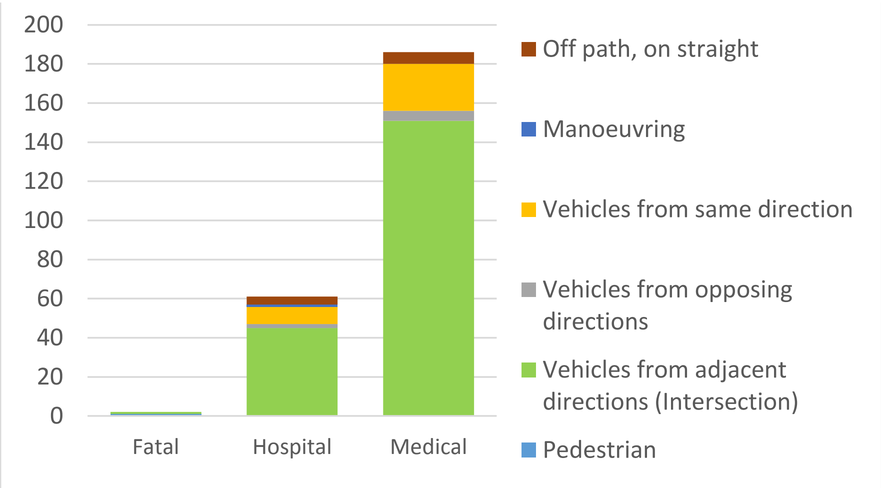
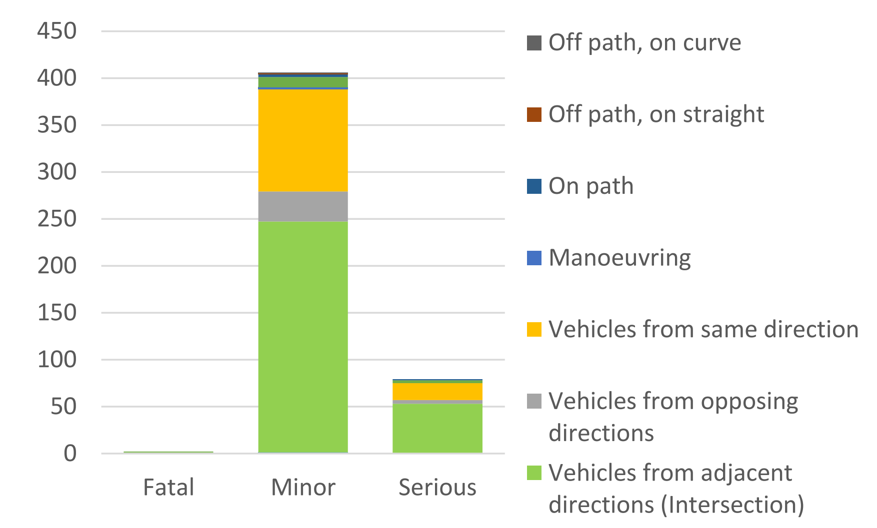


Figure 5.18: Crash groups by crash severity for NZ



5.3 Crashes by Light, Surface and Atmospheric Conditions

Figure 5.19 to Figure 5.21 show the lighting, surface and atmospheric conditions respectively at the time a crash occurred. Atmospheric conditions were not recorded in the Western Australian data.

A significant number of crashes occurred during daylight hours on dry roads. This would be expected as more cyclists are likely to ride in these conditions. What cannot be determined is the effect of the weather conditions on the likelihood of a cyclist crash as the numbers of cyclists travelling on the roads during the different weather conditions is unknown.

Figure 5.19: Percentage of crashes by lighting conditions

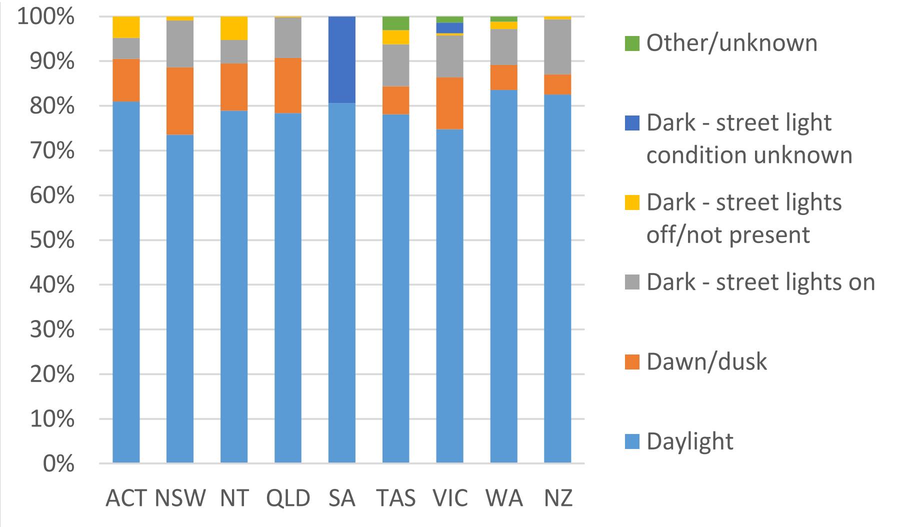
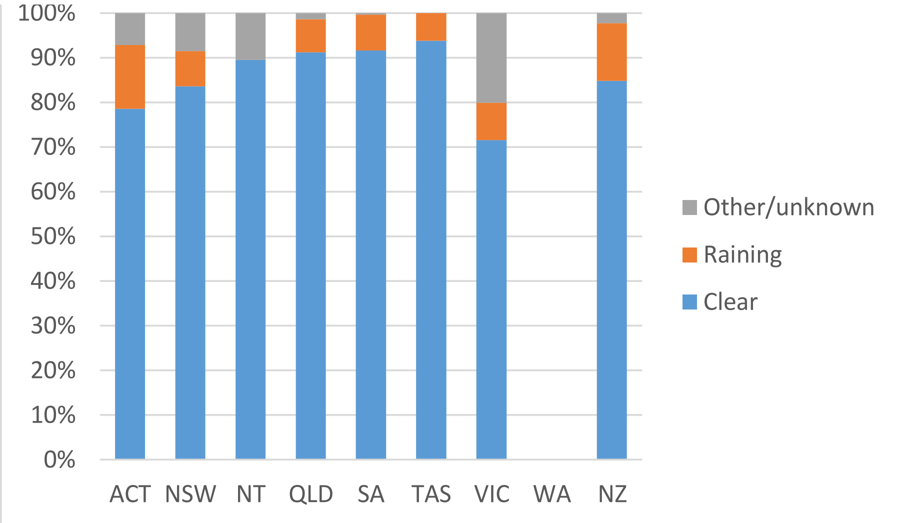


Figure 5.20: Percentage of crashes by surface conditions

Figure 5.21: Percentage of crashes by atmospheric conditions

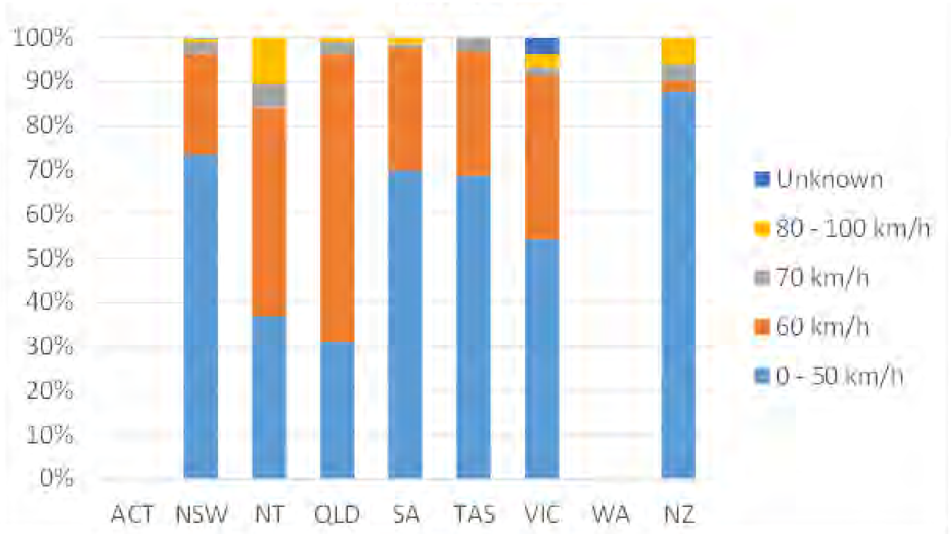


5.4 Speed Zones

A significant number of crashes, 93% of the crashes where the speed zone was indicated, occurred on roads with speed zones of 60 km/h or less (Figure 5.22), with 63% occurring on roads with speed zones 50 km/h or less and 30% occurring on roads with 60 km/h speed zone. This would seem to indicate that these crashes also occurred in urban areas, where the majority of roundabouts are expected to be located. Speed zones were not provided in the ACT or Western Australia datasets.

Appendix A.4 contains the details of the crashes by state and speed zone.

Figure 5.22: Percentage of crashes by speed zone

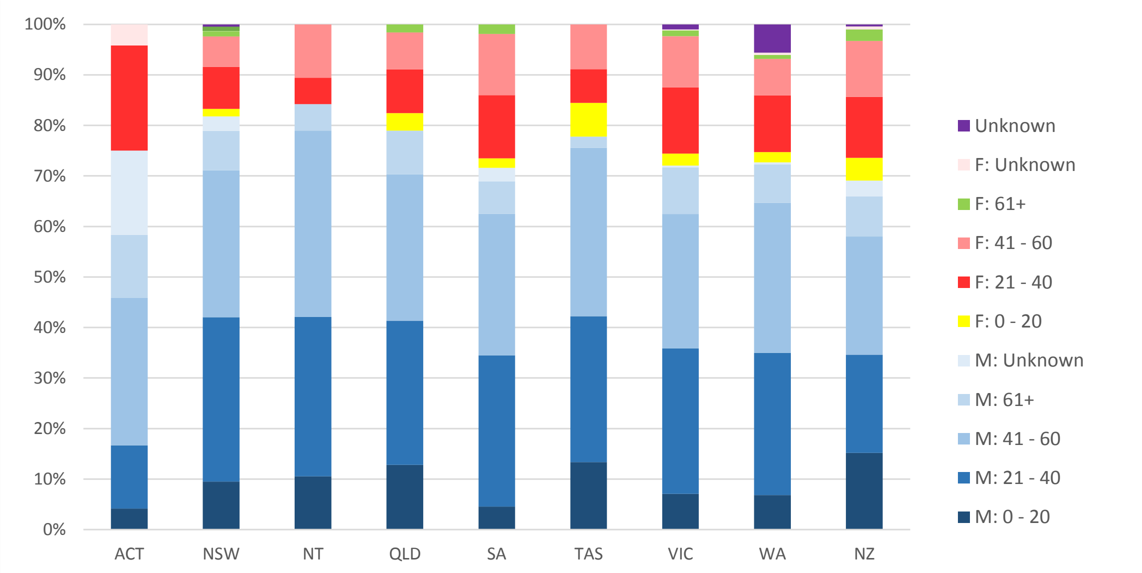


5.5 Crashes by Demographics

The majority of cyclists involved in crashes were male (over 70%), and generally between the age of 20–60 years (Figure 5.23).

Of interest is the number of crashes involving male cyclists in the 41–60 year age group. This is likely to be due to this age group of men frequently using cycling for their recreational or health and wellbeing.

Figure 5.23: Percentage of crashes by gender and age of cyclists



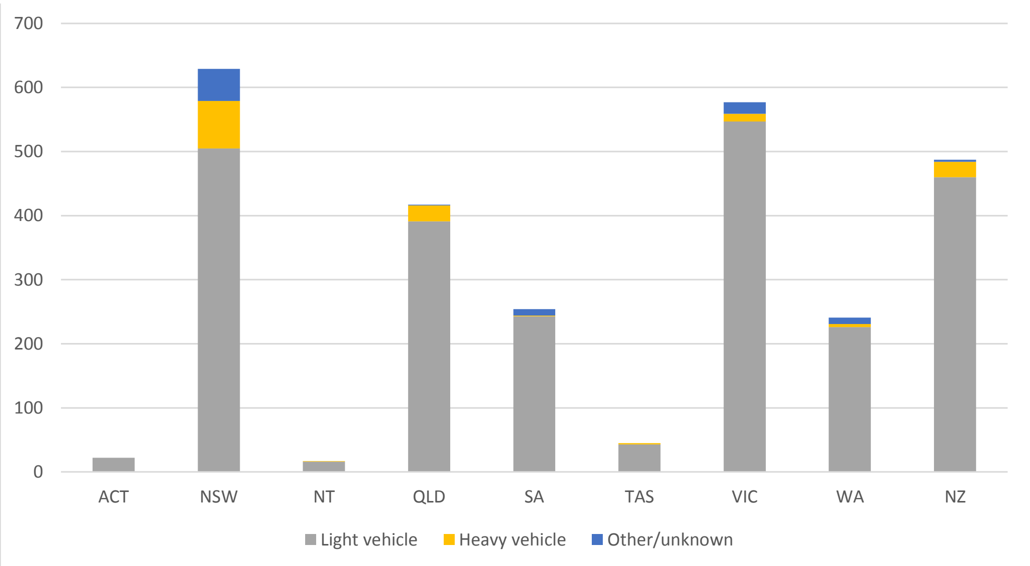
Note: Ages are shown in years.

5.6 Crashes by Vehicle Type

The majority of crashes involving cyclists at roundabouts were with a light motor vehicle, e.g. passenger car or van (Figure 5.24). Pedestrians and motorcycles were excluded in this graph due to their extremely low numbers.

More details on crashes by vehicle type can be found in Appendix A.

Figure 5.24: Number of other vehicles Involved in crashes



5.7 Data Limitations

5.7.1 Crash Numbers in Queensland

Queensland experienced a noticeable drop in cyclist crashes at roundabouts, between 2011 and 2013. This was queried with the Queensland Department of Transport and Main Roads (TMR), which indicated that this may simply be an indication of data lag. The TMR Webcrash system currently notes that the following datasets are finalised:

- fatal crashes to 31 December 2014
- hospitalisation crashes to 31 December 2013
- medical treatment crashes to 30 June 2012
- minor injury crashes to 30 June 2012
- PDO crashes to 31 December 2010.

5.7.2 'At Fault' and Error Statistics – South Australia

The South Australian dataset provided some additional fields on whether the cyclist was 'at fault' during the crash, and the error that the driver or cyclist made. Table 5.1 shows that the cyclist was only considered 'at fault' (i.e. identified as responsible for the crash) approximately 15% of the time. Table 5.2 shows that the most common errors (i.e. incorrect or dangerous actions that contributed, or led to the crash outcome) made by both drivers and cyclists was failure to give way, inattention and changing lanes to endanger. Note that property damage reports have been included in this analysis.

The information from this analysis indicates that motor vehicle drivers are failing to give way, which may be linked to the 'failed-to-see' concept.

Table 5.1: 'At fault' statistics – cyclists at roundabouts in South Australia

	Minor		PDO		Serious		Total	
	Count	%	Count	%	Count	%	Count	%
Cyclist NOT at fault	219	89%	173	82%	12	67%	404	85%
Cyclist at fault	26	11%	37	18%	6	33%	69	15%
Grand Total	245	100%	210	100%	18	100%	473	100%

Table 5.2: Error statistics – cyclists at roundabouts in South Australia

Error	All vehicle errors (including cyclists)		Cyclist errors only	
	Count	Percentage	Count	Percentage
No errors reported	461	49%	408	86%
Failure to give way	389	42%	32	7%
Changing lanes to endanger	15	2%	5	1%
Inattention	26	3%	18	4%
Incorrect turn	10	1%	3	1%
Overtaking without due care	10	1%	2	0%
Unknown	9	1%	0	0%
Following too closely	8	1%	2	0%
Failure to keep left	4	0%	4	1%
Driving under the influence	3	0%	2	0%
Reversing without due care	1	0%	0	0%
Vehicle fault	1	0%	1	0%
Total	937	100%	477	100%

5.7.3 Potential Contributing Factors to Crashes – New Zealand

The New Zealand dataset provides information on the possible contributing factors in a crash. The distribution of contributing factors indicates that the other party (i.e. not the cyclist) was at fault in the majority of the crashes (75%; as shown in Table 5.3). Table 5.4 lists the top five contributing factors towards a crash. Although the other party was generally seen as being 'at fault', it is important to note that factors such as dazzling sun and cyclists wearing dark clothing were seen to have an impact on the occurrence of crashes.

Table 5.3: Classification of contributing factors

Contributing factor classification	Factors listed[1]	
	Count	Percentage
Environmental	57	10%
Cyclist	85	15%
Other party	435	75%
Total	577	100%

1 *There could be more than one factor involved in a crash.*

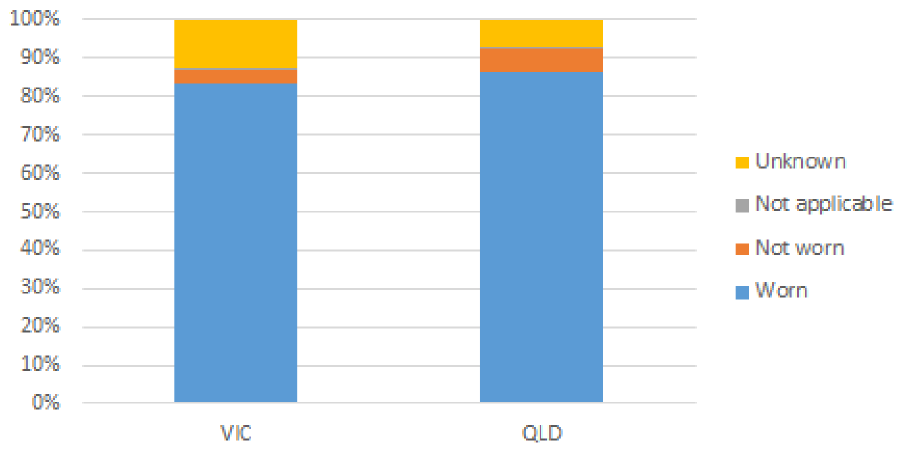
Table 5.4: Top five recurring potential contributing factors to a crash

Code	Count	Description
302 (other party)	200	Failed to give way at give way sign
375 (other party)	132	Did not look or see another party until too late, when required to give way to traffic from another direction
902 (environmental)	23	Weather, dazzling sun
302 (cyclist)	13	Failed to give way at give way sign
534 (cyclist)	11	Cyclist or motorcyclist wearing dark clothing

5.7.4 Helmet Conditions – Victoria and Queensland

In Victoria and Queensland, data was available on whether the cyclist was wearing a helmet. Figure 5.25 shows that there was a high occurrence of helmet use in both states, but equally there were still cyclists not wearing helmets even though they are required to do so.

Figure 5.25: Helmet conditions in Victoria and Queensland



5.8 Summary and Interpretation of Results

The crash analysis identified that the predominant crash was the adjacent direction type of crash. This crash type is consistent with the concept that the motor vehicle driver looked but failed to see the cyclist. Detailed examination of the location (refer to Section 7.2) may provide some more information to assist in eliminating or reducing this crash type.

The second most common crash type occurred with a vehicle and a cyclist travelling in the same direction. Some possible contributing factors for these types of crashes may be the vehicle approach speeds and the approach lane widths. The detailed examination of locations may identify contributing factors to this type of crash.

Crashes in 50 km/h or less and 60 km/h speed zones were significantly greater than in the higher speed zone (70 km/h or greater). This was not unexpected as the number of roundabouts and cyclists is most likely to also be higher in these slower speed zones.

Whilst the number of crashes in the higher speed zones was relatively low, it would be valuable to examine roundabouts in these locations to try to identify the elements contributing to the crashes at these higher speed roundabouts.

6. Sites with High Crash Numbers

A selected number of sites with high fatal and casualty crash numbers in Queensland, New South Wales and Victoria were identified for detailed examination. For the purposes of this investigation, the number of crashes that constitute a high-crash site was set at three or more over the five-year analysis period. It was found that there were 80 separate locations where this was the case over the 2009–13 period (Table 6.1).

Table 6.1: Number of high-crash locations (three or more crashes)

Number of crashes	Number of locations
≥ 5	15
4	16
3	49
Total	80

These crashes have been sorted into their respective speed zone limits in Table 6.2.

Table 6.2: Multiple crashes by speed zone

State	≤ 50 km/h speed zones	50–60 km/h speed zones	60 km/h speed zones	≥ 70 km/h speed zones
Victoria	18	7	6	2
New South Wales	17	12	1	1
Queensland	0	8	7	1
Total	35	27	14	4

Note: The speed zone was obtained from the crash data reports.

The detailed locations of these crashes is contained in Section 6.1.1 to Section 6.1.3.

6.1 Roundabout Locations

The roundabout locations have been grouped by the state location and speed zones of ≤ 50 km/h, 50–60 km/h, 60 km/h and are shown in Section 6.1.1 to Section 6.1.3. The roundabouts in the ≥ 70 km/h speed zones are shown in Section 6.2 and have been separated from the roundabouts in lower speed zones to assist in determining suitable locations for detailed examination.

Some additional information is shown for these locations, as identification of any changes to these roundabouts may influence their selection for detailed analysis. This was undertaken as a desktop audit utilising aerial photography and some contact with the agency responsible for the roundabout.

6.1.1 Victorian Sites

The locations in Victoria are shown in Table 6.3 that includes any comments that may influence the selection of the roundabout.

Table 6.3: Roundabouts with high numbers of bicycle crashes – Victoria

Site number	Street 1	Street 2	Local government area/town	Number of crashes	Urban/ rural	Speed zone (km/h)	Comments
Speed zone: 50 km/h or less							
1	Canning Street	Pigdon Street	Carlton	7	Urban	40–60	New central island layout circa 2010. Road humps introduced circa 2012.
2	Drummond Street	Pelham Street	Carlton	5	Urban	50	Bicycle lanes and waiting areas introduced circa 2010.
3	Drummond Street	Pigdon Street	Carlton	5	Urban	50	–
4	Monbulk Road	Kallista-Emerald Road	Kallista	5	Urban	50	–
5	Garton Street	Pigdon Street	Carlton	4	Urban	50	–
6	Barkly Street	Outer Crescent	Brighton	3	Urban	50	–
7	Bowen Crescent	Garton Street	Melbourne	3	Urban	40–50	–
8	Cardinal Road	Glenroy Road	Moreland	3	Urban	50	–
9	Coventry Street	Dodds Street	Melbourne	3	Urban	50	–
10	Grey Street	Powlett Street	Melbourne	3	Urban	50	–
11	Hope Street	Pearson Street	Moreland	3	Urban	50	–
12	Hotham Street	Powlett Street	Melbourne	3	Urban	50	–
13	Kerr Street	Napier Street	Yarra	3	Urban	50	–
14	Moubray Street	Nelson Road	Port Phillip	3	Urban	50	–
15	Union Street	Upton Road	Stonnington	3	Urban	40	–
16	Broadway	Milton Street	Port Phillip	3	Urban	50	Bicycle markings added 2014, bicycle lanes added 2015.
17	Bundeena Avenue	Kingsclere Avenue	Keysborough	3	Urban	50	–
18	Richardson Street	Victoria Street	Port Phillip	3	Urban	50	–
Speed zone: 50–60 km/h							
19	Balcombe Road	Beach Road	Bayside	8	Urban	50–60	Double roundabout layout.
20	Leveson Street	Queensberry Street	Melbourne	4	Urban	50–60	Extra space line markings circa 2010. Zebra crossings circa 2012.
21	Bent Ave	Murphy Street	Bayside	3	Urban	50–60	–

Site number	Street 1	Street 2	Local government area/town	Number of crashes	Urban/ rural	Speed zone (km/h)	Comments
22	Dorcas Street	Moray Street	Port Phillip	3	Urban	50–60	–
23	Fellows Road	Lawrence Road	Geelong	3	Urban	50–60	–
24	Gilbert Road	Henty Street	Darebin	3	Urban	50–60	–
25	View Mount Road	Whites Road	Wheelers Hill	3	Urban	50–60	–
Speed zone: 60 km/h							
26	Carpenter Street	Houston Street	Quarry Hill	5	Urban	60	Bicycle lanes introduced on all legs circa 2013.
27	Nepean Highway	Beach Road	Kingston	4	Urban	60	–
28	Norman Street	Forest Street	Ballarat	4	Urban	60	Bicycle lane introduced circa 2012.
29	Oriel Road	Banksia Street	Banyule	4	Urban	60	–
30	Childs Road	Dalton Road	Mill Park	3	Urban	60	Always had bicycle lanes in place.
31	Todd Road	Cook Street	Melbourne	3	Urban	60	Forth leg introduced from eastern side circa 2014. Intersection changed to be fully signalised cross. Under construction.

6.1.2 New South Wales Sites

The locations in New South Wales are shown Table 6.4 which includes any comments that may influence the selection of the roundabout.

Table 6.4: Roundabouts with high numbers of bicycle crashes – NSW

Site number	Street 1	Street 2	Local government area/town	Number of crashes	Urban/ rural	Speed zone (km/h)	Comments
Speed zone: 50 km/h or less							
1	Darling Drive	Pier Street	Haymarket	20	Urban	50	Repainting and line marking upgrades circa 2010. Construction on northern side reduces room for vehicles and bicycles. Construction ongoing.
2	Eastern Avenue	Tresidder Avenue	Kingsford/ Kensington	7	Urban	50	–
3	Barnstaple Road	Ingham Avenue	Five Dock	5	Urban	50	–
4	Heffron Road	Banks Avenue	Pagewood	5	Urban	50	–
5	Abercrombie Street	Codrington Street	Darlington	4	Urban	50	Road humps on western and northern approaches circa 2013. No bicycle facilities.

Site number	Street 1	Street 2	Local government area/town	Number of crashes	Urban/ rural	Speed zone (km/h)	Comments
6	Campbell Street	Carrington Street	Woonona	4	Urban	50	–
7	Darley Road	Allen Street	Leichhardt	4	Urban	50	–
8	Macpherson Street	Albion Street	Waverley Bronte	4	Urban	50	–
9	Mount Street	Oberon Street	Coogee	4	Urban	50	–
10	Wellbank Street	Flavelle Street	Concord	4	Urban	50	Bicycle island introduced on northern, eastern and southern approaches circa 2010. Road hump on southern exit circa 2013.
11	Allen Street	Elswick Street	Leichhardt	3	Urban	50	–
12	Ian Parade	Wellbank Street	Concord	3	Urban	50	–
13	Keira Street	Swan Street	Wollongong	3	Urban	50	Resurfacing circa 2014. No bicycle facilities.
14	Morley Street	Rothschild Avenue	Roseberry	3	Urban	40–50	–
15	National Park Street	Parkway Avenue	South Hamilton	3	Urban	50	–
16	Parkway Avenue	Smith Street	South Hamilton	3	Urban	50	–
17	Waterloo Road	Trafalgar Place	Marsfield	3	Urban	50	–
Speed zone: 50–60 km/h							
18	Hannell street	Branch Street/ North Cowper Street	Wickham	7	Urban	50–60	Multilane entries.
19	Anzac Parade	Rainbow Street	Kingsford	6	Urban	50–60	One roundabout, Rainbow Street and Gardeners Road are different legs, multilane entries. Construction reduced centre radius circa 2012. Bus lane introduced and resurfacing circa 2012.
20	Anzac Parade	Gardeners Road	Kingsford	5	Urban	50–60	
21	Murray Road	Pioneer Road	Corrimal	4	Urban	50–60	–
22	Phillip Street	Young Street	Redfern	4	Urban	50–60	–
23	Awaba Street	Moruben Road	Mosman	3	Urban	50–60	–
24	Bentick Street	Moon Street	Ballina	3	Urban	50–60	–
25	Darby Street	Parkway Avenue	Cooks Hill	3	Urban	50–60	–
26	Frenchs Forest Road	Sydney Road	Seaforth	3	Urban	50–60	–
27	Gordon Street	Hollingsworth Street	Port Macquarie	3	Urban	50–60	–
28	Malabar Road	Duncan Street	Maroubra	3	Urban	50–60	–

Site number	Street 1	Street 2	Local government area/town	Number of crashes	Urban/ rural	Speed zone (km/h)	Comments
29	Mandalong Road	Gateway Boulevard	Morisset	3	Urban	50–60	–
Speed zone: 60 km/h							
30	The Entrance Road	Cresthaven Avenue	Bateau Bay	3	Urban	60	–

6.1.3 Queensland Sites

The locations are shown in Table 6.5 that includes any comments that may influence the selection of the roundabout.

Table 6.5: Roundabouts with high numbers of bicycle crashes – Queensland

Site number	Street 1	Street 2	Local government area/town	Number of crashes	Urban/ rural	Speed zone (km/h)	Comments
Speed zone: 50 km/h or less							
Nil							
Speed zone: 50–60 km/h							
1	Florence Street	Lake Street	Cairns City	5	Urban	50–60	–
2	Cairns Western Arterial Road	Captain Cook Highway	Barron	3	Urban	50–60	–
3	Eenie Creek Road	Walter Hay Drive	Noosaville	3	Urban	60	Upgrade of bicycle lanes circa 2014.
4	Gatton Street	Severin Street	Parramatta Park	3	Urban	50–60	Bicycle lane provisions not clear (no green painting).
5	Logan Road	O'Keefe Street	Woolloongabba	3	Urban	50–60	–
6	Long Street	Ramsay Street	South Toowoomba	3	Urban	50–60	–
7	Masthead Drive	Shore Street West	Cleveland	3	Urban	50–60	–
8	Old Burleigh Road	Queensland Avenue	Broadbeach	3	Urban	50–60	Construction of bicycle lanes circa 2010.
Speed zone: 60 km/h							
9	Captain Cook Highway	Kennedy Highway	Smithfield	5	Urban	60	–
10	Eenie Creek Road	Langura Street	Noosa Heads	4	Urban	60	Fourth leg to roundabout on south constructed circa 2011. New line markings and upgrade of bicycle lanes.
11	Maroochydore-Noosa Road (David Low Way)	Sunshine Motorway off-ramp	Pacific Paradise	4	Urban	60	–

Site number	Street 1	Street 2	Local government area/town	Number of crashes	Urban/ rural	Speed zone (km/h)	Comments
12	Alderley Street	Mackenzie Street	Rangeville	3	Urban	60	–
13	Bamford Lane	Mill Road	Kirwan	3	Urban	60	–
14	Cotterill Avenue	Goodwin Drive	Bongaree	3	Urban	60	Bicycle lanes introduced on northern and southern approaches and resurfacing circa 2012.
15	Mount Coot-tha Road	Western Arterial Road	Mount Coot-tha	3	Urban	60	Construction works being undertaken near the site.
Speed zone: 50-70 km/h or less							
16	Helensvale Road	Hope Island Road	Hope Island	4	Urban	50–70	Construction work undertaken in 2009 and completed early 2010, no bicycle facilities.

6.2 Roundabouts on High Speed Roads

From the Victorian, New South Wales and Queensland crash data only three locations with three or more crashes were found in speed zones of ≥ 70 km/h. To obtain a greater number of sample locations in the higher speed zones the analysis of the roundabouts in high-speed zones was extended to include locations where two crashes had occurred. By extending the criteria a further two sites were found bringing the number of locations in the speed zones of 70 km/h or higher to six. These have been divided into their state locations in Table 6.6.

Table 6.6: High speed roundabouts

Site number	Street 1	Street 2	Local government area/town	Number of crashes	Urban/ rural	Speed zone (km/h)	Comments
Victoria							
1	Main Whittlesea Road	Arthurs Creek Road	Yan Yean	3	Rural	100	–
2	Eltham-Yarra Glen Road (Main Road)	Doncaster-Eltham Road (Fitzsimons Lane)	Eltham	3	Urban	60–70	Two legs are signalised, one leg unsignalised. No bicycle facilities.
3	Ford Road	Verney Road	Shepparton	2	Urban	80	–
New South Wales							
4	Northcliffe Drive	Southern Expressway	Berkeley	2	Urban	70	–
Queensland							
5	Douglas-Garbutt Road (Bruce Highway)	Townsville Port Road (Woolcock Street)	Garbutt	3	Urban	70	Earliest photo is circa 2014. No improvements made.
6	Helensvale Road	Hope Island Road	Hope Island	2	Urban	70	–

6.3 Summary

The identification of locations with high crash numbers has revealed that most of the crashes in Victoria, New South Wales and Queensland occurred in low-speed zones as outlined in Section 6.1.1 to Section 6.1.3. A preliminary examination of the sites identified that some of these roundabouts have been altered during the crash analysis period and so were excluded from detailed examination.

As there was only a relatively small number of crashes in the high-speed zones, the number of crashes to meet the requirements of a high-crash location was reduced to two. This enabled six sites to be identified for possible detailed examination.

6.4 Site Selection

6.4.1 Methodology

Following the identification of sites with high numbers of bicycle crashes an initial investigation was undertaken to examine any changes to the roundabout over the crash analysis period. If there were modifications identified to the roundabout over the analysis period, that were considered to influence the crash occurrence the location was not considered. An initial assessment of 78 locations was undertaken to identify suitable locations for detailed assessment.

The initial assessment was undertaken using an aerial photographic mapping tool, nearmap. The criteria used for selecting the sites for the investigation was:

- speed zone – a selection of sites across each of the speed zones may provide different alignments and layouts
- number of crashes
- central island size
- entry geometry
- number of entry lanes on the approaches.

It was also considered opportune to build on the information contained in Austroads (2014a) and examine some of these roundabouts.

Some locations were found to have been significantly modified or affected by adjacent development works since 2009. These sites were not included for consideration of detailed analysis.

Following consideration of the selection criteria the sites were selected for the detailed examination and are shown in Table 6.7.

Table 6.7: Locations for detailed analysis

No	Location	Speed zone (km/h)	Number of crashes	Number of lanes	Road classification
1	Eastern Avenue – Tresidder Avenue, Kingsford NSW	50	6	Single lane	Local urban
2	Drummond Street – Pigdon Street, Carlton, Vic	50	5	Single lane	Local urban
3	Barnstaple Road – Ingham Avenue, Five Dock, NSW	50	4	Single lane	Local urban
4	Heffron Road – Banks Avenue, Pagewood, NSW	50	5	Single lane	Local urban
5	Monbulk Road – Kallista-Emerald Road, Sherbrooke, Vic	50	5	Single lane	Arterial rural(1)
6	Bowen Crescent – Garton Street, Carlton, Vic	50	3	Single lane	Local urban
7	Union Street – Upton Road, Windsor, Vic	40	3	Single lane	Local urban
8	Seaworld Drive – Waterways Drive – Macarthur Drive, Main Beach, Qld	50	3	Multilane	Local urban
9	Anzac Parade – Rainbow Street, Kingsford, NSW	50–60	6	Multilane	Local urban
10	Phillip Street – Young Street, Redfern, NSW	50–60	4	Single lane	Local urban
11	Old Burleigh Road – Queensland Avenue, Broadbeach, Qld	50–60	3	Single lane	Local urban
12	Gilbert Road – Henty Street, Reservoir, Vic	50–60	3	Single lane	Local urban
13	Oriel Road – Banksia Street, Heidelberg, Vic	60	4	Single lane	Local urban
14	Childs Road – Dalton Road Mill Park, Vic	60	3	Multilane	Arterial urban
15	Cotlew Street – Wardoo Street Ashmore, Qld	60	1	Multilane	Arterial urban
16	Whittlesea Road – Arthurs Creek Road, Yan Yean, Vic	70	3	Single lane	Arterial rural
17	Helensvale Road – Hope Island Road, Hope Island (Gold Coast area) Qld	70	4	Multilane	Arterial rural

1 *The Monbulk Road is a rural arterial road and the roundabout is located on the entrance to a local village. For this project it is included in the arterial road rural group.*

Table 6.8 summarises the locations and road classification.

Table 6.8: Summary of locations and road classification

Road classification	Number of locations
Local urban	12
Arterial urban	2
Arterial rural	3

Table 6.9 summarises the crash types as identified by the crash analysis.

Table 6.9: Number and type of crashes

Crash type	Number of crashes	Number of crashes as percentage of total (%)
Adjacent direction, cross movement	46	71
Adjacent direction, turning movement	11	17
Sideswipe left-turning movement	4	6
Sideswipe right-turning movement	1	1.5
Opposing direction movement	1	1.5
Rear end (on approach road)	1	1.5
Loss of control	1	1.5
Total	65	100

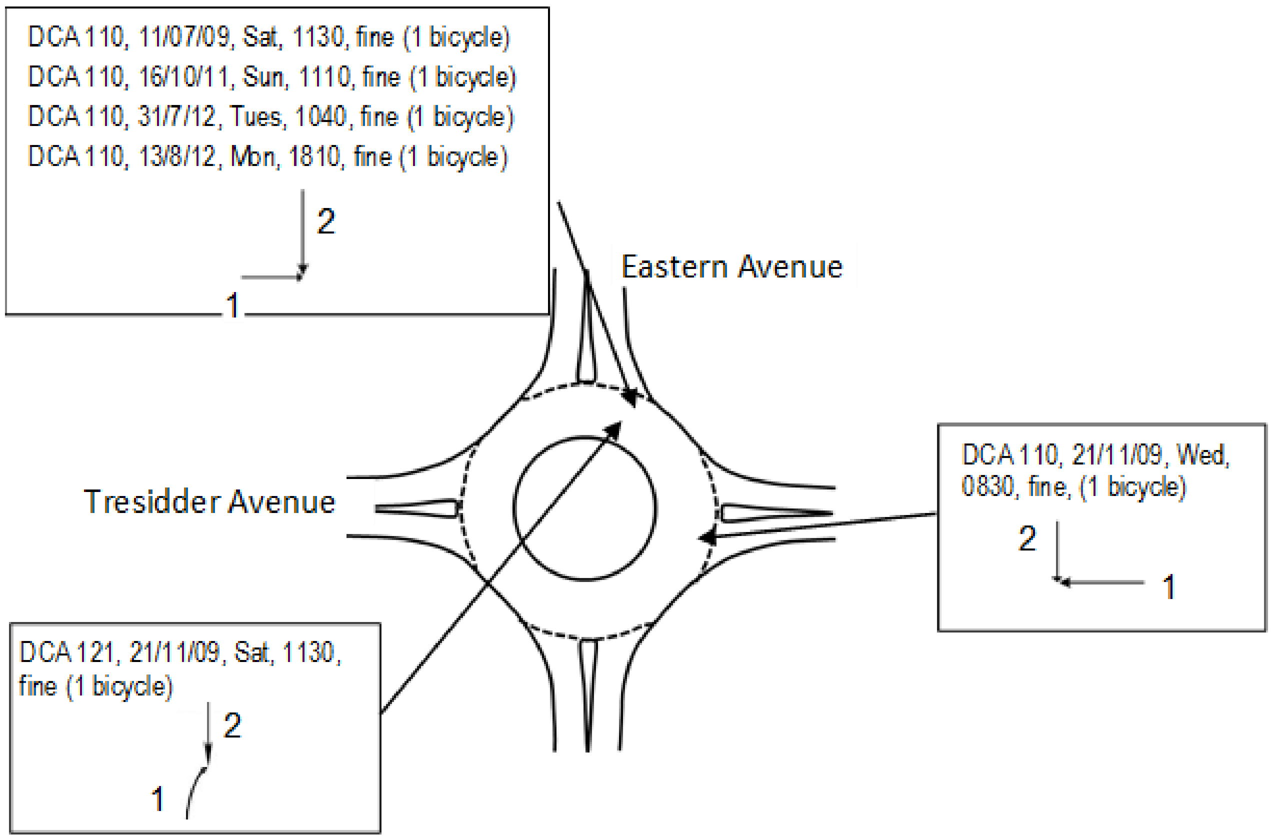
Note: The adjacent direction crashes predominantly involve motor vehicles entering the roundabout.

This data shows that 88% of the crashes involved adjacent direction cross and turning type crashes, which were found to occur at the entry to the circulating lanes; refer to an example shown in Figure 6.1. These types of crash form the focus for the geometric analysis. However, there were five sideswipe crashes that occurred across the different road classifications.

6.4.2 Crash Diagrams

Crash diagrams were prepared from the crash information to show the location and types of crash occurring at these intersections. An example is shown in Figure 6.1. The crash codes, or definitions for coding accidents (DCAs) are reported in accordance with the Victoria DCA codes to provide consistent information in the crash diagrams (Appendix B).

Figure 6.1: Example of a crash diagram



6.4.3 Geometric Information

For each of the nominated locations, the relevant road agency, either a state road agency or a local government agency, were contacted requesting the geometric information for the nominated roundabout. Not all of these agencies were able to provide geometric details and so the use of mapping systems, e.g. nearmap, was utilised to obtain information for locations.

The quality of the information obtained from the mapping systems was assessed by obtaining information for all of the locations and comparing the mapping system information with the geometric details provided by the road agency. This assessment revealed that the information obtained from the mapping systems would be suitable to undertake the investigations for this project. The aerial photographs within the mapping system were also able to show the vehicle travel paths at most of the roundabouts.

The analysis of the geometric elements that may have contributed to bicycle crashes at each roundabout was undertaken to identify:

- approach lane widths – entry, exit and circulating
- approach geometry
- central island size and shape
- travel path geometry
- sight distance.

The analysis only included the geometric elements relating to the location and type of crashes that had occurred.

6.4.4 Field Investigations

Site investigations were undertaken at each of the nominated locations to observe the operation of the roundabout and assist in identifying factors that may be contributing to the crashes. The investigation included:

- observations of the vehicle travel paths
- observations of available sight distance
- types of signage and delineation used
- presence and condition of cyclist and pedestrian facilities
- presence of street lighting
- identifying the type of surrounding land development.

The range of information collected was to enable the identification of possible countermeasures.

The available sight distance is an important design element as it provides an opportunity for an approaching driver to detect and respond to another vehicle. This was one of the key elements considered during the site investigations.

6.4.5 Traffic Data

The analysis of a roundabout would usually include traffic information to determine operating characteristics such as dominant flow directions, flow paths and gaps.

The key data used for this project are the crash details and the geometric details of the roundabout. Traffic data would be used to determine crash rates, but this is not necessary for a geometric analysis.

Vehicle speed data was not included in the scope of the project, and the speeds at the roundabout were estimated using the methods contained within the Guide to Road Design. Some additional vehicle speed information was also obtained from Austroads (2014a).

6.5 Contributing Factors

Based on *Guide to Road Safety: Part 8: Treatment of Crash Locati*ons (Austroads 2015c) the possible contributing factors to adjacent direction type crashes are restricted sight distances and high approach speeds. For sideswipe crashes, the contributing factors may include the lanes being too narrow for the traffic volumes and speeds.

Factors associated with crashes at roundabouts were also reported in *Improving the Performance of Safe System Infrastructure: Final Report* (Austroads 2015b) that undertook crash analysis at roundabouts. The analysis focused on motorcyclists and cyclists and identified factors associated with the adjacent direction severe crashes (Table 6.10). These factors are for motorcyclists and cyclists and whilst some caution should be used in interpreting the information, it is useful as a guide to the factors associated with cyclists.

Table 6.10: Summary of factors associated with adjacent direction severe crashes at roundabouts

Literature (mostly based on casualty crashes)	Severe crash site analysis (statistically modelled factors increasing probability of crashes being severe)	In-depth crash analysis (observed site factors present in severe crashes)
High traffic flows, vehicle or two-wheeler, approach and circulating	–	Local roads mostly, 50–60 km/h speed zones
High approach and entering speeds: • large entry curve radius • high approach speed zones • multiple circulating lanes	High speed roundabout design via combination of: • small or large central island • multiple approach lanes • multiple circulating lanes	Indicators of high speed design: • poor approach deflection (cyclists and motorcyclists) • large diameter central island (cyclists) • small diameter central island (motorcyclists) • wide circulating lanes (motorcyclists) • single approach/circulating lanes (cyclists and motorcyclists: factor of exposure to local roads)
Lack of cyclist bypass facilities	Hidden roundabout – not conspicuous from approach	Odd/irregular roundabout designs, confusing layout (cyclists and motorcyclists)

Source: Austroads (2015b).

The geometric factors associated with crashes at roundabouts identified in Austroads (2015b) related to high approach speeds, the size of the central island, the number of approach and circulating lanes.

The contributory factors are discussed in the following sections.

6.5.1 Sight Distance

The sight distances at each of the roundabouts was assessed against the guidance contained in AGRD Part 4B (Austroads 2015a) and the available sight distance was determined from the estimated entry curve speed.

At most of the roundabouts, the available sight distance exceeded the distances to meet Criterion 1, Criterion 2 and Criterion 3 suggested in AGRD Part 4B.

There were however, some approaches on some of the roundabouts, where the sight distance did not satisfy either criterion. In these cases the obstruction to the sight distance was due to trees, power and sign poles, which partly obscured cyclists.

The United Kingdom design guidance (Transport for London 2015) follows a different approach and suggest that reducing the sight distance on the approach may contribute to lower approach speeds. The guidance suggests that sight distance should be provided from a point 15 m prior to the holding line to the outer edge of the circulating lane at the entry of the leg to the right (refer also to Section 3.1.6).

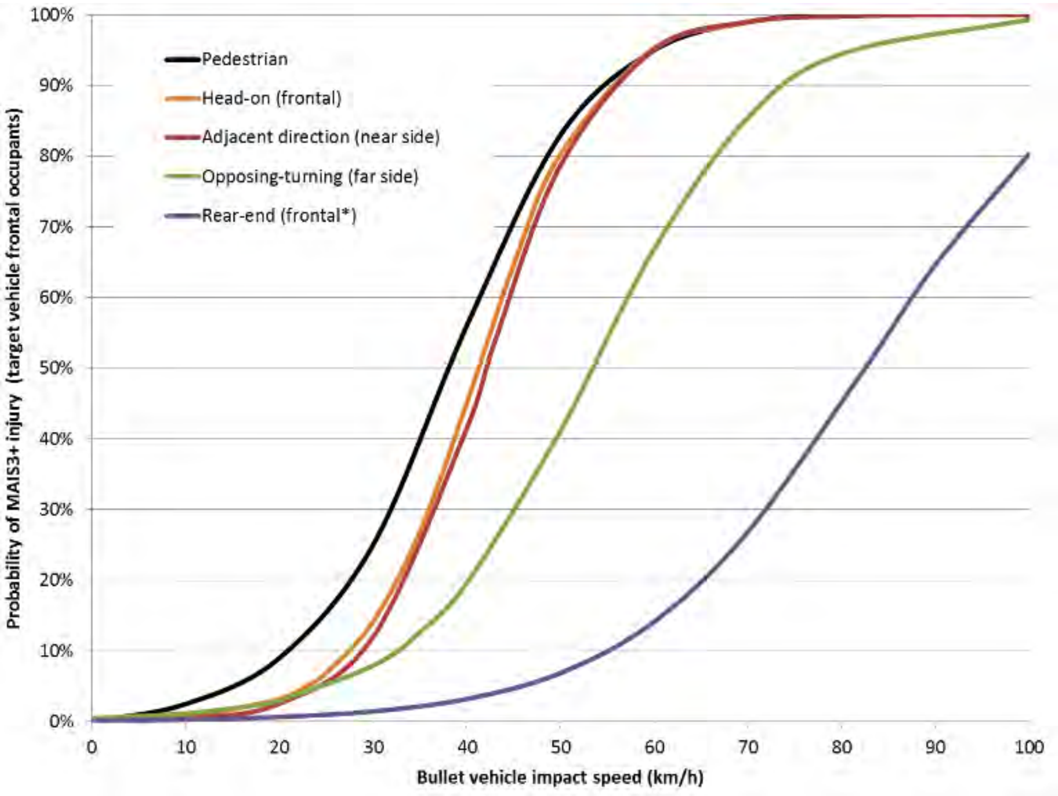
6.5.2 Vehicle Speeds

The crash analysis identified the occurrence of adjacent direction type crashes (cross or right-turning) and the geometric analysis indicated that vehicle speeds through the roundabout were higher than the Safe System speed of 30 km/h where motor vehicles and cyclists share the road space.

Austroads (2014a) found that, based on a small sample of speed measurements, average motor vehicle speeds at the entry to local road roundabouts were less than 30 km/h.

A speed of 20 km/h was identified in *Improving the Performance of Safe System Infrastructure: Final Report* (Austroads 2015b) as a speed that would minimise the probability of severe injury. This speed was based on a model of severe injury and impact speed (Figure 6.2).

Figure 6.2: Proposed model of severe injury probability vs bullet vehicle impact speeds in different crash types



** In rear-end crashes the frontal occupants of the bullet vehicle sustain greater risk of severe injury than those in the target vehicle.*

Notes:

The bullet speed is the speed of a vehicle that collides into another vehicle.

MAIS3+ is widely considered the serious injury threshold and includes fatality.

Source: Austroads (2015b), based on Bahouth et al. (2014), Davis (2001).

This research indicates that collision speeds of < 30 km/h reduce the likelihood of serious injuries, and moving towards a 20 km/h speed would be beneficial in reducing serious injuries. Further investigation of vehicle speeds and crashes involving cyclists is needed to provide guidance on an appropriate design speed at the roundabouts where vehicles and cyclists share the road space.

However, for the purposes of this report a target speed of 30 km/h has been adopted.

6.5.3 Lane Widths

The sideswipe crashes involved a left turning motor vehicle colliding with a cyclist. For each of the occurrences, the lane widths available were 4.5 m wide or greater. This should have provided sufficient width for the passing of the motor vehicle and cyclist. If the entry width did not permit the motor vehicle to enter alongside the cyclist, the cyclists would have been able to proceed ahead the motor vehicle, removing the opportunity for a side-swipe crash.

6.6 Selection of Countermeasures

Following the identification of the crash data, the roundabout’s geometry and factors identified in the site inspection, possible countermeasures to eliminate or reduce the crash severity or number of crashes have been identified.

The selection of countermeasures will consider:

- possible causes of the crashes
- the factors contributing to the crashes
- speed zones
- design vehicles
- site constraints.

In determining possible countermeasures a design speed of 30 km/h has been adopted as this speed is the target speed commonly used for locations where vehicles and vulnerable road users, such as cyclists, share the same road space.

Guidance on the selection of countermeasures has been obtained from *Guide to Road Safety: Part 8: Treatment of Crash Locations* (Austroads 2015c) that has recently been updated.

The countermeasures have been outlined to reduce or eliminate the identified crash types and not to provide a full roundabout design. However, the elements of the solutions could be incorporated into a full design solution.

There is also guidance, suggested in the Department for Transport (2016) to restrict sight distance on the approach to a roundabout to reduce excessive approach speeds. This design approach is not currently incorporated into the Austroads road design guides and this is discussed further in Section 8.1.6.

7. Geometric Analysis

The geometric analysis of the roundabouts was guided by the types of crashes occurring at each roundabout and undertaken at each location by obtaining the geometric data relating to:

- central island size
- approach geometry
- lane widths – entry, circulating and exit
- entry curve
- sight distance.

Travel paths were able to be obtained from aerial mapping. The travel path became a key area of analysis as this takes account of the geometry of the roundabout and provides guidance on the vehicle movement through the roundabout.

7.1 Vehicle Speed Assessment

The assessment of the speeds is one of the key matters to be assessed at each of the roundabouts. The methods provided within the *Guide to Road Design* series are:

- the ARNDT model that may be used to determine likely 85th percentile speeds for any horizontal geometric element of the roundabout, as contained in *Guide to Road Design: Part 4B: Roundabouts* (Austroads 2015a)
- the horizontal curve equation contained in *Guide to Road Design: Part 3: Geometric Design* (AGRD Part 3) (Austroads 2016a).

The ARNDT model is a software program that uses the roundabout geometry, speed environment and traffic flow data to:

- enable road designers to identify potentially hazardous geometry of proposed or existing roundabouts
- predict accident rates and costs for proposed or existing roundabouts. This enables a designer to determine if the additional construction costs of a particular roundabout layout warrant the saving in accident costs
- determine whether the accident rate at an existing roundabout is similar to that expected, given the geometry, traffic volumes and speed environment; or whether there are other major factors influencing accident rates.

The ARNDT model provides the 85th percentile speed for any horizontal geometric element of the roundabout. It uses a modified speed environment model for rural roads and was primarily developed for crash prediction and so its application on local urban roads is uncertain. It is however considered useful to obtain the speeds from the model as an indication, acknowledging the limitations for urban local roads. The ARNDT model is available in the Queensland Transport and Main Roads website <http://www.tmr.qld.gov.au/business-industry/Road-systems-and-engineering/Software/ARNDT.aspx> (Queensland Department of Transport and Main Roads 2016). The speeds obtained from the ARNDT model were primarily used in the assessment.

The horizontal curve equation (Equation 1) provides an estimate of the speed based on the curve radius but does not take into account the presence of other horizontal curves. It is however used in some jurisdictions to estimate the travel path speed at the roundabout.

Another method used by some jurisdictions is to estimate the speeds on the maximum path radius. This method uses Equation 1 and its application is shown in Figure 7.1:

$$V = \sqrt{127 \times R \times (e + f)} \quad (1)$$

where

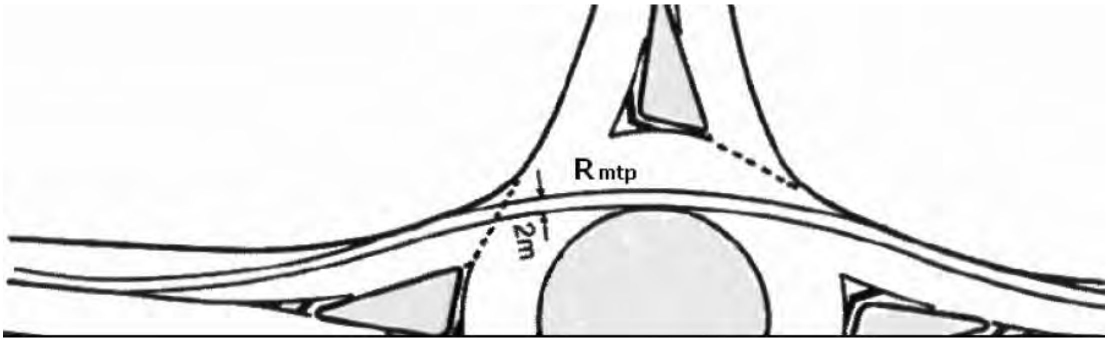
V = vehicle speed (km/h)

R = curve radius (m)

e = pavement superelevation (m/m)

f = side friction factor (refer to AGRD Part 3 (Austroads 2016a))

Figure 7.1: Radius of maximum travel path



Note: R_{mtp} is the radius of maximum travel path.

Source: Austroads (2009b).

The travel path radii were determined from aerial photographs and site observations that provided the actual travel paths of vehicles travelling through the roundabout. This was used to provide analysis of actual operation.

Each of the methods has limitations and would require validation for the locations to be analysed however, these are the methods outlined in the design guides and therefore have been adopted for this project. Consequently, the outcomes should only be used to provide an indication of vehicle speeds.

For the assessment of sight distances, Criterion 2 utilises the approach speeds of vehicles from the right or the circulating lane. In considering the approach sight distance to a cyclist, the information on cyclists' speeds is not available. To provide an indication of the sight distance requirements, vehicle speeds have been used. It is likely that cyclists will travel at slower speeds than motor vehicles and so the sight distance requirements may produce longer distances than needed to cater for cyclists. Therefore the comments relating to sight distance should be taken as an indication only.

7.2 Detailed Investigations

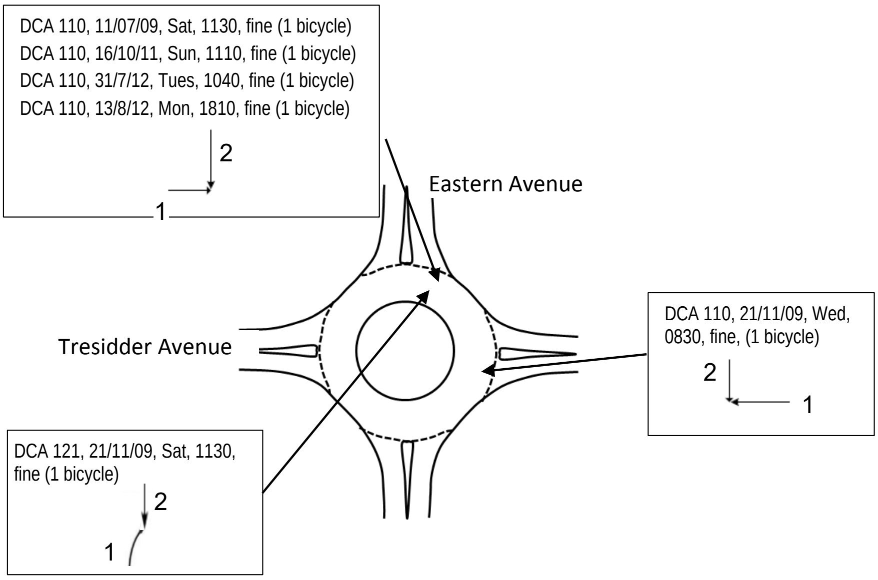
The details for each location have been determined and summarised in the following sections.

All crash types have been reported in accordance with the Victorian DCA codes.

For all of the aerial images and sketches north is to the top of the page.

It should be noted that the possible countermeasures outlines for each site are further discussed in Section 8. Suggested amendments to roundabout alignments have been identified using likely design vehicles and the Austroads turning templates (Austroads 2013b).

7.2.1 Eastern Avenue – Tresidder Avenue, Kingsford

Location	Eastern Avenue – Tresidder Avenue, Kingsford, New South Wales
Road classification	Local roads
Speed zone	50 km/h
Surrounding development	Residential
Description	Single lane roundabout, circular central island, located centrally on approach roads, raised splitter islands on all approaches
Bicycle facilities	Bicycle symbols marked along Tresidder Avenue
On-street parking	Bus stops located on Eastern Avenue on both approaches approx. 15 m from the holding lines On-street parking available within 15 m of the intersection
Aerial map	 *Source: nearmap© (2015), 'NSW', map data, nearmap©, Sydney, NSW.*
Crash history	Seven crashes involving cyclists
Crash diagram	 *Note: One crash reported as unknown*

Location	Eastern Avenue – Tresidder Avenue, Kingsford, New South Wales
Approaches	Straight approaches
Entry widths	Northern approach – 4.5 m Western approach – 4.2 m
Kerb alignment (northern approach)	Flaring on approach kerb, 1:30; kerb – 6 m radius
Inscribed circle diameter	18 m
Central island size	7.8 m diameter, raised encroachment area 2.4 m wide, with a 70 mm mountable bullnose, during crash period some landscaping in central area, subsequently altered to now being fully paved
Splitter islands	Approach islands full concrete, bevel faces (i.e. semi-mountable kerb profile)
Circulating lane width	7.5 m at centreline of east-west direction
Exit lane width	4.5 m
Exit kerb alignment	Flaring 1:15
Entry path radius/curve speed	North to south direction: • ARNDT model – 44 km/h • Horizontal curve equation – 30 m radius equates to a curve speed of 38 km/h (e = +0.03) West to east direction : • ARNDT model – 42 km/h
Circulating path radius/curve speed	North to south direction: • ARNDT model – 38 km/h • Horizontal curve equation – 30 m radius, equates to a curve speed of 35 km/h (e = –0.03)
Sight distance	Northern approach along western approach: • For Criterion 2 – 32 m available, restricted due cars parked into street • For an approach speed of 42 km/h, sight distance required is 46 m (Table 3.1, AGRD Part 4B (Austroads 2015a)) For Criterion 3 northern approach: the western approach speed is 42 km/h which equates to a sight distance requirement of 46 m (Table 3.1, AGRD Part 4B*)*, and the approach sight distance (absolute minimum) on the northern approach for a speed of 44 km/h is 35 m, (Equation 1, AGRD Part 4A (Austroads 2010))

Notes:

Criterion 2 refers to the sight distance available to a driver of a vehicle located at the holding line to vehicles approaching from the right or travelling on the circulating lanes.

Criterion 3 refers to the ability of a driver approaching the roundabout to observe other entering vehicles before that vehicle reaches the holding lines.

For Criterion 3, the absolute minimum sight distance is based on a reaction time of 1.5 sec and a coefficient of deceleration of 0.46 (AGRD Part 4A (Austroads 2010)).

The side friction value used for the curve speed estimation is 0.35, per Table 7.4 AGRD Part 3 (Austroads 2016a).

Discussion

This roundabout is located in a residential area on two-lane two-way roads. The road pavements are 9 m wide with parking permitted on both sides of the road to within 20 m of the holding lines of the roundabout. Bicycle symbols have been marked along Tresidder Avenue and a bus route is located along Eastern Avenue.

The approach grades are straight and do not restrict a drivers view of the intersection.

The crashes are predominantly adjacent direction type crashes, occurring at the northern entry and involving cyclists travelling in an easterly direction and cars travelling in a southerly direction.

One crash involved a cyclist entering the circulating carriageway colliding with a motor vehicle travelling on the circulating carriageway.

Contributing factors

Some possible contributing factors to adjacent direction type crashes are restricted sight distances and high approach speeds (Austroads 2015c).

Sight distance

The sight distance available from the northern approach (Eastern Avenue) along the western approach (Tresidder Avenue) is 32 m which is less than the distance to meet Criterion 2 in AGRD Part 4B for a driver observing an approaching vehicle or a circulating vehicle prior to entering the roundabout. For Criterion 3 (northern approach) the approach speeds require an absolute minimum approach sight distance of 35 m and an approach stopping distance 46 m. The sight line to meet the requirements of Criterion 3 is restricted by abutting development and so this criterion is not met. From the observations at the site, the sight distance from the northern approach along the western approach is restricted by trees located on the nature strips along Tresidder Avenue and Eastern Avenue.

Entry speed

The entry speeds based on the vehicle travel path are estimated to be 44 km/h, i.e. higher than the target speed of 30 km/h speed for locations with vulnerable road users. The approaches for each entry are straight on-street parking permitted along each side of the approach roads. On the northern approach a bus stop is located 15 m from the holding lines. When a bus is not present this would allow a straighter approach from this direction to the roundabout.

One crash involved a cyclist entering the roundabout colliding with a motor vehicle already on the circulating carriageway. The circulating path speed for a motor vehicle was estimated to be 38 km/h, which is higher than the target speed of 30 km/h. This crash may have been due to a misjudgement in the available gap or the cyclist may have been unable to stop when the motor vehicle on the circulating lane was detected.

Intersection conspicuity

The roundabout contains regulatory signs facing each approach. The signs are of standard size as commonly found in urban residential areas.

The central island is paved and the paving colour can appear to blend with the background. Splitter islands have been constructed on all approaches with supporting linemarking. At the time of inspection the linemarking was in good condition.

Possible countermeasures

The current design guidance suggests that the sight distance should be improved. Following this guidance the sight distance could be improved by removing the nature strip trees within the sight triangles from the northern and western approaches. Improving the sight distance from the western approach to the northern approach allows road users entering the roundabout on the right of drivers from the northern approach greater opportunity to observe and respond to the driving behaviours of drivers from the north. However, increasing sight distance may also increase approach speeds with drivers able to determine possible conflicts, or lack of them, well before reaching the roundabout.

To meet the sight distance requirement for Criterion 2, approach speeds need to be reduced to less than 30 km/h. The requirements to meet Criterion 3 would require approach speeds of less than 25 km/h.

Reducing the approach speeds from the northern approach would reduce the length of sight distance required by drivers and reduce the crash impact forces should a crash occur.

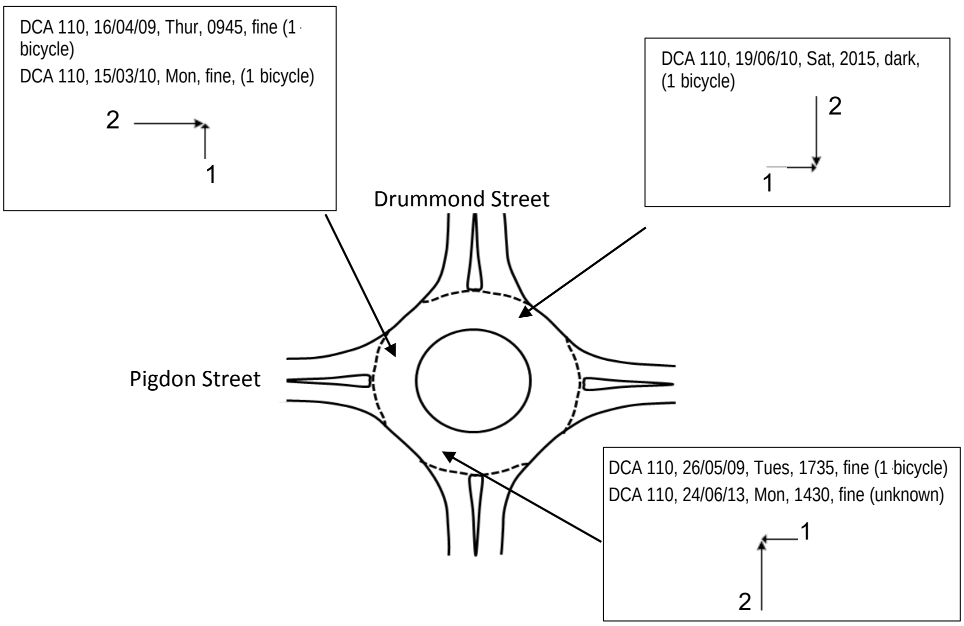
Countermeasures to reduce the approach speeds are to increase the travel path curvature by:

- reducing the entry path radius to a radius of 20 m by providing a straighter or radial-type entry
  This could be achieved by removing the splitter islands and extending the kerb return into the pavement to provide an entry width of 3.5 m to 4.0 m.
- increasing the central island diameter
- narrowing the entry width to create the perception of the need to slow down
- installing vertical displacement treatments.

Vertical displacement treatments, such as a road cushion or flat-top road hump, placed just prior to the holding lines may also be a possible countermeasure, particularly for the northern approach where the majority of bicycle crashes have occurred. However the use of a flat-top road hump may not be acceptable because of the bus route on Eastern Avenue (e.g. passenger comfort) and a road cushion may not be as effective in slowing vehicles as a flat-top road hump.

This type of treatment may also slow approach speeds of cyclists should this be identified as a contributing factor. A vertical displacement device, such as flat-top road hump is considered cycle friendly when ramps of 1(V) to 15 or 20(H) are provided (Austroads 2016b). However, these ramp grades may not slow motor vehicles sufficiently to achieve the motor vehicle target speeds on the approach to a roundabout.

7.2.2 Drummond Street – Pigdon Street, Carlton

Location	Drummond Street – Pigdon Street, Carlton, Victoria
Road classification	Collector road/local road
Speed zone	50 km/h
Surrounding development	Residential
Description	Single-lane roundabout Elongated circular central island, splitter islands on north-south approaches, median on east-west approaches Central island central to road approach centrelines Central island planted, central tree with lower complementary vegetation approximately 1 m above pavement
Bicycle facilities	Bicycle symbols on east-west approaches
On-street parking	Available on all approaches
Aerial map	 *Source: nearmap© (2015), 'VIC', map data, nearmap©, Sydney, NSW.*
Crash history	Five crashes involving cyclists
Crash diagram	

Location	Drummond Street – Pigdon Street, Carlton, Victoria
Approaches	Straight approaches
Entry widths	Northern approach – 7 m Southern approach – 7 m Eastern approach – 4.5 m, plus 2 m bicycle lane Western approach – 4.5 m, plus 2 m bicycle lane
Kerb alignment	Straight
Inscribed circle	The roundabout is an elongated shape 30 m long and 25 m wide
Central island size	North-south direction – 15 m long East-west direction – 19 m wide Encroachment area – 1 m wide Encroachment area and mountable bullnose on central island, bullnose present, rounded edge
Circulating lane width	North-south – 6 m East-west – 5 m
Exit lane width	Northern – 6 m Southern – 7 m Eastern – 5 m, plus 2 m bicycle lane Western – 5 m, plus 2 m bicycle lane
Exit kerb alignment	Straight
Entry path radius/curve speed	West to east direction: • ARNDT model – 42 km/h • Horizontal curve equation – 45 m radius, equates to a curve speed of 47 km/h (e = +0.03) South to north direction: • ARNDT model – 42 km/h • Horizontal curve equation – 50 m radius, equates to a curve speed of 49 km/h (e = +0.03)
Circulating path radius/curve speed	West to east direction: • ARNDT model – 32 km/h • Horizontal curve equation – 35 m radius, equates to a curve speed of 38 km/h (e = –0.03) South to north direction: • ARNDT model – 37 km/h • Horizontal curve equation – 30 m radius, equates to a curve speed of 35 km/h (e = –0.03)
Sight distance	Southern approach along eastern approach: • For Criterion 2 – 38 m available • For an approach speed of 42 km/h, sight distance required is 46 m (Table 3.1, AGRD Part 4B (Austroads 2015a) 22 m to circulating vehicle (central island vegetation), sight distance required is 16 m (circulating speed of 15 km/h, gap of 4 sec) For Criterion 3 southern approach: the eastern approach speed is 42 km/h which equates to a sight distance requirement of 46 m (Table 3.1, AGRD Part 4B) and the approach sight distance (absolute minimum) on the southern approach for a speed of 42 km/h is 33 m (Equation 1, AGRD Part 4A (Austroads 2010)
Sight distance	Western approach along southern approach: • For Criterion 2 – 35 m available • For an approach speed of 42 km/h sight distance required is 46 m (Table 3.1, AGRD Part 4B) 25 m to circulating vehicle (restricted due to central island vegetation) For Criterion 3 western approach: the southern approach speed is 42 km/h which equates to a sight distance requirement of 46 m (Table 3.1, AGRD Part 4B) and the approach sight distance (absolute minimum) on the western approach for a speed of 42 km/h is 33 m (Equation 1, AGRD Part 4A (Austroads 2010) For Criterion 3 southern approach: the eastern approach speed is 42 km/h, which equates to a sight distance requirement of 46 m (Table 3.1, AGRD Part 4B) and the approach sight distance (absolute minimum) on the southern approach for a speed of 42 km/h is 33 m (Equation 1, AGRD Part 4A)

Notes:
Criterion 2 refers to the sight distance available to a driver of a vehicle located at the holding line to vehicles approaching from the right or travelling on the circulating lanes.
Criterion 3 refers to the ability of a driver approaching the roundabout to observe other entering vehicles before that vehicle reaches the holding lines.

For Criterion 3, the absolute minimum sight distance is based on a reaction time of 1.5 sec and a coefficient of deceleration of 0.46 (AGRD Part 4A (Austroads 2010)).
The side friction value used for the curve speed estimation is 0.35, per Table 7.4 AGRD Part 3 (Austroads 2016a).

Discussion

A median 2.5 m wide is located along Pigdon Street (east to west direction) and Drummond Street (north to south direction) contains 10 m wide approach islands. Bicycle lanes have been marked along Pigdon Street terminating at the roundabout holding lines. Since 2013 these bicycle lanes have been terminated on the approaches in close proximity to the roundabout with sharrow markings installed to encourage cyclists and motorists to share the approach lane. A similar treatment has been introduced to Drummond Street.

On-street parking is permitted on both sides of all of the approach roads.

The crashes are predominantly adjacent direction type crashes, with three involving vehicles travelling in an easterly direction and two with vehicles travelling in a northerly direction.

Contributing factors

Some possible contributing factors to adjacent direction type crashes are restricted sight distances and high approach speeds (Austroads 2015c).

Sight distance

The sight distance available for drivers from the western approach to a vehicle on the northern approach is 35 m, which is less than the distances to meet Criterion 2 in AGRD Part 4B for a driver observing an approaching vehicle or a circulating vehicle prior to entering the roundabout. The sight distance available for drivers from the southern approach along the eastern approach is 38 m which is also less than the distance required to meet Criterion 2.

From the observations at the site, the sight distance is interrupted by street sign poles and power poles. These poles do not prevent approaching vehicles from being observed but cause some interruption to the view. The surrounding development provides solid fences or walls or vegetated gardens that block sight lines across adjacent private property. The sight lines for Criterion 3 are obstructed by this development and this criterion is not met. However, it is noted that Criterion 3 sight distance is not mandatory and based on research by Turner, Roozenburg and Smith (2009) and Campbell, Jurisich and Dunn (2012) the lack of sight distance may result in slower approach speeds.

Entry speed

The entry speeds for both the west to east and south to north directions, based on the vehicle travel paths, are estimated to be 42 km/h. This speed is higher than the target speed of 30 km/h for locations with vulnerable road users and should therefore be reduced to achieve the target speed.

Intersection conspicuity

The roundabout contains regulatory signs facing each approach. The signs are of standard size as commonly found in urban residential areas.

The central island is vegetated which restricts sight distance and although the vegetation would not obscure a vehicle, it would be harder to detect its presence. At the time of inspection the linemarking was in good condition.

The surrounding development creates a dark background, with deep shade along Drummond Street which decreases the visibility of cyclists on the northern approach.

Possible countermeasures

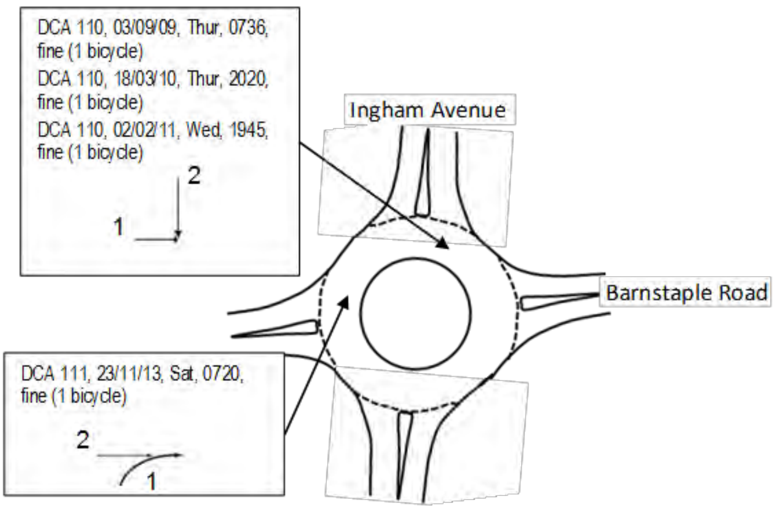
Improvements to sight distance would be difficult to achieve as it would require property acquisition. Removing or reducing the number of poles in the sight lines could be expected to assist drivers to detect approaching vehicles.

Reducing the speeds on the approaches would reduce the length of sight distance required by drivers and reduce the crash impact forces should a crash occur.

The approach speeds could be reduced by increasing the travel path curvature i.e. reducing the entry curve radius to 20 m. This would require the kerb returns to be extended into the travel lane and a straighter alignment to be provided into the roundabout, enabling a smaller curve to be incorporated without altering the central island. The design vehicle (e.g. service vehicle such as garbage collection vehicle) should be able to conveniently negotiate any changed layout.

Vertical displacement treatments, such as a flat-top road hump or cushion, placed just prior to the holding lines may also be a possible countermeasure. It is noted that a nearby location has had road cushions installed since 2013.

7.2.3 Barnstaple Road – Ingham Avenue, Five Dock

Location	Barnstaple Road – Ingham Avenue, Five Dock, New South Wales
Road classification	Local collector roads
Speed zone	50 km/h
Surrounding development	Residential
Description	Single-lane roundabout Circular central island, raised splitter islands on two approaches, south and west, painted on northern and eastern approaches, no directional signs on the central island Northern and southern approaches have an angled approach Central island offset from the centreline of the southern and northern approaches Central island planted, central tree with lower complementary vegetation approx. 1 m above pavement A bus route located along Barnstaple Road
Bicycle facilities	Bicycle symbols on approaches, variable spacing
On-street parking	Available on eastern approach (both sides in designated area)
Aerial map	 *Source: nearmap© (2016), 'NSW', map data, nearmap©, Sydney, NSW.*
Crash history	Five crashes involving cyclists
Crash diagram	 *Note: One crash reported as unknown.*

Location	Barnstaple Road – Ingham Avenue, Five Dock, New South Wales
Approaches	Straight approaches, kerb outstands located on north-eastern kerb return
Entry widths	Northern approach – 3.5 m Southern approach – 5 m Eastern approach – 4 m Western approach – 5 m
Kerb alignment	Straight
Inscribed circle diameter	26 m
Central island size	11.5 m diameter, encroachment area 1.7 m wide Bullnose present, chamfered edge
Circulating lane width	7.5 m all approaches
Exit lane width	Northern – 5 m Southern – 5 m Eastern – 4.5 m Western – 5 m
Exit kerb alignment	Straight
Entry path radius/curve speed	North to south direction: • ARNDT model – 36 km/h • Horizontal curve equation – 40 m radius, equates to a curve speed of 44 km/h (e = +0.03) West to East direction: • ARNDT model – 41 km/h
Circulating path radius/curve speed	North to south direction: • ARNDT model – 37 km/h • Horizontal curve equation – 30 m radius, equates to a curve speed of 40 km/h (e = –0.03)
Sight distance	Northern approach along the western approach: • For Criterion 2 – 55 m available • For an approach speed of 41 km/h sight distance required is 45 m (Table 3.1, AGRD Part 4B (Austroads 2015a)) 25 m available to circulating vehicle (limited due to central island vegetation), sight distance required is 16 m (circulating speed of 15 km/h, gap of 4 sec) For Criterion 3 northern approach: the western approach speed is 41 km/h which equates to a sight distance requirement of 45 m (Table 3.1, AGRD Part 4B, (Austroads 2015a) and the approach sight distance (absolute minimum) on the northern approach for a speed of 36 km/h is 26 m (Equation 1, AGRD Part 4A (Austroads 2010)

Notes:

Criterion 2 refers to the sight distance available to a driver of a vehicle located at the holding line to vehicles approaching from the right or travelling on the circulating lanes.

Criterion 3 refers to the ability of a driver approaching the roundabout to observe other entering vehicles before that vehicle reaches the holding lines.

For Criterion 3, the absolute minimum sight distance is based on a reaction time of 1.5 sec and a coefficient of deceleration of 0.46 (AGRD Part 4A (Austroads 2010)).

The side friction value used for the curve speed estimation is 0.35, per Table 7.4 AGRD Part 3 (Austroads 2016a).

Discussion

This roundabout is located in a residential area on two-lane two-way roads in a 50 km/h speed zone. The road pavements are 11 m to 14 m wide with parking permitted on both sides of the road to within 20 m of the holding lines of the roundabout. Bicycle symbols have been marked along both roads as a shared lane. A separate parking lane is provided on Barnstaple Road (eastern approach) and Ingham Avenue (southern approach) and a bus route is located along Barnstaple Road.

The approach grades are straight and do not restrict a drivers view of the intersection.

The roadside areas contain footpaths along the property lines and nature strips are grassed. High property boundary fences have been placed along each property at the intersection, with the exception of the south-western corner where there is an unfenced local park.

The crashes are predominantly adjacent direction type crashes, occurring at the northern entry and involving cyclists travelling in an eastbound direction and cars travelling in a southbound direction.

Contributing factors

Some possible contributing factors to adjacent direction type crashes are restricted sight distances and high approach speeds (Austroads 2015c).

Sight distance

The sight distance available from both the northern and western approaches is 55 m which is greater than the distance required to meet Criterion 2 in AGRD Part 4B (Austroads 2015a).

For Criterion 3 (northern approach) the absolute minimum approach sight distance of 26 m and an approach sight distance of 45 m along the approaches and the sight line to meet this criterion is blocked by the abutting development. The requirements for Criterion 3 are not met.

Entry speed

The entry speeds based on the vehicle travel path are estimated to be 36 km/h. This speed range is higher than the target speed of 30 km/h speed for locations with vulnerable road users.

Intersection conspicuity

The central island has been planted with grasses and a tree. The grasses provide some restriction to the visibility of vehicles across the central island. The splitter islands are raised on the northern and western approaches, and have a flush finish on the other two approaches.

The roundabout contains the regulatory signs facing each approach. The signs are of standard size as commonly found in urban residential areas.

Possible countermeasures

The sight distance exceeds the requirements for Criterion 2, but does not meet the requirements to meet Criterion 3. A reduction in the approach speeds to 25 km/h would be needed to meet the requirements of Criterion 3.

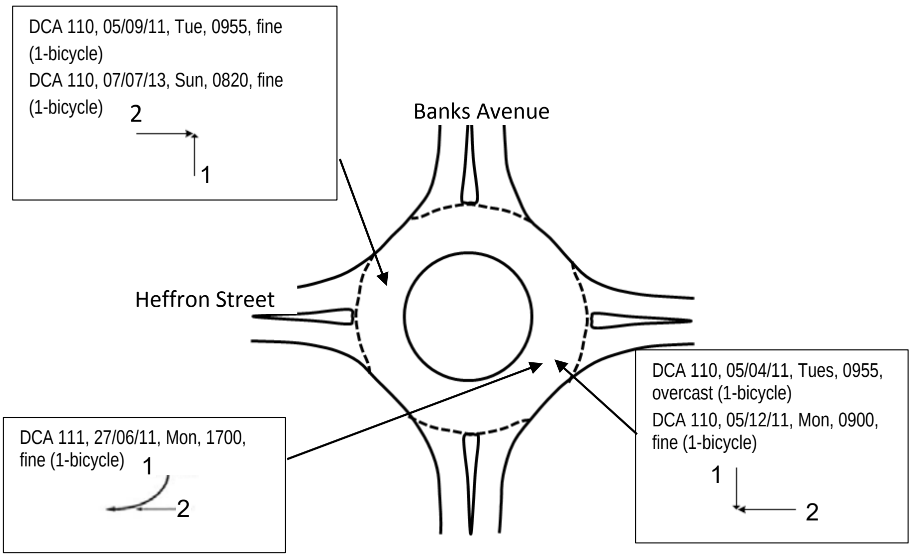
Countermeasures to reduce the approach speeds are to increase the travel path curvature by:

- reducing the entry path radius by extending the kerb along the western approach of Barnstaple Road and straightening the approach alignment with a further requirement for the splitter island to be altered to provide a straighter approach
- reducing the inscribed circle diameter and the left-turn kerb returns, which could be extended into the intersection pavement to coincide with a reduced inscribed circle
- increasing the central island diameter, whilst still catering for buses
- narrowing the entry width by extending the kerbs into the pavement.

Vertical displacement treatments, such as a road cushion or flat-top road hump, placed just prior to the holding lines may also be a possible countermeasure, particularly for the northern approach where the majority of bicycle crashes have occurred. However the use of a flat-top road hump may not be acceptable because of the bus route along Barnstaple Road (e.g. passenger comfort) and a road cushion may not be as effective in slowing vehicles as a flat-top road hump.

The conspicuity of the roundabout is enhanced by the presence of the central island planting and could be improved with the placement of directional signs.

7.2.4 Heffron Road – Banks Avenue, Pagewood

Location	Heffron Road – Banks Street, Pagewood, New South Wales
Road classification	Local collector roads
Speed zone	50 km/h
Surrounding development	Mix of industrial and residential
Description	Roundabout has two lanes in north-south direction and a wide single lane in east-west direction Circular central island, splitter islands on all approaches Central island on centreline of east-west direction; northern approach offset 5 m (to east) from southern approach Central island vegetated, vegetation approx. 1 m above pavement A bus route operates through the roundabout
Bicycle facilities	Bicycle lane east-west road terminating prior to holding lines
On-street parking	Available within 15 m of the intersection
Aerial map	 *Source: nearmap© (2015), 'NSW', map data, nearmap©, Sydney, NSW.*
Crash history	Five crashes involving cyclists
Crash diagram	

Location	Heffron Road – Banks Street, Pagewood, New South Wales
Approaches	Straight approaches, kerb outstands located on east-west direction Northern approach – flat-top road hump 25 m prior to holding line Western approach – flat-top hump pedestrian crossing 80 m prior to holding line
Entry widths	Northern approach: • inner lane – 3.5 m • outer lane – 3.5 m Southern approach: • inner lane – 3.5 m • outer lane – 3.5 m Eastern approach – 3.5 m Western approach – 4 m
Kerb alignment	Straight
Inscribed circle diameter	40 m
Central island size	19 m diameter, encroachment area 1.5 m wide Bullnose present, chamfered edge
Circulating lane width	North-south (Banks Avenue): • inner lane – 5 m • outer lane – 5 m East-west (Heffron Road) – 10 m
Exit lane width	North: • inner lane – 3.5 m • outer lane – 4.5 m South: • inner lane – 3.5 m • outer lane – 3.5 m East: 5 m (taper) West: 5 m (taper)
Exit kerb alignment	Straight
Entry path radius/curve speed	East to west direction: • ARNDT model – 45 km/h • Horizontal curve equation – 50 m radius, equates to a curve speed of 46 km/h (e = +0.03) • West to east the same as east to west direction North to south direction: • ARNDT model – 45 km/h
Circulating path radius/curve speed	East to west: direction • ARNDT model – 38 km/h • Horizontal curve equation – 40 m radius, equates to a curve speed of 40 km/h (e = –0.03) North to south direction path replicates south to north direction path The north-south travel path is the same as the east to west direction
Sight distance	Western approach along the southern approach: • For Criterion 2 – 37 m available • For an approach speed of 45 km/h, sight distance required is 50 m (Table 3.1, AGRD Part 4B (Austroads 2015a)) For Criterion 3 western approach, the southern approach speed is 45 km/h which equates to a sight distance requirement of 50 m (Table 3.1, AGRD Part 4B) and the approach sight distance on the western approach for a speed of 45 km/h is 36 m (Equation 1, AGRD Part 4A (Austroads 2010)

Location	Heffron Road – Banks Street, Pagewood, New South Wales
Sight distance	Eastern approach along northern approach: • For Criterion 2 – 60 m is available • For approach speed of 45 km/h, sight distance required is 50 m, Table 3.1, (AGRD Part 4B) For Criterion 3 eastern approach: the northern approach speed is 45 km/h which equates to a sight distance of 50 m and the approach sight distance (absolute minimum) on the eastern approach for a speed of 45 km/h is 36 m (Equation 1, AGRD Part 4A)

Notes:

Criterion 2 refers to the sight distance available to a driver to vehicles approaching from the right or travelling on the circulating lanes.

Criterion 3 refers to the ability of a driver approaching the roundabout to observe other entering vehicles before that vehicle reaches the holding lines.

For Criterion 3, the absolute minimum sight distance is based on a reaction time of 1.5 sec and a coefficient of deceleration of 0.46 (AGRD Part 4A (Austroads 2010)).

The side friction value used for the curve speed estimation is 0.35, per Table 7.4 AGRD Part 3 (Austroads 2016a).

Discussion

This roundabout is located in a residential/industrial area with 50 km/h speed zones. The roundabout has a two-lane approach on Banks Avenue (north-south) and a single-lane approach on Heffron Road (east-west). A golf course is located along the western side of Banks Avenue on both sides of Heffron Road. A wombat crossing is located on Heffron Road, on the western approach, 80 m prior to the holding lines, connecting the parts of the golf course. A flat-top hump has been constructed on Banks Avenue, northern approach, 25 m prior to the holding lines.

The roundabout provides a tangential alignment of the approaches. The central island is circular and located on the centreline of the approach roads. Due to the circular shape of the central island, the circulating lanes along the Heffron Road alignment through the roundabout are very wide (9.5 m). Kerb outstands have been provided in Heffron Road on the approaches to the roundabout and these contain low, densely planted vegetation.

Heffron Road contains a parking lane and bicycle lane, separated by a broken line. The bicycle lane ends just prior to the holding lines.

The roadsides are relatively wide and contain footpaths along the property lines with grassed nature strips, intermittently planted small trees and widely spaced power poles and traffic signs. The properties on the southern side of Heffron Road have high solid boundary fences.

The crashes are predominantly adjacent direction type crashes, involving vehicles travelling along Heffron Road (both directions) colliding with cyclists travelling along Banks Avenue (both directions).

Contributing factors

Some possible contributing factors to adjacent direction type crashes are restricted sight distances and high approach speeds (Austroads 2015c).

Sight distance

The sight distance available from the western approach in Heffron Road to the south is lower than the distance to meet Criterion 2 in AGRD Part 4B (Austroads 2015a).

The sight distance available from the eastern approach exceeds the distance required to meet Criterion 2. For Criterion 3 (western approach) the absolute minimum approach sight distance is 36 m and the approach sight distance is 50 m. The sight line to meet Criterion 3 is restricted by abutting development and so this criterion is not met.

Entry speed

The entry speeds are estimated to be 46 km/h. These speeds are higher than the target speed of 30 km/h speed for locations with vulnerable road users.

Intersection conspicuity

The central island has been planted with vegetation that is approximately 1.5 m above the pavement. The vegetation causes some restriction to the visibility of vehicles across the central island. The vegetation assists in identifying the presence of the central island, but obstructs the visibility to some vehicles on the circulating carriageway. The approaches are provided with linemarking, which was in good condition at the time of inspection.

The roundabout contains the regulatory signs facing each approach. The signs are of standard size signs as commonly found in urban residential areas.

Possible countermeasures

Sight distance from the western approach is less than the distance required to meet Criterion 2 and the solid boundary fence limits the available sight distance. Sight distance from the east is adequate. To meet the sight distance requirement for Criterion 3, approach speeds need to be reduced to less than 30 km/h.

Whilst the sight distance is less than the distance required for vehicle approach speeds, the issue seems to be that drivers entering the roundabout are failing to detect cyclists. Possible countermeasures would be aimed at reducing the crash impacts, i.e. reducing the vehicle speeds, particularly on the western and eastern approaches.

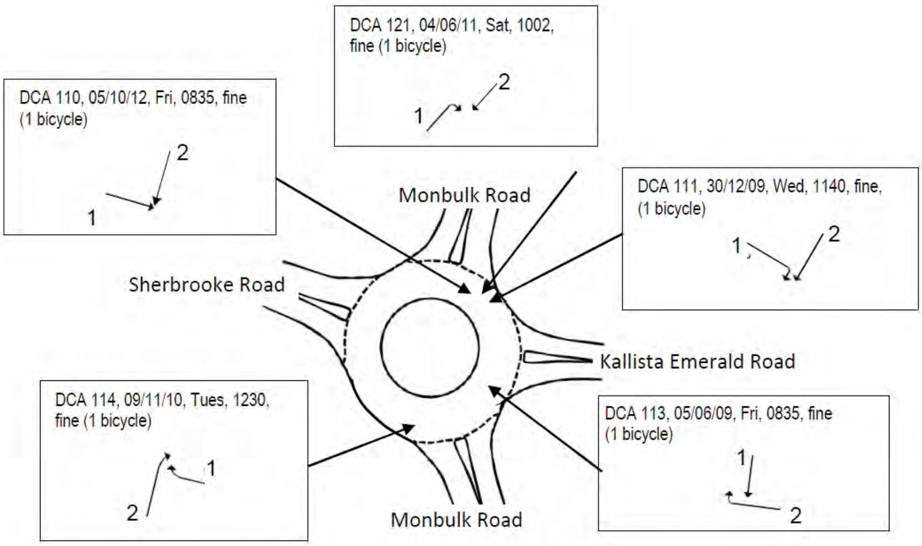
Countermeasures to reduce the approach speeds should be to increase the travel path curvature by reducing the entry path radius, widening of the kerb extensions on the Heffron Road approaches and straightening the approach alignment and offsetting it further from the centre of the central island towards the exit lane. The splitter islands would need to be realigned to provide a straighter approach, i.e. a radial-type approach.

The central island could be extended in a north-south direction, creating an oblong shaped island. This would reduce the radii of the travel path curves and therefore slow the vehicle speeds. Buses would need to be able to continue travelling through the roundabout and since the existing lane is very wide in the north-south direction, the extension of the central island would still cater for buses. Increasing the curvature where there are two circulating lanes may increase side-swipe crashes as motor vehicles drivers need to negotiate smaller radii curves. The roundabout could be converted to a single-lane roundabout, subject to other matters such as meeting the capacity requirements.

Vertical displacement treatments, such as flat-road humps or cushions, to cater for the bus route, placed just prior to the holding lines may also be a possible countermeasure.

The conspicuity of the roundabout is enhanced by the presence of the central island vegetation and could still be improved by the placement of directional signs. The plantings however, should not restrict the sight distance to vehicles on the circulating carriageway.

7.2.5 Monbulk Road – Kallista-Emerald Road, Kallista

Location	Monbulk Road – Kallista-Emerald Road, Kallista, Victoria
Road classification	Arterial road-local road
Speed zone	50 km/h
Surrounding development	Rural gateway to Kallista village. National park on western boundary
Description	Single-lane roundabout with encroachment area Circular central island, located on centrelines of approach roads Central island vegetated, vegetation approx. 1.8 m above pavement The north-eastern corner contains large trees that restrict the sight distance from the eastern approach The roundabout is located on a general plane falling from the north-east to the south-west direction
Bicycle facilities	Nil
On-street parking	Not permitted within 20 m of holding lines
Aerial map	 *Source: nearmap© (2015), 'VIC', map data, nearmap©, Sydney, NSW.*
Crash history	Five crashes involving cyclists
Crash diagram	

Location	Monbulk Road – Kallista-Emerald Road, Kallista, Victoria
Approaches	Straight approaches
Entry widths	Northern approach – 5.5 m Southern approach – 5 m Eastern approach – 4.5 m. South-eastern approach – 4 m
Kerb alignment	Straight
Inscribed circle diameter	30 m
Central island size	18.0 m diameter Encroachment area 1.5 m wide Bullnose present, rounded edge
Circulating lane width	5 m – 7.5 m
Exit lane width	North-western approach – 6 m Southern approach – 7.5 m North-eastern approach – 5 m South-eastern approach – 4.5 m
Exit kerb alignment	Straight
Entry path radius/curve speed	North-eastern to southern direction: • ARNDT model – 39 km/h • Horizontal curve equation – 40 m radius, equates to a curve speed of 44 km/h (e = +0.03) Northern approach speed: • ARNDT model – 45 km/h Eastern approach speed: • ARNDT model – 39 km/h
Circulating path radius/curve speed	North-eastern to southern direction: • ARNDT model – 39 km/h • Horizontal curve equation – 35 m radius, equates to a curve speed of 38 km/h (e = –0.03)
Sight distance	North-eastern approach along north-western approach: • For Criterion 2 – 35 m available, some restriction due to roadside tree and off-street car park • For an approach speed of 45 km/h, sight distance required is 50 m (Table 3.1, AGRD Part 4B (Austroads 2015a)) 25 m available to circulating vehicle (central island vegetation) For Criterion 3 north-eastern approach: the northern approach speed is 45 km/h which equates to a sight distance requirement of 50 m (Table 3.1, AGRD Part 4B) and the approach sight distance (absolute minimum) on the north-eastern approach for a speed of 39 km/h is 29 m (Equation 1 of AGRD Part 4A, Austroads 2010)
Sight distance	Eastern approach along the north-eastern approach: • For Criterion 2 – 28 m is available, restricted by a pedestrian fence • For an approach speed of 39 km/h, sight distance required is 43 m (Table 3.1, AGRD Part 4B)
Sight distance	South approach to a circulating vehicle – 25 m available (restricted by the central island vegetation)

Notes:

Criterion 2 refers to the sight distance available to a driver of a vehicle located at the holding line to vehicles approaching from the right or travelling on the circulating lanes.

Criterion 3 refers to the ability of a driver approaching the roundabout to observe other entering vehicles before that vehicle reaches the holding lines.

For Criterion 3, the absolute minimum sight distance is based on a reaction time of 1.5 sec and a coefficient of deceleration of 0.46 (AGRD Part 4A (Austroads 2010)).

The side friction value used for the curve speed estimation is 0.35, per Table 7.4 AGRD Part 3 (Austroads 2016a).

Discussion

This roundabout is located at a gateway to a small rural retail centre, with a national park on the western side of the roundabout and schools nearby. It is a single-lane roundabout with four approaches that are closely spaced except for the western side, adjacent to the national park. The approaches are generally straight with the splitter islands providing a nominal flaring to guide vehicles into the circulating lane. The central island is heavily vegetated, with vegetation 1.5 m high.

Trees abound in the area and there are two significant trees located on the nature strip at the north-eastern corner. The roundabout is located on routes that are very popular for recreational cycling.

There is a long straight downhill approach from Sherbrooke Road (north-western approach). Monbulk Road on the southern approach provides a straight uphill approach and the remaining two approaches descend to the roundabout.

There have been five crashes at this roundabout with three of the crashes involving vehicles travelling from Monbulk Road (north-eastern approach) colliding with cyclists travelling across the entry. One crash occurred at the Kallista Road-Emerald Road (eastern) approach and involved a vehicle entering the roundabout colliding with a cyclist travelling from the northern approach. One crash occurred involving a vehicle entering from the southern approach colliding with a cyclist crossing the entry.

Contributing factors

The crashes could be considered as adjacent direction type crashes as the roundabout operates like a series of T-intersections and some possible contributing factors to these type crashes are restricted sight distances and high approach speeds (Austroads 2015c).

Sight distance

The sight distance available from Monbulk Road (north-eastern approach) to Sherbrooke Road (northern approach) is 35 m which is less than the distance of 50 m required to meet Criterion 2 in AGRD Part 4B (Austroads 2015a). This is based on the estimated curve speeds of the vehicle entry path being 45 km/h. For Criterion 3 (north-eastern approach) the approach speeds require an absolute minimum approach sight distance of 29 m and an approach sight distance of 50 m. The sight line to meet this criterion is restricted by abutting development and so this criterion is not met.

The sight distance from eastern approach (Kallista-Emerald Road) to vehicles approaching from the north-eastern approach (Monbulk Road) is less than the distance to meet Criterion 2 in AGRD Part 4B.

Entry speed

The entry speeds from Monbulk Road north-eastern approach based on the curves along the vehicle travel path, are estimated to be 39 km/h. The circulating lane speed on the north-east to south direction is also 39 km/h.

The eastern approach (Kallista-Emerald Road) provides a straight approach and is positioned in a similar manner to a T-intersection. This alignment would affect the approach speeds to the roundabout. The entry speed is higher than the target speed of 30 km/h speed for locations where cyclists and pedestrians mix with motor vehicles.

Intersection conspicuity

The central island has been planted with vegetation that was 1.5 m above the pavement at the time of the site inspection. The vegetation restricts visibility of vehicles across the central island. The vegetation does however, assist in identifying the presence of the central island. The approaches are provided with linemarking, which was in good condition at the time of inspection.

The roundabout contains regulatory signs facing each approach. The signs are of standard size found in a rural gateway area.

Possible countermeasures

The sight distance from the north-eastern approach to the north-western approach is restricted by significant trees located on the nature strip at the north-eastern corner of the intersection. Removal of these significant trees would improve the sight distance, however, in this location preservation of trees is considered very important and removal of these significant trees would be problematic.

Reducing the vehicle entry speeds from the north-eastern approach (Monbulk Road) would be required to assist in reducing the number and severity of crashes involving cyclists. This would also reduce the sight distance required by drivers on this approach.

The sight distance from the eastern approach (Kallista-Emerald Road) is restricted by pedestrian fencing, which has been installed at the top of a steep batter between the footpath and the kerb.

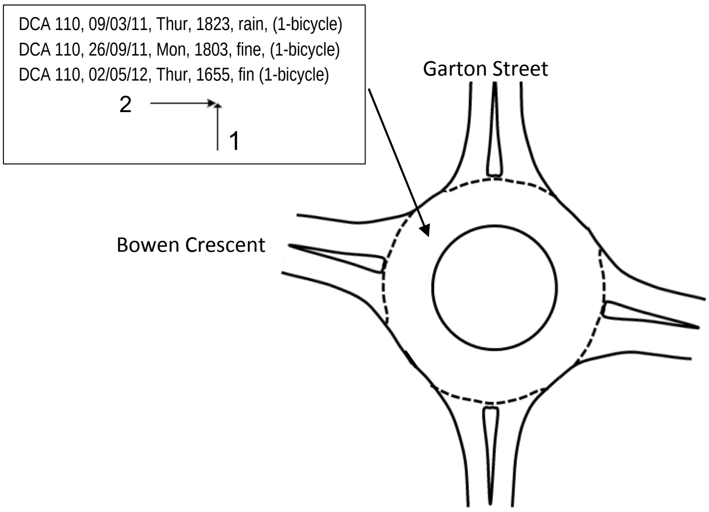
Countermeasures to reduce the approach speeds on the north-eastern approach could be achieved by increasing the travel path curvature. This could be achieved by realigning the entry to provide a straighter approach by extending the kerb at the entry and providing a splitter island. This would slow the speed of the entering vehicles and provide a small improvement to the sight distance from the eastern approach.

7.2.6 Bowen Crescent – Garton Street, Carlton

<table>
<tr><th>Location</th><th>Bowen Crescent – Garton Street, Carlton, Victoria</th></tr>
<tr><td>Road classification</td><td>Local collector roads</td></tr>
<tr><td>Speed zone</td><td>50 km/h</td></tr>
<tr><td>Surrounding development</td><td>Residential on northern and eastern sides of the intersection, recreational park on south-western corner</td></tr>
<tr><td>Description</td><td>Single-lane roundabout kerb edge
Central island located centrally within the intersection
Eastern and western approaches at approximately 65º to intersecting road
Central island contains a large tree with mulch surrounds
Road humps are located prior to the holding line:
• 30 m on southern approach
• 45 m on western approach</td></tr>
<tr><td>Bicycle facilities</td><td>Parking/bicycle lanes on three approaches (northern, eastern, western) with bicycle lanes ending at the holding lines and no bicycle lane marked on southern approach
Bicycle lane commence at the holding lines on northern exit</td></tr>
<tr><td>On-street parking</td><td>Parking in marked on-street parking bays on all approaches, 10 m from holding lines</td></tr>
<tr><td>Aerial map</td><td>

Source: nearmap© (2015), 'VIC', map data, nearmap©, Sydney, NSW.

</td></tr>
<tr><td>Crash history</td><td>Four crashes involving cyclists</td></tr>
<tr><td>Crash diagram</td><td>



</td></tr>
</table>

Location	Bowen Crescent – Garton Street, Carlton, Victoria
	Note: One crash reported as unknown.
Approaches	Straight approaches
Entry widths	Northern approach – 3 m, plus 2 m bicycle lane Southern approach – 4 m Eastern approach – 3 m, plus 2 m bicycle lane Western approach – 3 m, plus 1 m bicycle lane (at holding line, tapering from 2 m)
Kerb alignment	Straight
Inscribed circle diameter	20 m
Central island size	11 m diameter Kerb with rounded edge
Circulating lane width	4 m – 5 m
Exit lane width	Northern approach – 3.5 m, plus 2 m bicycle lane Southern approach – 7 m Eastern approach – 4 m plus 1.5 m bicycle lane Western approach – 6 m
Exit kerb alignment	Straight
Entry path radius/curve speed	West to east direction: • ARNDT model – 39 km/h • Horizontal curve equation – 50 m radius equates to a curve speed of 49 km/h (e = +0.03) South to north direction: • ARNDT model – 38 km/h
Circulating path radius/curve speed	West to east direction: • ARNDT model – 32 km/h • Horizontal curve equation – radius – 30 m, equates to a curve speed of 35 km/h (e = –0.03)
Sight distance	Western approach along southern approach: • For Criterion 2 – 30 m available, some restriction due to on-street car parking • For an approach speed of 38 km/h, sight distance required is 41 m (Table 3.1, AGRD Part 4B (Austroads 2015a)) 25 m to circulating vehicle (central island vegetation) For Criterion 3 western approach: the southern approach speed is 38 km/h which equates to a sight distance requirement of 41 m (Table 3.1, AGRD Part 4B) and the approach sight distance (absolute minimum) on the western approach for a speed of 39 km/h is 29 m, (Equation 1, of AGRD Part 4A (Austroads 2010))

Notes:

Criterion 2 refers to the sight distance available to a driver of a vehicle located at the holding line to vehicles approaching from the right or travelling on the circulating lanes.

Criterion 3 refers to the ability of a driver approaching the roundabout to observe other entering vehicles before that vehicle reaches the holding lines.

For Criterion 3, the absolute minimum sight distance is based on a reaction time of 1.5 sec and a coefficient of deceleration of 0.46 (AGRD Part 4A (Austroads 2010)).

The side friction value used for the curve speed estimation is 0.35, per Table 7.4 AGRD Part 3 (Austroads 2016a).

Discussion

This roundabout is located in an urban area with a major sporting recreational area on the south-western corner of the intersection. It is a single-lane roundabout with the central island located on the centrelines of the approach roads. The east-west direction alignment (Bowen Crescent) provides an angled approach to the central island.

The central island contains low grasses and a large tree located towards the centre of the island. Garton Street (north-south alignment) contains a narrow (2.5 m wide) median. Road humps are located in Bowen Crescent (western approach) approximately 40 m from the holding lines and on the southern approach of Garton Street, approximately 25 m from the holding lines.

All approaches have relatively flat grades.

The crashes are predominantly adjacent direction type involving vehicles travelling from the western approach colliding with cyclists travelling in a northbound direction.

Contributing factors

Some possible contributing factors to adjacent direction type crashes are restricted sight distances and high approach speeds (Austroads 2015c).

Sight distance

The sight line for Criterion 2 passes through on-street parking bays and when vehicles are present, there is 30 m sight distance available for drivers from the western approach to the south, which is less than the distance of 41 m required to meet Criterion 2 based on the estimated curve entry speed of 38 km/h. It should be noted that the approach speeds may also be influenced by the road hump located prior to the holding lines however this is unclear as measured approach speeds are not available. For Criterion 3 (western approach) the absolute minimum approach sight distance is 29 m and the approach sight distance is 41 m. The sight line passes through on-street parking bays on the southern approach and when there are no vehicle present Criterion 3 is met. When vehicles occupy the parking bays the sight line to meet Criterion 3 is obstructed by these vehicles.

The location of the bicycle lane on the northern exit may influence the cyclists travelling along Garton Street to keep to the left of the available lane space which would place them on the outer edge of the circulating lane. This may place them on the perimeter of driver's vision on Bowen Crescent, consequently, the drivers on the western approach may fail to see the cyclists.

Entry speed

The entry curves on the western approach on Bowen Crescent cater for entry speeds that are greater than the 30 km/h target speed. It would be reasonable to assume that the higher entry speeds would be contributing to the likelihood of crashes because drivers would have less time to detect the presence of a cyclist on the roundabout, and such speeds would increase the severity of a crash.

Intersection conspicuity

Visibility to the central island is adequate and assisted by the vegetation and tree planted in the island.

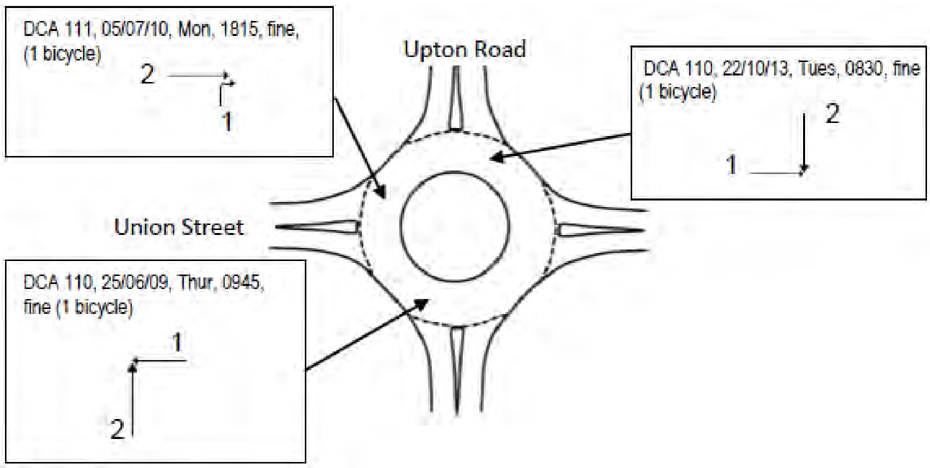
Standard size regulatory signs have been installed and placed to be clear of any street trees.

Possible countermeasures

The entry speeds from the western approach could be reduced by decreasing the entry path radius, providing a straighter approach, extending the northern kerb to ensure vehicles follow the design path and increasing the central island by elongating it to the north along Garton Street. This would increase the curvature on the travel path for vehicles entering from Bowen Crescent (western approach). The bicycle lane would need to be terminated prior to the holding line to achieve the entry path radius.

The southern entry on Garton Street could be narrowed by extending the western kerb to reduce the entry width providing a narrower area for drivers from the east to observe any approaching vehicles.

7.2.7 Union Street – Upton Road, Windsor

Location	Union Street – Upton Road, Windsor, Victoria
Road classification	Local roads
Speed zone	40 km/h
Surrounding development	Residential
Description	Single-lane roundabout with encroachment area Circular central island, located on centrelines of approach roads Central island vegetated, central tree with lower complementary vegetation approx. 1 m above pavement. Bluestone border edging on landscape area Small walls, 0.5 m high located on south-eastern and south-western kerb returns
Bicycle facilities	Nil
On-street parking	Available on all approaches, within 10 m of intersecting kerb line
Aerial map	 *Source: nearmap© (2014), 'VIC', map data, nearmap©, Sydney, NSW.*
Crash history	Three crashes involving cyclists
Crash diagram	

Location	Union Street – Upton Road, Windsor, Victoria
Approaches	Straight approaches
Entry widths	Northern approach – 4.5 m Southern approach – 4.5 m, approach lane 3 m Eastern approach – 4.5 m, approach lane 3 m Western approach – 4.5 m, approach lane 3 m
Kerb alignment	Straight
Inscribed circle diameter	16 m
Central island size	8 m diameter Encroachment area 1.5 m wide Bullnose present, rounded edge
Circulating lane width	4.5 m
Exit lane width	Northern – 4.5 m Southern – 4.5 m Eastern – 4.5 m Western – 4.5 m
Exit kerb alignment	Straight
Entry path radius/curve speed	ARNDT model – 34 km/h Horizontal curve equation: radius – 40 m, equates to a curve speed of 44 km/h (e = +0.03) Note: all approaches have the same geometry
Circulating path radius/curve speed	ARNDT model – 28 km/h West to east direction – 30 m, equates to a curve speed of 35 km/h (e = –0.03). East to west direction is the same as the west to east direction
Sight distance	Southern approach along eastern approach: For Criterion 2 – 22 m available For an approach speed of 34 km/h, sight distance required is 37 m (Table 3.1, AGRD Part 4B (Austroads 2015a)) Vegetation on central island is 1.0 m high and allows circulating vehicles to be observed For Criterion 3 southern approach: the eastern approach speed is 34 km/h, which equates to a sight distance requirement of 37 m (Table 3.1, AGRD Part 4B) and on the southern approach, the sight distance (absolute minimum) for an approach speed of 34 km/h is 24 m (Equation 1, AGRD Part 4A (Austroads 2010))
Sight distance	Northern approach along western approach: For Criterion 2 – 29 m available For an approach speed of 34 km/h, sight distance required is 37 m (Table 3.1, AGRD Part 4B) For Criterion 3 northern approach: the western approach speed is 34 km/h, which equates to a sight distance requirement of 37 m (Table 3.1 AGRD Part 4A) and the sight distance (absolute minimum) on the northern approach, for an approach speed of 34 km/h is 24 m (Equation 1, AGRD Part 4A)

Notes:

Criterion 2 refers to the sight distance available to a driver of a vehicle located at the holding line to vehicles approaching from the right or travelling on the circulating lanes.

Criterion 3 refers to the ability of a driver approaching the roundabout to observe other entering vehicles before that vehicle reaches the holding lines.

For Criterion 3, the absolute minimum sight distance is based on a reaction time of 1.5 sec and a coefficient of deceleration of 0.46 (AGRD Part 4A (Austroads 2010)).

The side friction value used for the curve speed estimation is 0.35, per Table 7.4 AGRD Part 3 (Austroads 2016a).

Discussion

This roundabout is located in an urban residential area near a major retail precinct. Properties typically have high boundary fences that do not permit visibility across the boundaries. The central island is located on the centrelines of the approaches and the approaches are a radial-type.

The central island contains an encroachment area with the central part of the island vegetated and contained by a small wall. The left kerb returns are 4 m radius and the southern side contains small walls around the kerb return.

All approaches are straight and relatively flat.

Three crashes have occurred at different locations on the roundabout. The crashes have some commonality in that the vehicles were entering the roundabout and collided with cyclists in the roundabout. Two of these crashes involved vehicles travelling along Upton Road and the third crash involved a vehicle entering from Union Street, western approach, colliding with a cyclist undertaking a right turn.

Contributing factors

The roundabout is located in an area that has a significant amount of activity, mainly pedestrian movements, both along the streets and entering and leaving the parked cars, and vehicles entering and leaving the parking spaces.

The crashes were adjacent direction type crashes and some possible contributing factors are restricted sight distances and high approach speeds (Austroads 2015c).

Sight distance

The sight distance available from both the western and northern approaches is restricted by development on the properties at the intersection and so does not meet Criterion 2 or Criterion 3 in AGRD Part 4B (Austroads 2015a).

The available sight distance to meet the requirements of Criterion 2, vehicle speeds need to be reduced to 20 km/h to 25 km/h. To meet Criterion 3 requirements speeds would need to be reduced below 20 km/h.

The sight distance at this location is close to the United Kingdom guidance on restricting sight distance from 15 m prior to the holding line to assist in reducing excessive approach speeds.

Entry speed

Both Upton Road and Union Street provide parking on both sides of the road and this has the effect of narrowing the available road pavement, albeit still wide enough for vehicles to pass. This would influence the operating speed in the street, however, actual vehicle speeds are not available.

The estimated entry curve speed would permit speeds higher than the target speed of 30 km/h and consequently reducing the possible speeds may assist in reducing the severity and number of crashes.

Intersection conspicuity

Visibility to the central island is adequate on each approach and is accentuated by the raised planting in the central island and the presence of directional arrow boards facing each entry.

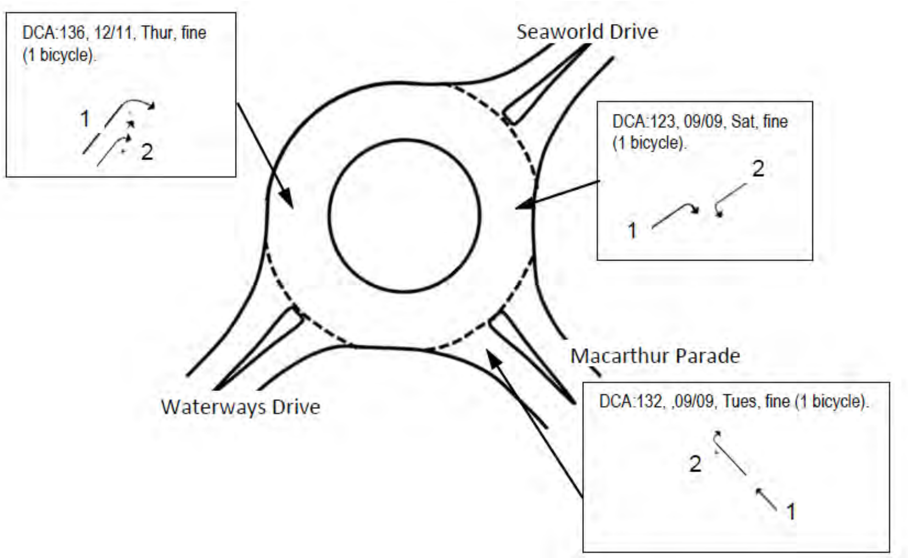
Possible countermeasures

Improvements to sight distances would require sight lines across the corners of the properties at the roundabout; however, this may be counterproductive if vehicle speeds increase with the increase in sight distance. Alternatively, the sight distance required could be reduced by reducing the approach speeds. This roundabout has a radial-type alignment, but operates in part similarly to a tangential-type roundabout, with the travel paths able to utilise the left side of the 4.5 m wide entry lane.

The entry curve radius could be reduced by extending the kerb to reduce the entry lane widths and create a tighter entry curve, requiring a slower entry speed. This would also result in the existing 4 m kerb return radii being increased to match the altered kerb alignments, but in this location these radii would still be in the order of 7 m and not expected to increase motor vehicle speeds through the roundabout.

In this location there is very little road space available to provide significant changes to travel paths and so flat-top road humps or road cushions on the approaches may be needed to provide the speed reduction.

7.2.8 Seaworld Drive – Waterways Drive, Main Beach

Location	Seaworld Drive – Waterways Drive, Main Beach, Queensland
Road classification	Local collector roads
Speed zone	60 km/h
Surrounding development	Residential on western side and yacht club on eastern side
Description	Multilane roundabout Approaches provide a tangential-type entry Central island is grassed with single tree and a streetlight pole
Bicycle facilities	Bicycle lanes on northern and eastern approaches, continuing through the roundabout, excluding the exit lanes No bicycle lane on western approach
On-street parking	Available on eastern approach at recreation ground
Aerial map	 *Source: nearmap© (2013), 'QLD', map data, nearmap©, Sydney, NSW.*
Crash history	Three crashes involving cyclists
Crash diagram	

Location	Seaworld Drive – Waterways Drive, Main Beach, Queensland
Approaches	Straight with a large entry curve
Entry widths	Northern approach: • inner lane – 3.3 m • outer lane – 3.4 m Bicycle lane – 1.5 m Eastern approach – 4.5 m Bicycle lane – 1 m Western approach: • inner lane – 3.7 m • outer lane – 3.5 m
Inscribed circle diameter	44 m
Central island size	25 m diameter Semi-mountable kerb edge
Circulating lanes width	North to west direction: • inner lane – 4 m • outer lane – 4.3 m Otherwise 6–8 m
Exit lane width	Northern approach: • inner lane – 4.5 m • outer lane – 4.5 m Eastern approach – 4.5 m Bicycle lane – 1.5 m Western approach: • inner lane – 3.5 m • outer lane – 3.5 m Bicycle lane – 1.5 m
Exit kerb alignment	Straight
Entry path radius/curve speed	West to north direction: ARNDT model – 52 km/h Horizontal curve equation – 40 m radius, equates to a curve speed of 44 km/h (e = +0.03)
Circulating path radius/curve speed	West to north direction: • ARNDT model – 31 km/h • Horizontal curve equation – 17 m radius, equates to a curve speed of 26 km/h (e = –0.03) Turning speeds are estimated to be 26 km/h (e = –0.03) North to west direction: • Circulating lane 17 m radius equates to a curve speed of 26 km/h (e = –0.03)
Exit path radius/curve speed	North to east direction: • Horizontal curve equation – 37 m radius equates to a curve speed of 42 km/h (e = +0.03)
Sight distance	East to north direction: • For Criterion 2 – >70 m available Unrestricted to circulating vehicle (grassed, flat central island)

Notes:

Criterion 2 refers to the sight distance available to a driver of a vehicle located at the holding line to vehicles approaching from the right or travelling on the circulating lanes.

Criterion 3 refers to the ability of a driver approaching the roundabout to observe other entering vehicles before that vehicle reaches the holding lines.

For Criterion 3, the absolute minimum sight distance is based on a reaction time of 1.5 sec and a coefficient of deceleration of 0.46 (AGRD Part 4A (Austroads 2010)).

The side friction value used for the curve speed estimation is 0.35, per Table 7.4 AGRD Part 3 (Austroads 2016a).

Discussion

This roundabout is located on local roads on the edge of a residential area providing important traffic routes that serve commercial and tourist developments.

The approaches have two lanes in the west to north direction (Waterways Drive – Seaworld Drive) and a single approach lane from the eastern direction (Macarthur Parade). The horizontal geometry consists of a straight alignment with a curved entry to establish the tangential-type entry to the roundabout.

The central island is large, 25 m diameter, and grassed with a single tree and a streetlight pole within the central island.

There have been three bicycle crashes reported; two of the crashes involved turning movements of both a vehicle and a bicycle and the third crash was a rear-end type crash in Macarthur Parade.

The bicycle lanes exist on the approaches and through the roundabout, and the cyclists travelling across an exit are required to give way to vehicles leaving the roundabout. Whilst the crash data does not indicate that this was a contributor to the crashes it does place cyclists in a vulnerable position when using the bicycle lane. A key finding in Austroads (2014a) was that at lower speed roundabouts there are safety disadvantages of riding to the left within a roundabout and so providing bicycle lanes should be avoided if the target speed of 30 km/h is achieved.

Contributing factors

The available sight distance from each approach exceeds the distances to meet Criterion 2 provided in AGRD Part 4B (Austroads 2015a). Sight distance is not considered a contributing factor to the types of crashes that have occurred.

Possible contributing factors for sideswipe crashes include narrow lane widths and poor delineation of lane lines. At this roundabout, the linemarking of the circulating lanes was in good condition at the time of the site inspection. With such a wide lane, there is opportunity for the motor vehicle to pass cyclists, even if the cyclist was in the middle of the lane. This crash may also indicate that a contributing factor is a differential in turning speeds between the motor vehicle and the cyclist.

Entry speeds

The entry speeds determined using the horizontal curve radius equation were estimated to be 44 km/h. This speed is higher than the 30 km/h target speed for the mixing of vehicles and cyclists/pedestrians.

The left turn from the north to east direction (Seaworld Drive into Macarthur Parade) has a 37 m curve radius that equates to a curve speed of 42 km/h which is also higher than the 30 km/h target speed. A bicycle lane has been provided from the northern approach to the eastern approach and the circulating lane is 9 m wide at this location.

Austroads (2014a) included some speed survey results at this roundabout (Table 7.1). The results reported were the average speeds but the report included speed profile graphs for all of the speeds recorded which indicated that speeds up to 40 km/h were recorded on the western approach and 42 km/h on the northern approach (Appendix C). These speeds are only slightly lower than the estimated speeds using the methods referred to in Section 7.1.

The direction that the vehicles took on leaving the roundabout was not reported and therefore this information only provides an indication of the speeds on the approach to this roundabout.

Table 7.1: Average approach speeds Waterways Drive/Seaworld Drive/Macarthur Parade

		Speed by distance from the holding line (km/h)			
	Approach	30 m	20 m	10 m	5 m
Waterways Drive	East	39.5	35.7	30.3	27.3
Seaworld Drive	North	41.4	37.5	33.0	31.8
Macarthur Parade	West	37.7	32.9	28.7	26.4

Source: Austroads (2014a).

Possible countermeasures

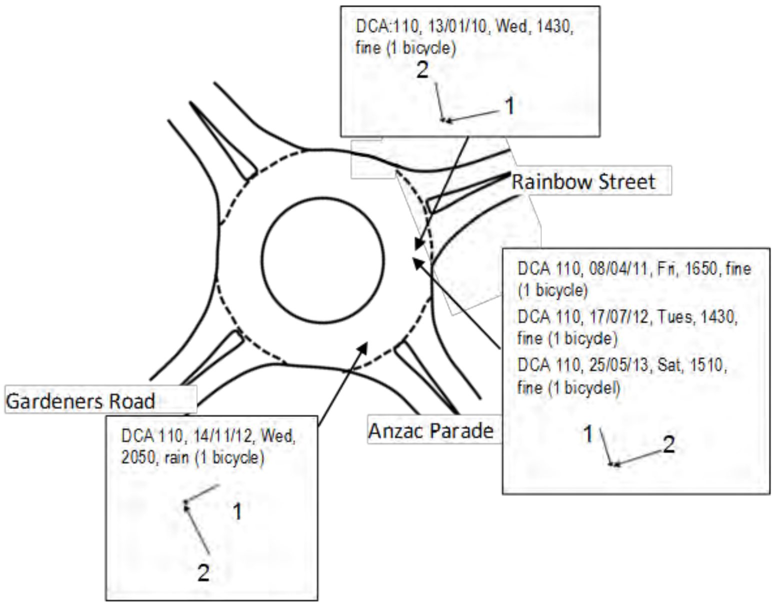
The method to eliminate sideswipe crashes would be to reduce the vehicle speeds on the roundabout, which could be achieved by increasing the curvature on the approach and travel path in the roundabout. This would require the entry to be reduced in width which would bring the motor vehicles and bicycles closer together.

Removing the bicycles from the circulating lanes would provide separation of the motor vehicles and bicycles. In this location an off-road bicycle path (track[2]) could be provided in the available space in the roadside area. However, an off-road bicycle path would require the crossing of approach and departure legs two lanes wide, resulting in a crossing distance of up to 9 m.

To encourage use of the path and manage the possible conflict at a crossing, priority to cyclists (and pedestrians) is needed. Priority could be established through the use of treatments such as a formal crossing, such as a signalised crossing, but would need to be located in such a way as to enable drivers to detect the crossing and stop if necessary. This may lengthen the off-road travel path distance and discourage its use.

2 A bicycle track is a term used in some jurisdictions for a bicycle-only path.

7.2.9 Anzac Parade – Rainbow Street, Kingsford

Location	Anzac Parade – Rainbow Street, Kingsford, New South Wales
Road classification	Arterial road/local collector road
Speed zone	60 km/h (Anzac Parade); 50 km/h (Rainbow Street)
Surrounding development	Commercial
Description	Two-lane roundabout in three directions with a single lane in the north to east direction, circular central island, two-lane entry on approach roads, median or splitter islands on approaches Bus routes through the roundabout from three approaches (northern, south-eastern and eastern)
Bicycle facilities	Nil
On-street parking	Rainbow Street – nil
Aerial map	 *Source: nearmap© (2015), 'NSW', map data, nearmap©, Sydney, NSW.*
Crash history	Six crashes involving cyclists
Crash diagram	
Approaches	Eastern – straight with curve at entry Northern – straight with curve at entry

Location	Anzac Parade – Rainbow Street, Kingsford, New South Wales
Entry width	Eastern approach: • inner lane – 5 m • outer lane – 4 m Northern approach: • inner lane – 4.5 m • outer lane – 4.5 m
Inscribed circle diameter	60 m
Central island size	42 m diameter, mountable kerb, grassed with central section vegetated
Splitter islands	Approach islands full concrete, bevel faces
Circulating lane width	North to south-east direction: • inner lane – 5.5 m • outer lane – 5.5 m East to south direction: • inner lane – 6 m • outer lane – 6.5 m
Exit lane width	Inner lane – 5.0 m Outer lane – 4.5 m
Exit kerb alignment	Straight
Entry path radius/curve speed	Eastern approach: • ARNDT model – 49 km/h • Horizontal curve equation – 40 m radius, equates to a curve speed of 44 km/h (e = +0.03) South-eastern approach: • ARNDT model – 54 km/h • Horizontal curve equation – 30 m radius, equates to a curve speed of 38 km/h (e = +0.03) Northern approach: • ARNDT model – 52 km/h • Horizontal curve equation – 30 m radius, equates to a curve speed of 38 km/h (e = +0.03)
Circulating path radius/curve speed	Northern approach to south-eastern approach: • ARNDT model – 39 km/h • Horizontal curve equation – 27 m radius, equates to a curve speed of 33 km/h (e = –0.03) East to south-west direction: • ARNDT model – 49 km/h • Horizontal curve equation – 50 m radius, equates to a design speed of 45 km/h (e = –0.03)
Sight distance	Eastern approach along northern approach: • For Criterion 2 – 80 m available • For an approach speed of 52 km/h the required sight distance is 57 m (Table 3.1, AGRD Part 4B (Austroads 2015a)) For Criterion 3, eastern approach: the northern approach speed is 52 km/h which equates to a sight distance requirement of 57 m and the approach sight distance (absolute minimum) on the eastern approach for a speed of 49 km/h is 41 m (Equation 1 of AGRD Part 4A (Austroads 2010))
Sight distance	South-eastern approach along eastern approach: • For Criterion 2 – 55 m is available • For an approach speed of 38 km/h, sight distance requirement is 42 m

Notes:
Criterion 2 refers to the sight distance available to a driver of a vehicle located at the holding line to vehicles approaching from the right or travelling on the circulating lanes.
Criterion 3 refers to the ability of a driver approaching the roundabout to observe other entering vehicles before that vehicle reaches the holding lines.
For Criterion 3, the absolute minimum sight distance is based on a reaction time of 1.5 sec and a coefficient of deceleration of 0.46 (AGRD Part 4A (Austroads 2010)).
The side friction value used for the curve speed estimation is 0.35, per Table 7.4 AGRD Part 3 (Austroads 2016a).

Discussion

During the analysis period a bus lane was constructed on the south-eastern approach and across the south-western approach to a service road. As a result this part of the roundabout has not been included in this analysis. As it is considered that the analysis of the crashes in the vicinity of Rainbow Street (eastern approach) may still provide some useful outcomes for this project this has been included.

The roundabout is located in a residential/commercial area with two-lane or three-lane entries, which is an indicator of the traffic volumes travelling though the roundabout. The speed zones differ on the approaches with Anzac Parade (south-eastern approach) being 60 km/h and Rainbow Street being 50 km/h. A left-turn slip lane is provided for vehicles from Rainbow Street.

Bicycle lanes or markings have not been provided on any of the approaches.

The crashes are predominantly adjacent direction type crashes with three of the crashes involving vehicles entering from the eastern approach and two crashes involving vehicles entering from the south-eastern approach.

Contributing factors

The crashes are adjacent direction type crashes and possible contributing factors to these type of crashes are restricted sight distances, high approach speeds and lack of driver awareness of the intersection (Austroads 2015c).

Sight distance

The sight distance available for drivers from the eastern approach (Rainbow Street) exceeds the distances required to meet Criterion 2 and Criterion 3 in AGRD Part 4B (Austroads 2015a). The alignment of the approach along Rainbow Street allows a clear view to vehicles entering from northern approach, and vehicles on the circulating lanes.

Sight distance from the southern approach (Anzac Parade) meets the requirements for Criterion 2.

Sight distance is not considered to be a contributing factor.

Entry speed

The entry curve speed from the eastern approach (Rainbow Street) is 49 km/h. The circulating speed on the eastern approach to south-western approach equates to a higher speed of 49 km/h. These speeds are higher than 30 km/h target speed for locations where there are vulnerable road users.

Possible countermeasures

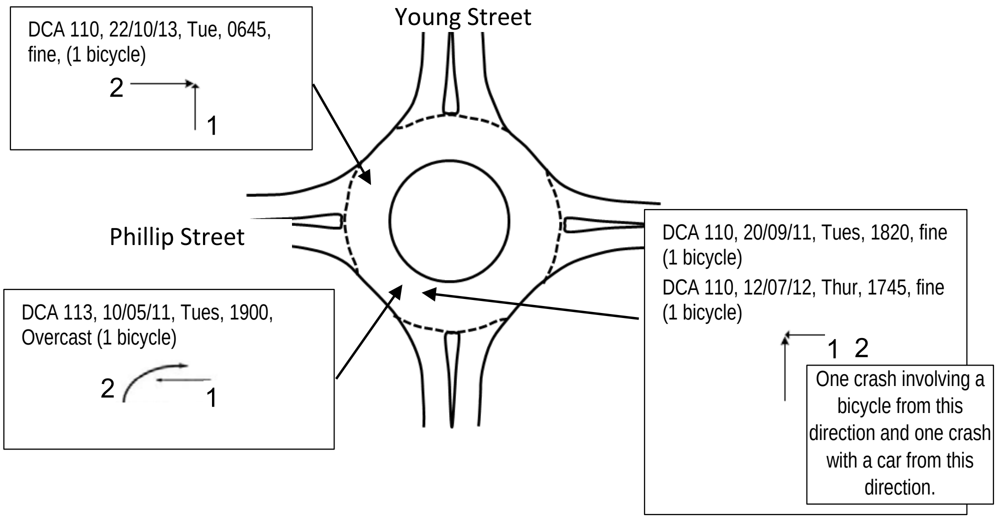
Sight distance improvements are not considered necessary as the available distances exceeds those required by AGRD Part 4B (Austroads 2015a).

The entry alignment straightened to a radial-type approach and the curve radius on the Rainbow Street (eastern) approach reduced to provide a smaller radius of 20 m, but this still results in vehicle entry speeds higher than 30 km/h. The central island could be extended along Anzac Parade in a southern direction and the circulating lanes reduced to enable a smaller entry curve radius being developed however, the entry speeds were found to be greater than 30 km/h.

An off-road bicycle path or more likely a shared path could be provided in this location. Crossing close to the roundabout could be undertaken across an exit for vehicles from Anzac Parade (northern approach) but this would create a conflict point where drivers may not expect a crossing. Driver expectation may be diminished at this location due to the presence of a signalised pedestrian crossing approximately 50 m further to the east on Rainbow Street. Providing a shared path to this crossing would be the preferred crossing point, but would result in a long travel path mixed with pedestrians. An off-road shared path in this location is unlikely to be used by cyclists due to the extra distance, slower speeds, delays at the signalised crossing and potential conflict with pedestrians.

A further possible non-geometric design treatment for this type of roundabout with would be to signalise the approach legs, providing a time-separation between the motor vehicles and cyclists.

7.2.10 Phillip Street – Young Street, Redfern

Location	Phillip Street – Young Street, Redfern, New South Wales
Road classification	Local collector roads
Speed zone	50 km/h
Surrounding development	Mix of commercial and residential
Description	Single-lane roundabout, circular central island, splitter islands on all approaches Central island on centreline of Young Street (north-south approaches) and on Phillip Street (eastern approach) The western approach on Phillip Street is offset 2.4 m to the south
Bicycle facilities	Young Street is a designated bicycle route
On-street parking	Available within 15 m of the intersection Bus route along Phillip Street with stops located within 10 m of intersection
Aerial map	 Source: nearmap© (2016), 'NSW', map data, nearmap©, Sydney, NSW.
Crash history	Four crashes involving cyclists
Crash diagram	

Location	Phillip Street – Young Street, Redfern, New South Wales
Approaches	Straight approaches, kerb outstands located east-west
Entry width	Northern approach – 5.2 m Southern approach – 4.8 m Eastern approach – 5.2 m Western approach – 4.2 m
Kerb alignment	Straight
Central island size	11 m diameter, encroachment area 3.7 m wide
Inscribed circle diameter	22 m
Circulating lane width	5.4 m
Exit lane width	5.4 m
Exit kerb alignment	Straight
Entry path radius/curve speed	South to north; west to east directions: ARNDT model – 44 km/h Horizontal curve equation – 40 m radius, equates to a curve speed of 35 km/h (e = +0.03)
Circulating path radius/curve speed	South to north; west to east directions: • ARNDT model – 35 km/h • Horizontal curve equation – 30 m radius, equates to a curve speed of 35 km/h (e = –0.03)
Sight distance	Southern approach along eastern approach: • For Criterion 2 – 28 m available when bus at stop; 34 m available when no bus at stop • For an approach speed of 44 km/h, sight distance required is 48 m (Table 3.1, AGRD Part 4B (Austroads 2015a)) For Criterion 3, southern approach: the eastern approach speed is 44 km/h which equates to a sight distance requirement of 48 m (Table 3.1, AGRD Part 4B) and the approach sight distance (absolute minimum) on the southern approach for a speed of 44 km/h is 35 m (Equation 1 AGRD Part 4A (Austroads 2010))
Sight distance	Western approach along southern approach: • For Criterion 2 – 25 m available • Table 3.1 AGRD Part 4B (Austroads 2015a): for approach speed of 44 km/h, sight distance of 48 m is required For Criterion 3, western approach: the southern approach speed of 44 km/h which equates to a sight distance requirement of 48 m and the approach sight distance (absolute minimum) on the western approach for a speed of 44 km/h is 35 m (Equation 1 AGRD Part 4A)

Notes:

Criterion 2 refers to the sight distance available to a driver of a vehicle located at the holding line to vehicles approaching from the right or travelling on the circulating lanes.

Criterion 3 refers to the ability of a driver approaching the roundabout to observe other entering vehicles before that vehicle reaches the holding lines.

For Criterion 3, the absolute minimum sight distance is based on a reaction time of 1.5 sec and a coefficient of deceleration of 0.46 (AGRD Part 4A (Austroads 2010)).

The side friction value used for the curve speed estimation is 0.35, per Table 7.4 AGRD Part 3 (Austroads 2016a).

Discussion

This roundabout is a single-lane roundabout, located in an urban residential/commercial area with a signalised intersection 70 m to the west along the western approach (Phillip Street). The western approach on Phillip Street is 3 m wider than the eastern approach and slightly offset to the south. The central island is located on the centrelines of the north-south road (Young Street) and the eastern approach on Phillip Street. Kerb outstands have been placed on the western approach to reduce the lanes widths to be similar to the eastern approach.

The central island has an encroachment area 3.7 m wide and a small central area that is slightly elevated above the road pavement and vegetated with small grasses and a single tree.

A bus service operates through the roundabout.

Four bicycle crashes have occurred at this roundabout with three of the crashes being at the southern entry (Young Street) and one crash occurring at the western entry (Phillip Street). Two crashes involved a vehicle travelling along Phillip Street (one in each direction) and two crashes involved vehicles entering from Young Street (southern approach).

Contributing factors

The contributing factors involving adjacent direction type crashes include restricted sight distances, high approach speeds and lack of awareness of the intersection (Austroads 2015c).

Sight distance

The sight distances are less than the distances necessary to meet the requirements for Criterion 2 and Criterion 3 from both the western approach and the southern approach.

In this inner urban location, opportunities to improve the sight distance are limited to ensuring the roadside areas provide a clear sight line along the approaching roads. In this location, street furniture or trees were not found to be restricting the sight line. The restrictions were due to property development up to the property boundaries.

On the southern approach, the sight lines are available from a point 15 m prior to the holding line for a distance of 25 m from a possible conflict point. This equates to approach speeds of 25 km/h and these distances are similar to the guidance contained in Department for Transport (2016) to assist in reducing excessive approach speeds.

Entry speeds

The entry curve speeds from both Phillip Street and Young Street are higher than the 30 km/h target speed for cases where vulnerable road users are present.

Possible countermeasures

At this location, improvements to sight distance would require property acquisition or moving the holding lines of the roundabout into the intersection, i.e. reducing the size of the central island. The effect of reducing the central island would be to decrease the curvature along the travel paths through the roundabout, which may increase vehicle speeds.

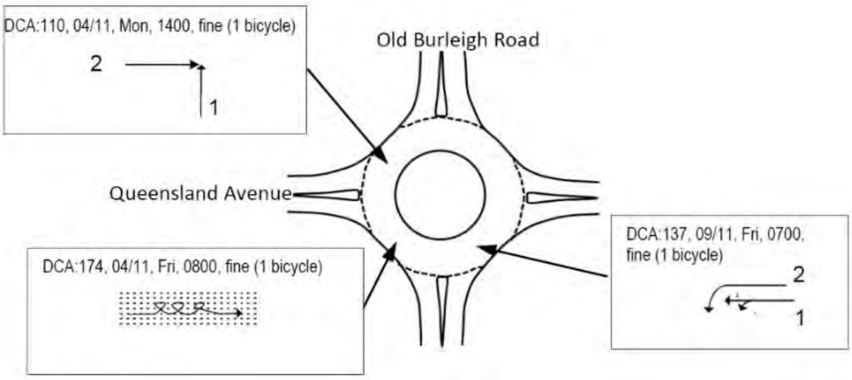
Reducing the approach speeds could be achieved by increasing the travel path curvature by reducing the curve radii along the travel path. There is opportunity to increase this curvature on the approaches by:

- straightening the approach and splitter islands
- extending the kerb lines into the road pavement space to reduce the approach lane widths.

These modifications would enable an entry curve radius of 20 m to 25 m to be achieved which would slow the entering vehicles to 30 km/h. However, the treatment would also have to provide for the convenient movement of the design vehicle for the intersection, including buses and service.

Other countermeasures to reduce approach speeds would be to narrow the lanes and provide flat-top road humps suitable for buses.

7.2.11 Old Burleigh Road – Queensland Avenue, Broadbeach

Location	Old Burleigh Road – Queensland Avenue, Broadbeach, Queensland
Road classification	Local roads
Speed zone	50 km/h
Surrounding development	High density residential areas on three sides and recreation park on one corner. Commercial precinct to the west of the intersection
Description	Single-lane roundabout, with centre island offset to the south from the centreline of the east-west directions Approaches provide a tangential-type entry Central island mounded approximately 1.0 m above pavement and low vegetation Approaches similar on three entries, eastern approach provides a straighter approach compared to the other entries Uncontrolled pedestrian crossings provided across each of the approaches
Bicycle facilities	Painted bicycle lanes on all approaches that continue through the intersection, excluding the exit lanes. Bicycle lane colour is a different shade of green across entry lanes
Aerial map	 *Source: nearmap©, (2013), 'QLD', map data, nearmap©, Sydney, NSW.*
Crash history	Three crashes involving cyclists
Crash diagram	 *Note: One crash DCA 137 was reported as a single vehicle crash but the crash data indicated the crash involved a car and a bicycle turning left. For this project the vehicle movement description has been followed.*

Location	Old Burleigh Road – Queensland Avenue, Broadbeach, Queensland
Approaches	The approaches have large radius curves, almost providing a straight path to the roundabout
Entry widths	Southern approach – 3.5 m Bicycle lane – 1 m Other approaches – 4.5 m Bicycle lane tapers approaching the holding line from 1.5 m to 1 m in width
Inscribed circle diameter	35 m
Central island size	21 m diameter Encroachment are 1.7 m wide Semi-mountable kerb edge
Circulating lanes width	5 m
Exit lane width (eastern exit)	3.5 m and a 1 m bicycle lane
Entry path radius/curve speed	West to east direction: • ARNDT model – 46 km/h • Horizontal curve equation – 70 m radius, equates to a curve speed of 58 km/h (e = +0.03) South to north direction: • ARNDT model – 43 km/h
Circulating path radius/curve speed	West to east direction: • ARNDT model – 43 km/h • Horizontal curve equation – 45 m radius, equates to a curve speed of 43 km/h (e = –0.03)
Exit path radius/curve speed	East to south direction: Horizontal curve equation – 30 m radius, equates to a curve speed of 38 km/h (e = +0.03)
Sight distance	Western approach along southern approach: • For Criterion 2 – 55 m available • For an approach speed of 43 km/h, sight distance of 47 m is required (Table 3.1, AGRD Part 4B (Austroads 2015a)) For Criterion 3 western approach: the southern approach speed is 43 km/h which equates to an approach sight distance requirement of 47 m (Table 3.1 AGRD Part 4B) and the approach sight distance (absolute minimum) on the western approach for a speed of 46 km/h is 37 m (Equation 1 AGRD Part 4A (Austroads 2010)) Circulating vehicles: unrestricted

Notes:

Criterion 2 refers to the sight distance available to a driver of a vehicle located at the holding line to vehicles approaching from the right or travelling on the circulating lanes.

Criterion 3 refers to the ability of a driver approaching the roundabout to observe other entering vehicles before that vehicle reaches the holding lines.

For Criterion 3, the absolute minimum sight distance is based on a reaction time of 1.5 sec and a coefficient of deceleration of 0.46 (AGRD Part 4A (Austroads 2010)).

The side friction value used for the curve speed estimation is 0.35, per Table 7.4 AGRD Part 3 (Austroads 2016a).

Discussion

This roundabout is located in a residential area and is close to a retail precinct. The entry lanes are 3.5 m to 4.5 m wide. Bicycle lanes have been installed on the approaches and continue through the roundabout on the outer edge of the circulating lane.

The approaches are straight and the vertical alignment of the approaches does not impact on the sight distance to the roundabout. The eastern approach (Queensland Avenue) contains a 90 degree bend 65 m prior to the holding lines.

The central island has a kerbed edge, without an encroachment area and is mounded and vegetated with low shrubs.

The bicycle crash types involved a motor vehicle entering the roundabout from the western approach (Queensland Avenue) colliding with a cyclist travelling to the north, a sideswipe type crash involving a vehicle and a bicycle turning left from the eastern approach (Queensland Avenue), and a single vehicle out-of-control and run-off-road (left) type crash.

The bicycle lanes continue through the roundabout and cyclists travelling across an exit (i.e. turning right around the periphery of the roundabout) are required to give way to vehicles leaving the roundabout. Whilst the crash data did not indicate that this was a contributor to the crashes, a cyclist undertaking such a manoeuvre may be in a vulnerable position when using the bicycle lane.

Contributing factors

Some possible contributing factors to adjacent direction type crashes are restricted sight distances, high approach speeds and lack of driver awareness of the intersection (Austroads 2015c).

Possible contributing factors for a sideswipe crash are narrow lanes, a differential in speeds between the bicycle and a motor vehicle as the driver commences a left turn in expectation that there is sufficient clearance for the cyclist and/or the cyclist would give way. Alternatively, the driver, whilst waiting for a gap in circulating traffic, may not be aware that a cyclist had moved up between the motor vehicle and the left kerb.

Sight distance

On the western approach, the sight distance available exceeds to requirements for Criterion 2 but the requirements for Criterion 3 are not met. If the approach speeds were reduced to 30 km/h, the requirements for Criterion 3, from this approach, would be met.

The site inspection revealed that there were two power poles within the sight lines for drivers approaching from the west, which provided some intrusion into the view but were not considered to obstruct a driver's view to vehicles approaching from the north.

Entry speed

The entry from the western approach (Queensland Avenue) is a 4.5 m wide vehicle lane with a 1 m bicycle lane which combined create a 5.5 m wide entry. The exit width at the eastern exit is a 3.5 m wide vehicle lane and a 1 m wide bicycle lane creating a total exit width of 4.5 m.

On the travel path along the west to east direction (Queensland Avenue), the entry curve speed was estimated to allow a speed of 46 km/h. The higher speed is greater than the speed zone limit and so it would not be expected that vehicles would travel at this speed into the roundabout. However, it does indicate that the western approach allows a relatively fast entry, which is contrary to Austroads guidelines.

Austroads (2014a) reported, from a small sample, average vehicle speeds at this roundabout (Table 7.2). Speed profile graphs showing all of the speeds recorded were also included which indicated that speeds up to 39 km/h were recorded on the western approach (Appendix C). These speeds are lower than the estimated speeds.

The direction that the vehicles took on leaving the roundabout was not reported and consequently this information only provides an indication of the speeds on the approach to this roundabout.

Table 7.2: Approach speeds Old Burleigh Road/Queensland Avenue

		Speed (km/h) by distance from the holding line			
	Approach	30 m	20 m	10 m	5 m
Old Burleigh Road/ Queensland Avenue	West	39.4	36.1	30.5	27.2

Source: Austroads (2014a).

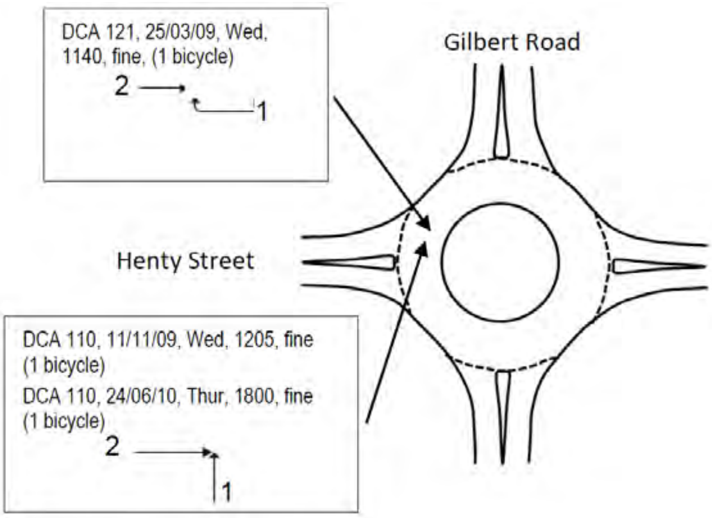
The results do indicate, however, that most drivers may be approaching this roundabout at a much slower speed than determined by the horizontal curve equation.

Further investigation of the vehicle approach speeds to roundabouts would provide further information on the operation of these roundabouts. This information would be useful to determine the approach speeds to roundabouts with different travel path geometries.

Possible countermeasures

The sight distance is adequate for drivers approaching from the west and consequently the countermeasures need to focus on requiring the driver to follow a tighter curved travel path. This would aim to slow vehicles entering the roundabout irrespective of their final direction in accordance with Austroads guidelines. Retention of the bicycle lanes through the roundabout would keep the entry relatively wide (vehicle travel lane plus bicycle lane) and make it difficult to reduce entry speeds. In order to reduce approach and entry speeds it would be preferable to terminate the bicycle lane prior to the holding lines, extend the kerb into the existing lane and straighten the splitter island. This would result in a narrower entry lane and a tighter travel path at the entry, thus reducing the speed of motor vehicles on the approaches.

7.2.12 Gilbert Road – Henty Street, Reservoir

Location	Gilbert Road – Henty Street, Reservoir, Victoria
Road classification	Local collector roads
Speed zone	50–60 km/h
Surrounding development	Commercial precinct to the south with industrial area to the west and a recreation ground on the north-eastern corner
Description	Single-lane roundabout with encroachment area Elongated circular central island, located on centrelines of north-south approach roads and offset Central island vegetated Kerb extension on south-western corner with low height vegetation Northern approach has a steep uphill grade
Bicycle facilities	Bicycle lanes on Gilbert Road (north-south approaches), merging with traffic lane prior to holding lines
On-street parking	Indented parking on eastern approach at recreation ground
Aerial map	 *Source: nearmap© (2013), 'VIC', map data, nearmap©, Sydney, NSW.*
Crash history	Three crashes involving cyclists
Crash diagram	

Location	Gilbert Road – Henty Street, Reservoir, Victoria
Approaches	Northern approach at approx. 75º Other approaches are straight
Entry widths	Northern approach – 4 m Southern approach – 3.8 m Eastern approach – 4 m Western approach – 3.6 m
Inscribed circle diameter	20 m x 28 m
Central island size	12.7 m elongated length, 7.5 m across Encroachment area – 1 m wide Bullnose present, rounded edge
Circulating lane width	4.5 m – 4.9 m
Exit lane width	Northern approach – 4.8 m Southern approach – 4.8 m Eastern approach – 4 m Western approach – 3.6 m
Entry path radius/curve speed	West to east direction: • ARNDT model – 37 km/h • Horizontal curve equation – 30 m radius, equates to a curve speed of 38 km/h (e = +0.03) South to north direction: • ARNDT model – 34 km/h
Circulating path radius/curve speed	West to east direction: • ARNDT model – 29 km/h • Horizontal curve equation – 25 m radius, equates to a curve speed of 32 km/h (e = –0.03)
Sight distance	Western approach along southern approach: • For Criterion 2 – 30 m available (low groundcover vegetation on south-western kerb extension causes some obstruction) • For an approach speed of 34 km/h, sight distance required is 37 m (Table 3.1, AGRD Part 4B (Austroads 2015a) 25 m available to a circulating vehicle. For a circulating vehicle at this location 22 m sight distance is required For Criterion 3 western approach: the southern approach speed is 34 km/h which equates to an approach sight distance requirement of 37 m, and the approach sight distance (absolute minimum) on the western approach for a speed of 37 km/h is 27 m (Equation 1, AGRD Part 4A (Austroads 2010))

Notes:

Criterion 2 refers to the sight distance available to a driver of a vehicle located at the holding line to vehicles approaching from the right or travelling on the circulating lanes.

Criterion 3 refers to the ability of a driver approaching the roundabout to observe other entering vehicles before that vehicle reaches the holding lines.

For Criterion 3, the absolute minimum sight distance is based on a reaction time of 1.5 sec and a coefficient of deceleration of 0.46 (AGRD Part 4A (Austroads 2010)).

The side friction value used for the curve speed estimation is 0.35, per Table 7.4 AGRD Part 3 (Austroads 2016a).

Discussion

This roundabout is located in a predominantly residential area on local collector roads at the northern end of a strip shopping centre.

Bicycle lanes are marked on Gilbert Road and terminate prior to the holding lines. Bus routes are located along Gilbert Road and Henty Street (western approach).

All three bicycle crashes from the crash analysis occurred at the western approach (Henty Street), and involved motor vehicles entering from the west colliding with cyclists on the roundabout. In two cases the cyclists were travelling from the south (Gilbert Road) and in the remaining case the cyclist was undertaking a right turn around the central island after entering from the eastern approach.

Contributing factors

Some possible contributing factors to adjacent direction type crashes are restricted sight distances, high approach speeds and lack of driver awareness of the intersection (Austroads 2015c). It would appear that the drivers may have failed to detect the presence of the cyclist as they entered the roundabout, which could have been due to the approach and entry speed.

Sight distance

The sight distance from Henty Street along Gilbert Road to the south is restricted by vegetation on the south-western corner of the intersection which appears to be associated with the development of the property on that corner. The requirements for Criterion 2 and Criterion 3 on this approach are not met.

The Criterion 2 sight distance of 30 m available from the western approach corresponds to an entry speed of 28 km/h on the southern approach, based on Table 3.1 of AGRD Part 4B (Austroads 2015a).

Entry speed

The predominant reported bicycle crashes involve vehicles travelling along Henty Street and the travel path curvature equates to an entry speed of 38 km/h slowing to 32 km/h around the central island.

The entry speed is higher than the target speed of 30 km/h where there are vulnerable road users, but actual speeds may be closer to 30 km/h with the slower circulating speed.

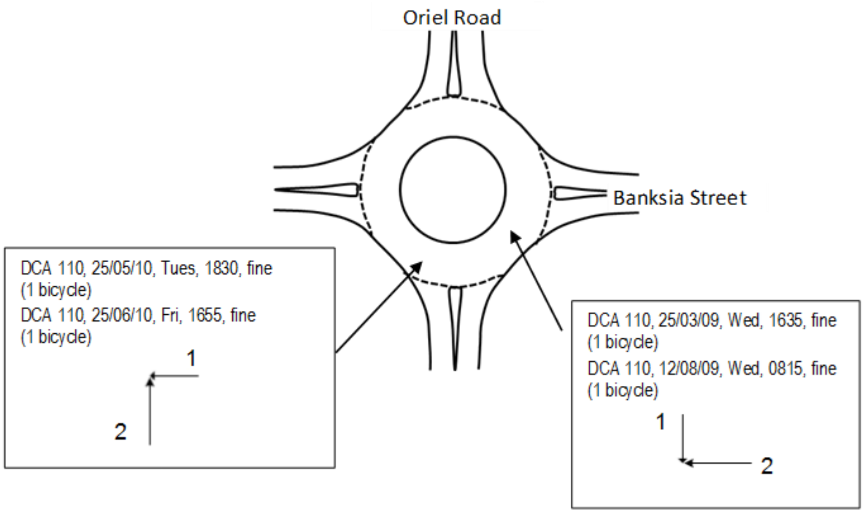
Possible countermeasures

Reducing the approach speed to less than 30 km/h would enable the requirements for Criterion 2 to be met. To meet the requirements for Criterion 3, the approach speeds would need to be reduced to 25 km/h.

The sight distance could also be improved by removing the vegetation on private property on the south-western corner of the roundabout. Keeping vegetation to a set level can be problematic as it requires continual monitoring and maintenance to ensure the set level is retained.

Entry curve speeds are higher than preferred, and these could be reduced so that entering drivers have more time to scan and detect cyclists. This could be achieved by providing a straighter approach alignment on Henty Street and extending the kerb on the north-western corner to have the entry curve commence closer to the circulating lanes, which then requires a tighter curve.

7.2.13 Oriel Road – Banksia Street, Heidelberg

Location	Oriel Road – Banksia Street, Heidelberg, Victoria
Road classification	Local collector roads
Speed zone	60 km/h
Surrounding development	Residential
Description	Single-lane roundabout Approaches provide a tangential-type entry. The central island is located on the centrelines of both road approaches Central island located on the centrelines of both approaches and contains trees and single streetlight pole A bus route is located on Oriel Road (north-south direction) with stops approximately 30 m from the intersection Pedestrian signals located on the southern approach 18 m from the holding line A small strip shopping centre is located on the southern side of the eastern approach
Bicycle facilities	Bicycle lanes on north-south road terminated 30 m prior to the holding lines, no bicycle lanes on eastern and western approaches
Aerial map	 *Source: nearmap© (2013), 'VIC', map data, nearmap©, Sydney, NSW.*
Crash history	Four crashes involving cyclists
Crash diagram	
Approaches	The Oriel Road approaches have a curved entry, with Banksia Street entries having a very small curve at the holding lines

Location	Oriel Road – Banksia Street, Heidelberg, Victoria
Entry widths	Northern approach – 5.5 m Eastern approach – 6.5 m Southern approach – 4 m Western approach – 5 m
Inscribed circle diameter	35 m
Central island size	18 m diameter Barrier kerb edge
Circulating lanes width	8.5 m
Exit lane width	Northern approach – 11 m Eastern approach – 5 m Southern approach – 5.5 m Bicycle lane – 2 m
Exit kerb alignment	Straight
Entry path radius/curve speed	South to north direction: • ARNDT model – 46 km/h • Horizontal curve equation – 75 m radius, equates to a curve speed of 60 km/h (e = +0.03) North to south direction: • ARNDT model – 45 km/h East to west direction: • ARNDT model – 46 km/h • Horizontal curve equation – 55 m radius, equates to a curve speed of 52 km/h (e = –0.03)
Circulating path radius/curve speed	North to south direction: • ARNDT model – 35 km/h • Horizontal curve equation – 45 m radius, equates to a curve speed of 43 km/h (e = –0.03) East to west direction: • ARNDT model – 38 km/h • Horizontal curve equation – 35 m radius, equated to a curve speed of 38 km/h
Sight distance	Eastern approach along northern approach: • For Criterion 2 – 55 m available • For an approach speed of 46 km/h, sight distance required is 50 m (Table 3.1, AGRD Part 4B (Austroads 2015a)) For Criterion 3 eastern approach: the northern approach speed of 45 km/h equates to an approach sight distance requirement of 49 m (Table 3.1, AGRD Part 4B) and the approach sight distance (absolute minimum) on the eastern approach for a speed of 45 km/h is 36 m (Equation 1 AGRD Part 4A) Sight distance is unrestricted to circulating vehicle
Sight distance	Southern approach along eastern approach: • For Criterion 2 – 45 m available • For an approach speed of 45 km/h, sight distance required is 49 m (Table 3.1, AGRD Part 4B) (Austroads 2015a)) For Criterion 3 southern approach: the eastern approach speed is 45 km/h which equates to a sight distance requirement of 49 m and on the southern approach, for a speed of 46 km/h the approach sight distance (absolute minimum) is 37 m (Equation 1 AGRD Part 4A)

Notes:

Criterion 2 refers to the sight distance available to a driver of a vehicle located at the holding line to vehicles approaching from the right or travelling on the circulating lanes.

Criterion 3 refers to the ability of a driver approaching the roundabout to observe other entering vehicles before that vehicle reaches the holding lines.

For Criterion 3, the absolute minimum sight distance is based on a reaction time of 1.5 sec and a coefficient of deceleration of 0.46 (AGRD Part 4A (Austroads 2010)).

The side friction value used for the curve speed estimation is 0.35, per Table 7.4 AGRD Part 3 (Austroads 2016a).

Discussion

This roundabout is located in a residential area with a works depot located on western approach (Banksia Street), a strip shopping centre at the south-eastern corner and schools along eastern approach (Banksia Street). A signalised pedestrian crossing is located in southern approach, approximately 15 m from the holding lines. The approaches are generally flat vertical grades.

A bus route operates along the north-south road.

The four bicycle crashes were adjacent direction type crashes located on the southern side of the roundabout and involved motor vehicles entering the roundabout and colliding with cyclists travelling on the circulating carriageway. Two of the crashes involved motor vehicles entering the roundabout from the southern approach (Oriel Road) and two involved motor vehicles entering the roundabout from the western approach (Banksia Street).

Contributing factors

Some possible contributing factors to adjacent direction type crashes are restricted sight distances, high approach speeds and lack of driver awareness of the intersection (Austroads 2015c). It would appear that the drivers may have failed to detect the presence of cyclists as they entered the roundabout, which could have been due to the approach and entry speed.

Sight distance

The sight distance available from the eastern approach (Banksia Street) along the northern approach (Oriel Road) is just lower than the sight distance required for Criterion 2 in AGRD Part 4B (Austroads 2015a). For Criterion 3 the sight lines are partly obstructed by trees, but a view of approaching vehicles is able to be obtained. On this basis, sight distance is not considered a contributing factor to the crashes involving vehicles approaching from the east.

The sight distance available from the southern approach, along eastern approach, is 45 m which is less than the required sight distance of 49 m based on the entry curve speed. Sight distance is restricted by vehicles in the designated parking bays and the presence of a bicycle rack and A-frame advertising could distract the driver, without otherwise restricting the sight distance. The requirements for Criterion 3 were also not met.

Entry speed

The travel path geometry is governed by the wide entry, the large inscribed circle compared to the central island size and the wide exits, and the exit curves being straight or having a relatively large radius. As a result, the curve speeds through the roundabout are higher than the target speed of 30 km/h.

Possible countermeasures

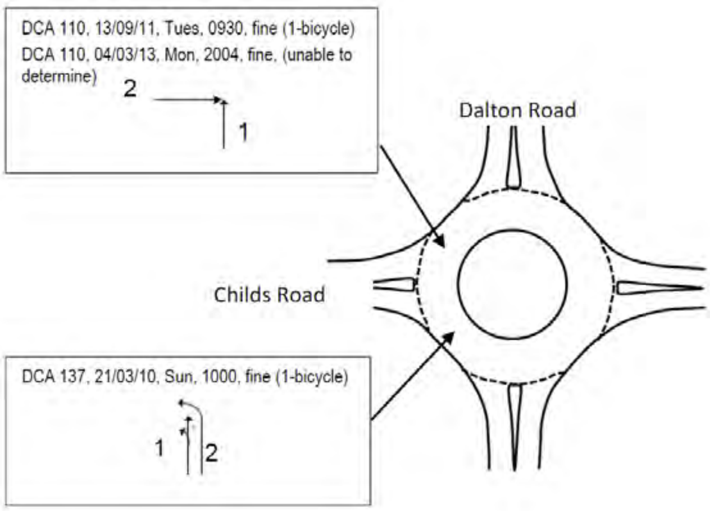
Improvements to the sight distance from the southern approach (Oriel Road) along the eastern approach (Banksia Street) could be improved by removing parking spaces to lengthen the available sight distance. The relocation of the street furniture i.e. bicycle rack and A-frame advertising, would remove a distraction and these should be moved to a position that is clear of the sight line.

The travel path speeds could be reduced by increasing the travel path curvature. At this roundabout, there is road space available to incorporate tighter curves for the three sections of the travel path, i.e. the entry, circulating lane and exit lane.

Possible treatments to achieve this are:

- straighten the approaches
- extend the kerb lines into the lane to reduce the width of the approach lane and exit lane
- provide an encroachment area around the roundabout to cater for buses
- extend the medians or splitter island to suit the kerb extensions.

7.2.14 Childs Road – Dalton Road, Mill Park

Location	**Childs Road – Dalton Road, Mill Park, Victoria**
Road classification	Arterial roads
Speed zone	60–70 km/h
Surrounding development	Residential
Description	Two-lane roundabout with two approach lanes and exit lanes Circular central island, located centrally to the approach roads Central island is grassed with trees planted in the central island Pedestrian fencing located in median on eastern approach, commencing 7 m prior to holding line and extending 10 m along the median
Bicycle facilities	Bicycle lanes on approaches continue through the roundabout with coloured lanes marked on the approaches, across the medians and across the entries
On-street parking	Indented parking in designated parking areas
Aerial map	 *Source: nearmap© (2013), 'VIC', map data, nearmap©, Sydney, NSW.*
Crash history	Three crashes involving cyclists
Crash diagram	
Approaches	All approaches have a curved alignment

Location	Childs Road – Dalton Road, Mill Park, Victoria
Entry widths	Eastern approach: • inner lane – 4 m • outer lane – 4 m • bicycle lane – 1.5 m Southern approach: • inner lane – 4 m • outer lane – 4 m • bicycle lane – 1.5 m
Inscribed circle diameter	55 m
Central island size	33.5 m diameter Encroachment area – 2 m wide
Circulating lane width	East-west direction: • inner lane – 5 m • outer lane – 5.5 m
Exit lane width	Western approach: • inner lane – 3.5 m • outer lane – 3.5 m
Exit kerb alignment	Curved
Entry path radius/curve speed	East to west direction: • ARNDT model – 55 km/h • Horizontal curve equation – 50 m radius, equates to a curve speed of 49 km/h (e = +0.03) Southern approach: • ARNDT model – 55 km/h • Horizontal curve equation – 50 m radius, equates to a curve speed of 49 km/h. (e = +0.03)
Circulating path radius/curve speed	East to west direction: • ARNDT model – 45 km/h • Horizontal curve equation – radius – 35 m, equates to a curve speed of 38 km/h (e = –0.03)
Exit path radius/curve speed	South to east direction: • Horizontal curve equation – radius – 60 m, equates to a curve speed of 54 km/h. (e = +0.03)
Sight distance	Eastern approach along southern approach: • For Criterion 2 – 70 m available, some interruption due to trees on the naturestrip • For an approach speed of 53 km/h, sight distance required is 74 m (Table 3.1, AGRD Part 4B (Austroads 2015a)) (arterial road) For Criterion 3 eastern approach: the southern approach speed is 55 km/h, which equates to a sight distance of 74 m and the approach sight distance (absolute minimum) on the eastern approach is 46 m (Equation 1 AGRD Part 4A (Austroads 2010)) Circulating vehicles can be seen from all approaches

Notes:

Criterion 2 refers to the sight distance available to a driver of a vehicle located at the holding line to vehicles approaching from the right or travelling on the circulating lanes.

Criterion 3 refers to the ability of a driver approaching the roundabout to observe other entering vehicles before that vehicle reaches the holding lines.

For Criterion 3, the absolute minimum sight distance is based on a reaction time of 1.5 sec and a coefficient of deceleration of 0.46 (AGRD Part 4A (Austroads 2010)).

The side friction value used for the curve speed estimation is 0.35, refer to Table 7.4 AGRD Part 3 (Austroads 2016a).

Discussion

This is a two-lane roundabout located in an urban area at the intersection of two arterial roads. Each approach has two entry lanes and a bicycle lane that continues through the roundabout.

The approach grades are relatively flat and the grade does not restrict the driver's view of the intersection.

There have been three bicycle crashes at this roundabout, with two of the crashes involving vehicles entering from the eastern approach (Childs Road) colliding with cyclists travelling in a northbound direction. The third crash was a sideswipe crash involving a vehicle turning left across the path of a cyclist.

The layout of the roundabout is similar to the layout suggested in AGRD Part 4B (Austroads 2015a) with the use of reverse curves on each approach.

The bicycle lanes pass through the roundabout and cyclists travelling across an exit are required to give way to vehicles leaving the roundabout. Whilst the crash data did not indicate that this was a contributor to the crashes, it does place cyclists in a vulnerable position when using the bicycle lane.

Contributing factors

The adjacent direction type crashes are associated with a lack of sight distance and high approach speeds (Austroads 2015c).

In the case of the left-turn sideswipe crashes Austroads (2015c) suggests that the lanes may be too narrow (for traffic composition, speed, curvature of road, angle of lanes) or the lane lines are not visible.

At this roundabout bicycle lanes are marked from the southern approach around the left corner into the eastern departure. This allows a cyclist travelling in the bicycle lane to reach the holding line of the roundabout and possibly passing on the left side of a motor vehicle and may not be detected if the driver was looking to their right to select a gap to enter the circulating lanes.

Sight distance

The sight distance available to drivers on the eastern approach (Childs Road) is just below the distance to meet Criterion 2 and meets the requirements for Criterion 3 of AGRD Part 4B (Austroads 2015a).

The requirements for Criterion 3 are met albeit with some interruption due to trees on the naturestrip.

Entry Speed

The entry curve speed on the eastern approach is estimated to be 49 km/h to 53 km/h, which is consistent with the guidance provided in AGRD Part 4B for an arterial road roundabout.

With the presence of cyclists, this speed is greater than the target speed of 30 km/h where there are vulnerable road users using the roundabout.

Possible countermeasures

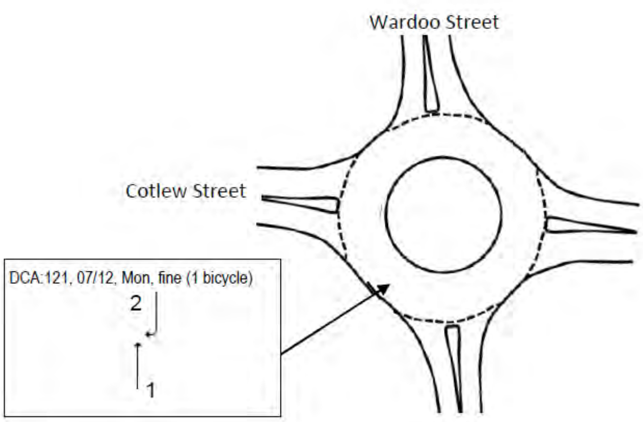
To reduce the entry speed on the eastern approach, the entry curve would need to be reduced to a radius of 20 m, which could be achieved by reducing the circulating carriageway to one lane, resulting in a significant impact on the capacity of the roundabout.

To achieve the target speed of 30 km/h other treatments would be needed, such as vertical displacement devices, which are not in current use on high-speed roads. It is understood that VicRoads have recently installed a vertical displacement treatment on an arterial road, and it is not known if any evaluation has been undertaken for the treatment.

The left-turning speed needs to be reduced to the target speed of 30 km/h if cyclists are to mix with the motor traffic. Cyclists need to be able to position themselves in the lane to prevent motor vehicles from overtaking them in the same lane. Possible measures to assist in establishing this position is to provide pavement markings, such as a sharrows, to alert motor vehicle drivers of the likelihood that cyclists may occupy the space indicated by the sharrow. Providing a sharrow would then need the removal of the bicycle lane to prevent confusion over the position cyclists may take to travel into the roundabout.

If the entry speed cannot be reduced to 30 km/h, bicycles should be separated from the motor traffic lanes through the provision of a separate off-road shared path. Cyclists would need to cross two lanes at each entry and exit and without being given priority, this would result in travel delays that would be much longer than travelling through the roundabout. Priority to cyclists may overcome this issue, but the operation of the roundabout may be affected if there are insufficient breaks in the bicycle traffic and vehicles may queue back from the crossing point into the circulating lanes.

7.2.15 Cotlew Street – Wardoo Street, Ashmore

Location	Cotlew Street – Wardoo Street, Ashmore, Queensland
Road classification	Local collector roads
Speed zone	60 km/h
Surrounding development	Residential
Description	Roundabout is located on a crest with steep approach grades on the eastern and western approaches Two-lane roundabout, with centre island located centrally to the intersecting road Approaches provide a tangential-type entry Central island grassed Approaches have a large radius curve to provide the tangential entry Uncontrolled pedestrian crossings provided across each of the approaches of the roundabout
Bicycle facilities	Bicycle lanes are provided on the southern approach terminating prior to the holding lines
Aerial map	 *Source: nearmap© (2013), 'QLD', map data, nearmap©, Sydney, NSW.*
Crash history	One crash involving a cyclist
Crash diagram	
Approaches	Large radius curves providing an almost straight path to the roundabout

Location	Cotlew Street – Wardoo Street, Ashmore, Queensland
Entry widths	Southern approach: • inner lane – 3 m • outer lane – 3 m Bicycle lane – 1 m Bicycle lane ends 15 m prior to holding line
Inscribed circle	50 m
Central island size	32 m diameter Barrier kerb edge
Circulating lanes width	Inner lane – 4.5 m Outer lane – 5 m
Exit lane width	Southern approach: • inner lane – 3 m • outer lane – 3.5 m Eastern approach: • inner lane – 3.5 m • outer lane – 4 m
Entry path radius/curve speed	South to north direction: • ARNDT model – 55 km/h • Horizontal curve equation – 85 m radius equates to a curve speed of 64 km/h (e = +0.03) West to east direction: • ARNDT model – 50 km/h • Horizontal curve equation – 50 m radius; equates to a curve speed of 45 km/h (e = –0.03)
Circulating path radius/curve speed	East to west direction: • ARNDT model – 40 km/h • Horizontal curve equation – radius – 30 m (outer lane) equates to a curve speed of 35 km/h (e = +0.03) North to east direction: • ARNDT model – 34 km/h • Horizontal curve speed – 19 m radius, equates to a curve speed of 28 km/h
Sight distance	South to west direction: • Unrestricted for circulating vehicles

Notes:

Criterion 2 refers to the sight distance available to a driver of a vehicle located at the holding line to vehicles approaching from the right or travelling on the circulating lanes.

Criterion 3 refers to the ability of a driver approaching the roundabout to observe other entering vehicles before that vehicle reaches the holding lines.

For Criterion 3, the absolute minimum sight distance is based on a reaction time of 1.5 sec and a coefficient of deceleration of 0.46 (AGRD Part 4A (Austroads 2010)).

The side friction value used for the curve speed estimation is 0.35, per Table 7.4 AGRD Part 3 (Austroads 2016a).

Discussion

This roundabout is located in a residential area at the intersection of two sub-arterial type roads.

There has been one crash reported at this roundabout at the southern approach (Wardoo Street), involving a vehicle turning right colliding with a northbound cyclist who had entered the roundabout from the southern approach.

Contributing factors

The crash involved a vehicle within the roundabout colliding with a cyclist who, based on the location of the crash, would have entered the roundabout after the vehicle commenced to turn. Of relevance is the turning speed of the motor vehicle and this has been estimated to be 34 km/h, which is close to the target 30 km/h speed for motor vehicles and cyclists mix.

The inner circulating lane may contain a right-turning vehicle and a vehicle travelling straight through and the right-turning vehicle may not have indicated an intention to turn and the cyclist proceeded on the basis of the lack of indication from the turning driver.

A characteristic of this roundabout is that the layout would allow relatively high entry speeds and exit speeds; however, the crash was related to circulating speed.

Sight distance

For the crash reported, adequate sight distance was available for the cyclist to observe the turning vehicle.

Entry speed

Austroads (2014a) reported, from a small sample, average speeds at this roundabout as shown in Table 7.3, and included speed profile graphs speeds for all of the speeds recorded (refer to Appendix C) which indicated that speeds up to 41 km/h were recorded on the western approach. These speeds are lower than the estimated speeds.

Table 7.3: Approach speeds – Wardoo Street/Cotlew Street

		Speed by distance from the holding line (km/h)			
	Approach	30 m	20 m	10 m	5 m
Wardoo Street	South	40.1	35.2	28.4	24.4
Cotlew Street	West	42.9	37.5	30.4	26.5

Source: Austroads (2014a).

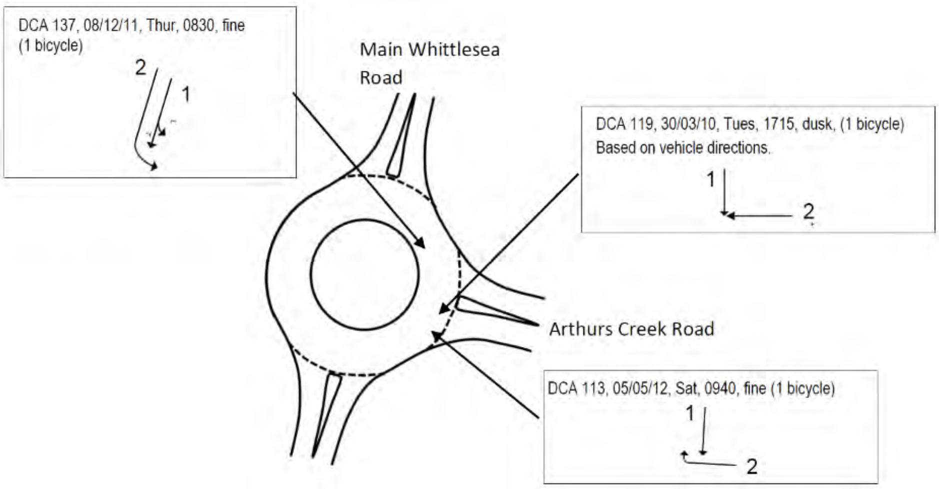
Whilst this information is based on a small sample it could indicate that the speeds determined using the horizontal curve equation may not be appropriate to this type of situation.

Possible countermeasures

The estimated circulating speed of the motor vehicle has been estimated to be close to the target speed of 30 km/h for locations where motor vehicles mix with cyclists. Reducing entry speeds to the target speed may not prevent this type of crash. Cyclists need to be separated from motor vehicles which can be achieved by providing an off-road path. This would require cyclists to cross the entry and exit lanes creating an area of possible conflict with motor vehicles. Priority would need to be provided to cyclists (and pedestrians) with the installation of a pedestrian crossing or traffic signals. When installing this type of facility consideration needs to be given to visibility to enable drivers to detect and respond when cyclists of pedestrians are utilising the crossing.

Providing a greater level of certainty on the direction vehicles travel through the roundabout, by having designated right-turn only lanes, which may have alerted the cyclist to the turning vehicle.

7.2.16 Whittlesea Road – Arthurs Creek Road, Yan Yean

Location	Whittlesea Road – Arthurs Creek Road, Yan Yean, Victoria
Road classification	Arterial Road/local road
Speed zone	100 km/h
Surrounding development	Rural
Description	Single-lane roundabout • Approaches provide a tangential-type entry • Paved central island with single streetlight pole • Bus stop located on the northern approach approximately 60 m from the intersection
Bicycle facilities	Bicycle lanes on northern and southern approaches. The lane in the north to south direction continues through the roundabout, but the green lane marking is not provided across the exit lane to the eastern leg. In the south to north direction an off-road bicycle path commences 30 m prior to the holding line and ends 20 m beyond the exit point of the roundabout. There is no bicycle lane on the eastern approach
Aerial map	 *Source: nearmap© (2013), 'VIC', map data, nearmap©, Sydney, NSW.*
Crash history	Three crashes involving cyclists
Crash diagram	
Approaches	The approaches have a curved entry

Location	Whittlesea Road – Arthurs Creek Road, Yan Yean, Victoria
Entry widths	Northern approach – 3.5 m Bicycle lane – 2 m tapering to 1.5 m at holding line Eastern approach – 4 m Southern approach – 3.5 m
Inscribed circle	30 m
Central island size	17 m diameter Semi-mountable kerb edge
Circulating lanes width	6.5 m
Exit lane width	Northern approach – 4.5 m Eastern approach – 5 m Southern approach – 4 m Bicycle lane – 2 m
Exit kerb alignment	Straight
Entry path radius/curve speed	North to south direction: • ARNDT model – 54 km/h • Horizontal curve equation – 50 m radius, equates to a curve speed of 49 km/h (e = +0.03) Eastern approach: • ARNDT model – 51 km/h (for speed environment of 60 km/h on approach to roundabout)
Circulating path radius/curve speed	North to south direction: • ARNDT model – 43 km/h • Horizontal curve equation – 60 m radius, equates to a curve speed of 49 km/h (e = –0.03) Eastern to north direction: • ARNDT model – 28 km/h
Exit path radius/curve speed	North to east direction (left-turn): Horizontal curve equation – 25 m radius, equates to a curve speed of 35 km/h (e = +0.03)
Sight distance	Eastern approach along northern approach: For Criterion 2 – 65 m available • For an approach speed of 54 km/h, sight distance required is 75 m (Table 3.1 AGRD Part 4B (Austroads 2015a)) For Criterion 3 eastern approach: the northern approach speed of 54 km/h which equates to a sight distance requirement of 75 m and the approach sight distance (absolute minimum) on the eastern approach for a speed of 51 km/h is 44 m (Equation 1, AGRD Part 4A (Austroads 2010)) Unrestricted to circulating vehicle

Notes:

Criterion 2 refers to the sight distance available to a driver of a vehicle located at the holding line to vehicles approaching from the right or travelling on the circulating lanes.

Criterion 3 refers to the ability of a driver approaching the roundabout to observe other entering vehicles before that vehicle reaches the holding lines.

For Criterion 3, the absolute minimum sight distance is based on a reaction time of 1.5 sec and a coefficient of deceleration of 0.46 (AGRD Part 4A (Austroads 2010)).

The side friction value used for the curve speed estimation is 0.35, per Table 7.4 AGRD Part 3 (Austroads 2016a).

Discussion

This single-lane roundabout is located at a T-intersection in a rural area and in a 100 km/h speed zone. Bicycle lanes have been provided in the north-south direction (Whittlesea Road) with the southbound bicycle lane continuing through the intersection and the northbound bicycle lane ending prior to the roundabout and recommencing a short distance north of the roundabout. A separate bicycle path (track) has been provided for northbound cyclists away from the circulating lanes of the roundabout. Whittlesea Road is also a popular route for training cyclists.

The approaches are straight with a curved entry to provide a tangential-type approach. The vertical alignment of the approach roads does not impact on the sight distance to the roundabout.

The central island is paved and contains a streetlight pole.

Three bicycle crashes were reported at this roundabout with two of the crashes involving motor vehicles entering from the eastern approach (Arthurs Creek Road) and colliding with southbound cyclists. The third crash involved a sideswipe crash between a motor vehicle turning left into Arthurs Creek Road and a southbound cyclist.

Contributing factors

The contributing factors to adjacent direction type crashes are restricted sight distance and high approach speeds.

Sight distance

The sight distance available from the eastern approach to the north is just below the distance required to meet Criterion 2 in AGRD Part 4B (Austroads 2015a).

For Criterion 3 from the eastern approach the sight lines are restricted by trees and so the requirements to meet this criterion are not met.

Entry speed

Entry speeds are higher than the target speed of 30 km/h where there are vulnerable road users present. In this location, the speed on the northern approach would need to be reduced by a series of reverse curves, reducing the 100 km/h speed to 30 km/h at entry.

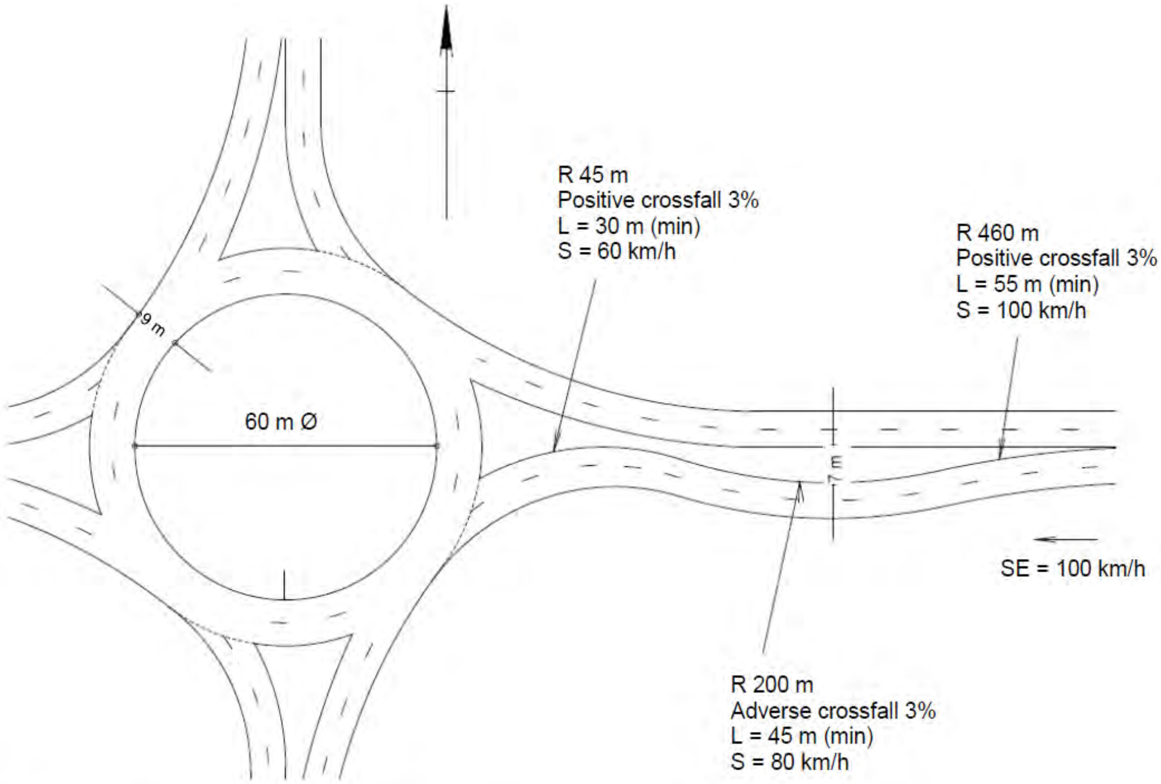
Left-turn sideswipe crashes can be caused by lanes that are too narrow for the traffic volume or speeds and perhaps human behaviour factors. The entry width on the northern approach is 3.5 m with a 2 m wide bicycle lane creating an entry 5.5 m wide. The bicycle lane extends through the roundabout, excluding the exit lanes, allowing motor vehicles to overtake cyclists. The left-turn radius from the northern approach to the eastern approach allows an estimated speed of 35 km/h. The left-turn speed is greater than the target speed of 30 km/h for situations where motor vehicle mix with vulnerable road users.

Possible countermeasures

The entry speed on the northern approach needs to be reduced to the target speed of 30 km/h and in this situation, reverse curves as shown in Figure 7.2 have been used at other sites to reduce speeds to 50 km/h. Reducing the vehicle speeds to 30 km/h could be achieved through the use of reverse curves. However, four curves would probably be required so that the decrease in speed between successive curves does not exceed 30 km/h. In this location this is a large reduction in speed and acceptance of this level of reduction would need to be ascertained.

Entry curvature could be achieved by increasing the central island size but this resulted in speeds greater than the target speed on the circulating lane.

Figure 7.2: Roundabout in a high-speed rural environment – two reverse curves



Notes:
SE = Approach speed prior to entry curve/s (km/h).
R = Curve radius (m)
L = Length of curve at entry (m).
S = Speed on the curve at entry (km/h).

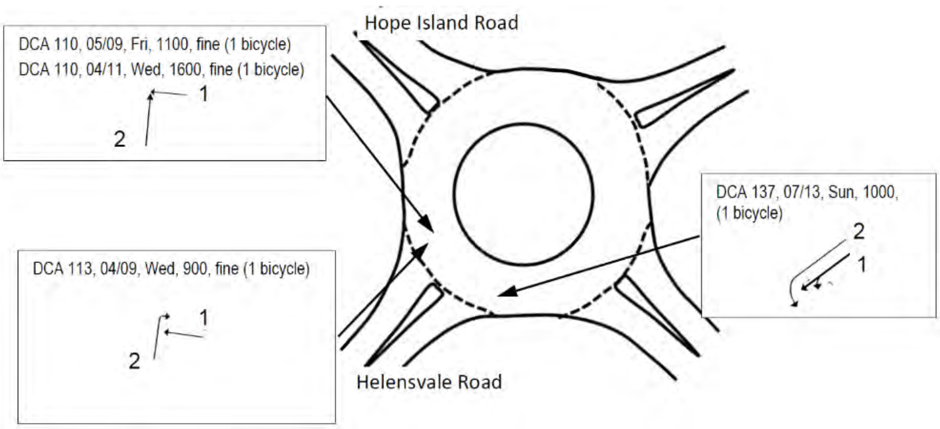
Source: Queensland Department of Transport and Main Roads, cited in Austroads (2015a).

Reducing the left-turn speed from the northern approach would require a smaller curve radius to be provided on the same alignment as the existing kerb. This treatment could retain the bicycle lane which would result in a relatively wide opening. This would still allow a vehicle to cut across the bicycle lane and take a larger radius turn into Arthurs Creek Road. Ending the bicycle lane prior to the holding line would enable a narrower entry width, but the speeds through the roundabout would need to be less than 30 km/h.

Another possible treatment to prevent the left-turn sideswipe crash is to end the bicycle lane prior to the holding lanes and provide an off-road shared path. A shared path could be provided as a footpath is located along this section of Whittlesea Road serving a bus stop. This would require cyclists to reduce their speed prior to entering the shared path and crossing the intersecting road (Arthurs Creek Road). In this location the crossing would most likely be uncontrolled and new conflict points would be created at the crossing.

To prevent crashes involving vehicles entering the roundabout from Arthurs Creek Road, cyclists could be provided with an off-road shared path separated from the circulating lanes of the roundabout, in a similar manner to the path provided for the northbound cyclists. This does however, create new conflict points in undertaking the crossing of Arthurs Creek Road and the location of the crossing would need to be close to the roundabout to enable left-turning drivers to observe cyclists crossing. Whittlesea Road is used by many experienced cyclists for training and these cyclists desire to maintain a consistent speed and consequently may not consider a short section of off-road path and an unprotected crossing of Arthurs Creek Road, a satisfactory alternative to travelling through the roundabout.

7.2.17 Helensvale Road – Hope Island Road, Hope Island

Location	Helensvale Road – Hope Island Road, Hope Island, Queensland
Road classification	Arterial road/local collector road
Speed zone	50–70 km/h
Surrounding development	Rural roadsides, residential areas nearby
Description	Two-lane roundabout, with two-lane entries and exits Approaches provide a tangential-type entry Central island grassed
Bicycle facilities	Bicycle lanes on the northern and south-eastern approaches, terminating at the holding line. Off-road path provided parallel with the circulating lanes, with uncontrolled crossings provided on each approach
Aerial map	 *Source: nearmap© (2013), 'QLD', map data, nearmap©, Sydney, NSW.*
Crash history	Four crashes involving cyclists
Crash diagram	 *Note: DCA 113 may be a DCA 110, based on the location*
Approaches	The approaches have a curved entry

Location	Helensvale Road – Hope Island Road, Hope Island, Queensland
Entry widths	South-eastern approach: • inner lane – 3.5 m • outer lane – 4.2 m Bicycle lane – 2 m
Inscribed circle diameter	145 m
Central island size	125 m diameter Semi-mountable kerb edge
Circulating lanes width	South-western entry: • inner lane – 4.5 m • outer lane – 4.5 m
Exit lane width	South-western exit: • inner lane – 4 m • outer lane – 4 m
Entry path radius/curve speed	South-western approach: ARNDT model – 58 km/h Horizontal curve equation – 65 m radius, equates to a curve speed of 56 km/h (e = +0.03)
Circulating path radius/curve speed	ARNDT model – 58 km/h Circulating lane 65 m radius, equates to a turning speed of 51 km/h (e = –0.03)
Exit path radius/curve speed	South-western approach: ARNDT model – 58 km/h Horizontal curve equation – 100 m radius, equates to a curve speed of 69 km/h (e = +0.03)
Sight distance	South-eastern approach to the south approach: • For Criterion 2 – > 100 m available • For an approach speed of 58 km/h, sight distance required is 82 m (Table 3.1 AGRD Part 4B (Austroads 2015a)) For Criterion 3 south-eastern approach: the approach speed of 58 km/h equates to a sight distance of 82 m and the approach sight distance (absolute minimum) on the south-eastern approach for a speed of 58 km/h is 53 m (Equation 1, AGRD Part 4A (Austroads 2010)) Circulating vehicles: unrestricted

Notes:

Criterion 2 refers to the sight distance available to a driver of a vehicle located at the holding line to vehicles approaching from the right or travelling on the circulating lanes.

Criterion 3 refers to the ability of a driver approaching the roundabout to observe other entering vehicles before that vehicle reaches the holding lines.

For Criterion 3, the absolute minimum sight distance is based on a reaction time of 1.5 sec and a coefficient of deceleration of 0.46 (AGRD Part 4A (Austroads 2010)).

The side friction value used for the curve speed estimation is 0.35, refer to Table 7.4 AGRD Part 3 (Austroads 2016a).

Discussion

This roundabout is very large, with a central island 125 m in diameter and located at the intersection of two arterial roads and a local collector road. The surrounding area is residential and the road environs provide a rural character to the roundabout. The arterial road approaches have a 70 km/h speed limit.

Bicycle lanes have been provided on the three arterial road approaches all terminating at the holding lines. In addition to the bicycle lanes an alternative off-road shared path has been provided on each approach to allow a cyclist to travel around the roundabout separated from the circulating vehicles in the roundabout. Guidance is provided by an advisory sign that indicates that cyclists may continue into the roundabout in traffic or use the shared path (Figure 7.3).

Figure 7.3: Example of bicycle advisory sign at a roundabout

The shared paths connect around the perimeter of the roundabout and cross each of the approaches without cyclists or pedestrians being given any priority.

There have been four bicycle crashes at this roundabout, with three of the crashes involving vehicles entering the roundabout from Helensvale Road (southern approach) and colliding with cyclists travelling in the circulating lane. The fourth crash involved a vehicle turning left to leave the roundabout at the Helensvale Road exit, causing a sideswipe crash.

Contributing factors

Some possible contributing factors to adjacent direction type crashes are restricted sight distances and high approach speeds. For sideswipe crashes, contributing factors may include the lanes being too narrow for the traffic volumes and speeds (Austroads 2015c).

The differences in vehicle speeds with a vehicle overtaking a cyclist and turning across the cyclist's path may be a contributing factor in the left-turn sideswipe crash.

Sight distance

The sight distance at this intersection exceeds distances to meet Criterion 2 and Criterion 3 of AGRD Part 4B (Austroads 2015a) and is therefore not considered to be a contributing factor to the reported crashes.

Entry alignment

The entry curve intersects the circulating lanes at a flat angle. This results in the vehicle being orientated such that the drivers observation angle to a cyclist on the outer edge of the circulating lane is 120º which is the maximum angle for a left-turning vehicle suggested in Figure 3.4 of AGRD Part 4A (Austroads 2010). Whilst the observation angle is not greater than the maximum observation angle, detecting a smaller object, may be difficult and lead to a cyclist not being seen.

Entry speed

The entry curve speed of 50 km/h on the Helensvale Road approach (southern approach) is consistent with the entry speed guidance provided in AGRD Part 4B.

This speed however is greater than the target speed of 30 km/h to minimise fatal and serious injuries to cyclists.

Exit alignment

The exit alignment to Helensvale Road (south-western) approach contains an exit curve of 100 m radius. This equates to a curve speed of 69 km/h, which would enable exiting vehicles to accelerate out of the circulating lane. At this speed a driver may overtake cyclists and cross their travel path with an error of judgement leading to a crash.

Shared path alignment

The shared path provides an alternative travel path for cyclists to travel around the roundabout. The bicycle lane and off-road path on the Helensvale Road approach do not overlap which results in cyclists having to travel a short distance without the protection provided by a bicycle lane or path.

During the site inspection, several cyclists travelled through the intersection and all continued to travel around the outer edge of the circulating lanes of the roundabout.

Possible countermeasures

The driver observation angle could be improved by realigning the entry curve to a straighter approach just prior to the holding lines. This would create a steeper angle at the entry and improve the driver’s capability to observe an approaching motor vehicle or cyclist.

The incorporation of reverse curves would follow the current practice of providing reverse curves to reduce approach speeds but a lower entry speed than current guidance suggest would need to be adopted. The curves could then be determined in a similar manner to the current design process.

The separated shared path does not have a smooth horizontal or vertical alignment at the exit from the on-road bicycle lane or re-entry onto the bicycle lane. At the exit, a cyclist is required to undertake a 90 degree turn and travel across a kerb ramp then immediately undertake another 90 degree turn to travel along the path. At the exit, a similar arrangement has been provided with sharp turns required to turn towards the on-road bicycle lane and travel across a kerb ramp. Improving the alignment of the path, by providing an entry that allows a faster path entry and exit would improve the rider comfort and reduce the disruption associated with using the off-road facility. Guidance on the entry/exit ramps is currently provided in *Guide to Road Design: Part 3: Geometric Design* (Austroads 2016a).

8. Possible Treatments

In considering possible treatments, the roundabouts have been considered as either a single-lane or a multilane roundabout. Treatments may vary depending on the location, i.e. local road or arterial road.

The two most prevalent crash types occurring were:

- adjacent directions (cross or right-turning) – 88% of crashes
- sideswipe (left) – 6% of crashes.

The contributing factors were identified as being the relatively high speed at which vehicles may be entering the roundabout on the entry path curve, which was found to be greater than the 30 km/h target speed, exacerbated by the wide lane widths on some of the roundabouts.

Sight distance was found to be lower than the distances to meet the criterion contained in AGRD Part 4B (Austroads 2015a) on a small number of the roundabouts, but the crash outcomes were the same at roundabouts with adequate sight distance.

The key issue is the vehicle speed on the approach curve at the entry to the roundabout. The elements that influence this speed are:

- approach alignment, i.e. straight or curved
- entry path curve radius
- entry lane width
- central island
- sight distance
- presence of any vertical deflection treatments.

These elements are discussed in Section 8.1, Section 8.2 and Section 8.3.

8.1 Single-lane Roundabouts

Single-lane roundabouts are found across the road network, particularly the Australian road network and most frequently on urban local roads where speed limits are 50 km/h to 60 km/h.

8.1.1 Approach Alignment

In the urban local road environment approach roads are typically on a straight alignment, with splitter islands placed on the centreline of the approach, guiding the vehicle movements onto the circulating lane. On-street parking is generally permitted on the approaches within 10 m of the holding lines where there is sufficient road width to also accommodate the through-lane width.

The incorporation of horizontal curves on the approaches, to achieve a speed reduction from 50 km/h to 30 km/h, prior to entry to roundabout, would require a reverse curve with a radius of 20 m[3]. The introduction of this type of treatment would need to avoid creating pinch points for cyclists. This treatment may also be difficult to incorporate into a local road due to the width of road space needed to provide the curves.

3 Note that the 20 m radius curve has been determined by using the speed models referred to in Section 7.1.

If the incorporation of reverse curves on the approach cannot be achieved then the speed reduction being sought would need to be achieved by using treatments prior to the roundabout, such as vertical displacement devices (Section 8.1.5) or through the geometry of the entry curve.

Discussion of the use of reverse curves has been incorporated into AGRD Part 4B (Austroads 2015a) and several roundabouts in this study were designed to be consistent with the current guidance. These treatments are detailed in AGRD Part 4B.

The approach alignment could also be offset from the centre of the roundabout to create a greater deflection which would increase the curvature of the travel path.

If after considering the possible treatments, where motor vehicle speeds cannot be reduced to the target speed of 30 km/h, facilities that provide cyclists to be separated from the motor traffic should be implemented.

Cyclist positioning

Cyclists need to be able to position themselves on the approach lane to prevent being overtaken by a motor vehicle. This is discussed in more detail in Section 8.3.2.

8.1.2 Entry Path Curve Radius

The roundabouts examined were found to follow a tangential type of alignment that resulted in a relatively large entry path curve, consistent with the current guidance in AGRD Part 4B (Austroads 2015a), with the resulting entry speed being greater than the 30 km/h target speed.

To achieve an entry speed of 30 km/h, it was found to be necessary to create an entry path radius of 20 m[4] or smaller, based on the methods outlined in Section 7.1. Achieving this radius is dependent upon the entry width and the left kerb radius and the position of the central island relative to the approach lane, as these elements determine the path followed by drivers as they enter roundabouts. The relative positioning of each of these elements is important to establish the desired travel path radius.

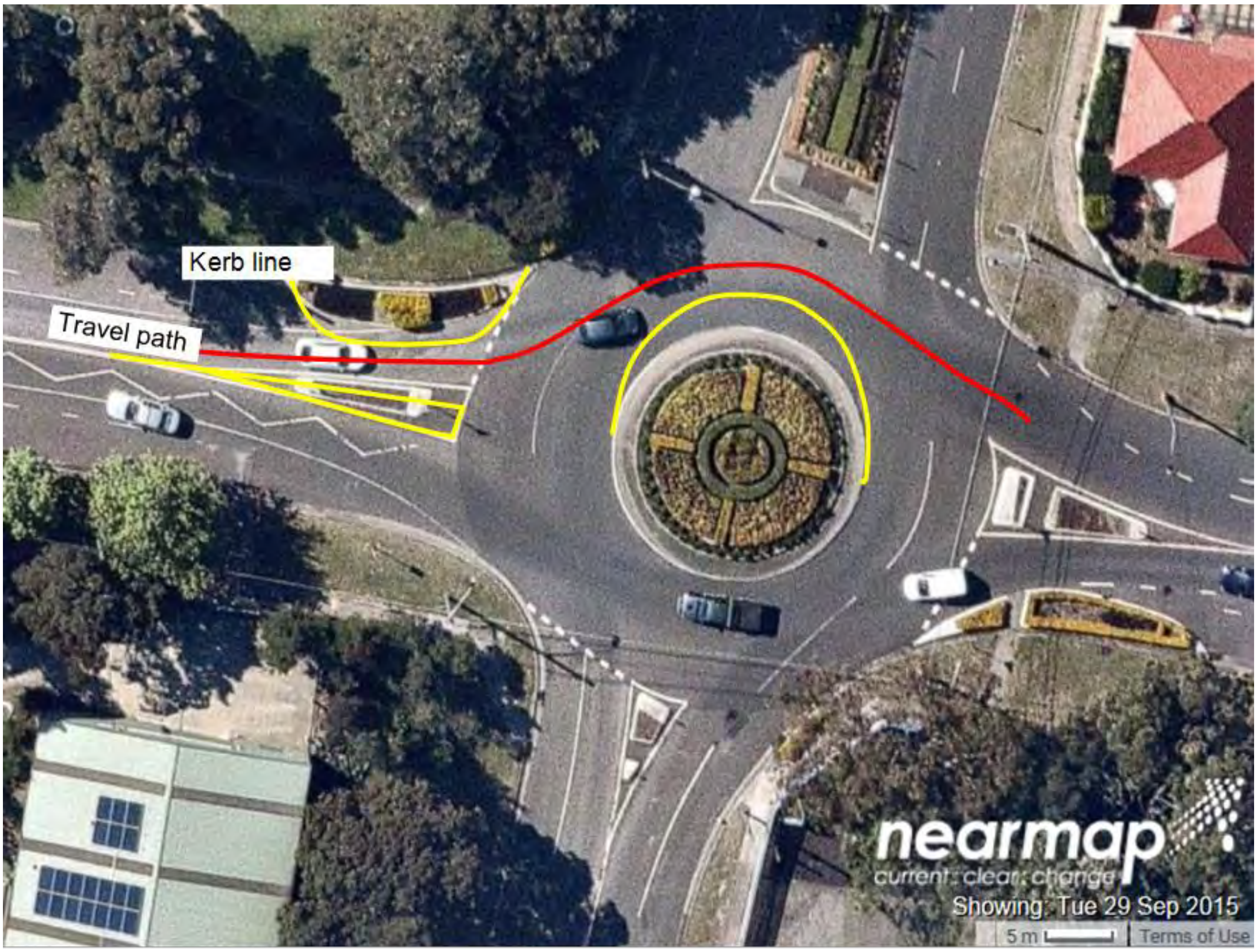
To obtain an entry path radius of 20 m, it was found that the commencement of the entry path curve needed to be close to the circulating lanes which could be achieved by straightening the approach and providing a left-turn kerb radius of 8 m to 10 m. The entry lane width was narrowed to 3.5 m to enable the travel path location be forced closer to the centreline of the approach road. Any flaring of the approach resulted in larger radius travel paths being possible. This type of approach is similar to the radial-type approach of roundabouts found in the Netherlands. This entry path radius could be achieved on local roads, where the design vehicles are the passenger car and a single-unit truck/bus.

An example of how this could be achieved at an existing local road roundabout is shown in Figure 8.1 (west to east movement only shown). This example also required the central island to be enlarged to achieve the desired entry path curve radius.

The design guidance for a radial-type roundabout can be developed from the design parameters used in the United Kingdom and the Netherlands. Table 8.1 provides design values for a single-lane roundabout. The radial-type roundabout has not been extensively used in Australia and would need to be evaluated to confirm that the anticipated outcomes were being achieved.

4 The 20 m radius is determined by using a side friction value of 0.35. If drivers travel through the curve with $f > 0.35$ the desired entry speed will be exceeded.

Figure 8.1: Example of entry alignment and central island on a local road



Note: This roundabout only has two lanes marked for the north to south direction.

Source: Modified nearmap© (2015), 'VIC, map data, nearmap©, Sydney, NSW.

8.1.3 Entry Lane Width

The entry lane width assists in positioning the vehicle at the commencement of the entry curve and it is preferable to keep the entry lane width as narrow as possible whilst providing a width to cater for the adopted design vehicle. Minimum lane widths of 3 m to 3.3 m were found to be suitable for the lane width, but it should be noted that the entry width also needs to cater for the design vehicle adopted for the roundabout.

AGRD Part 4B (Austroads 2015a) supports a narrower entry on roads with low speeds (< 50 km/h) and low volumes (< 3000 vpd) where the cyclist is sharing the lane with motor traffic the entry width should be less than 3.0 m to avoid the cyclist being forced into the kerb.

AGRD Part 3 (Austroads 2016a) also suggests that where bicycles are mixed with general traffic lane widths of 3.0 m to 3.3 m (or 3.7 m to 4.5 m) should be used.

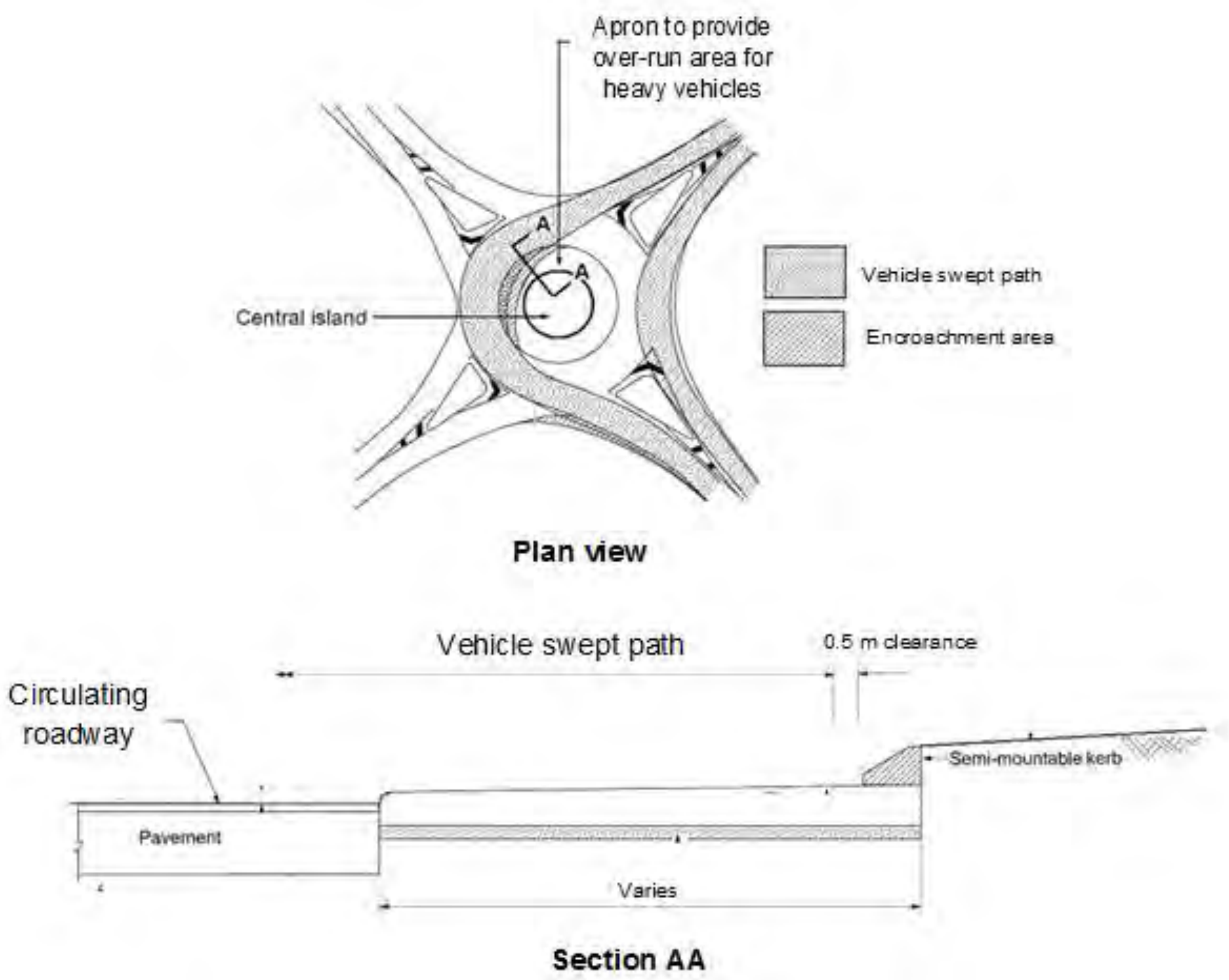
To keep the lane width to a minimum at the holding line, any bicycle lane provided on the approach would need to be merged with the through traffic lane prior to the holding line to remove the opportunity for motor vehicles to use the bicycle lane as part of their travel path. More information on merge areas is provided in Section 8.3.2.

8.1.4 Central Island

The position and size of the central island and the circulating width relative to the approach lane have a strong influence on the travel path curvature. The size of the central island will depend on the width of the approach roads, including any median or splitter islands and needs to be large enough to cater for the turning movements of the design vehicle. Its position relative to the approach entry lanes needs to be established so that the desired entry path curvature and speed reduction are achieved.

The central island can have an encroachment area (Figure 8.2) designed to constrain the desired travel path curvature for cars whilst allowing larger vehicles, such as service trucks to travel across the encroachment area to complete their movements.

Figure 8.2: Example of an encroachment area



Source: Modified Austroads (2015a).

8.1.5 Vertical Displacement Treatments

If the entry path speeds cannot be reduced to the target speed then vertical displacement devices, such as raised platforms or flat-road humps, may be a suitable treatment to reduce motor vehicle speeds through a roundabout. These types of devices have been principally installed on local roads as traffic management treatments. The application of these treatments on high-speed arterial roads has not been undertaken in Australia and so their application on these types of roads is uncertain, although it is understood there is a treatment being trialled in Victoria at a signalised intersection. Other treatments (Queensland Department of Transport and Main Roads 2015a) that are used at work sites to reduce vehicle speed may provide speed reduction in a non-work situation, but these would need to be evaluated for the different situations.

Traffic on urban local roads is generally comprised of lower volumes and of smaller types of vehicles (e.g. single-unit trucks and passenger cars) travelling at lower speeds and local roads are therefore suitable to incorporate vertical displacement devices, acknowledging that there are vehicles, such as buses that may need to be accommodated.

The types of devices include:

- road hump
- road cushion
- flat-top road hump
- wombat crossing.

Road hump

Road humps (e.g. Watts profile) are not a favoured treatment for cyclists due to the discomfort experienced in crossing the hump, therefore may not be a suitable treatment. A bicycle-only bypass at the road hump (Figure 8.3) can facilitate smoother bicycle travel. This bypass type of treatment provides a short separation from the traffic in the through-lane for the cyclist and requires the cyclist to merge into the through lane prior to the roundabout.

Figure 8.3: Example of a road hump with bypass

Source: Austroads (2014b).

Road cushion

A road cushion is a form of road hump that occupies only a part of the roadway (Figure 8.4). This treatment is considered more suitable for bus routes and cyclists as compared to a road hump and may be less likely to slow down emergency vehicle response times.

Figure 8.4: Example of a road cushion

Source: Austroads (2016b).

Flat-top road hump

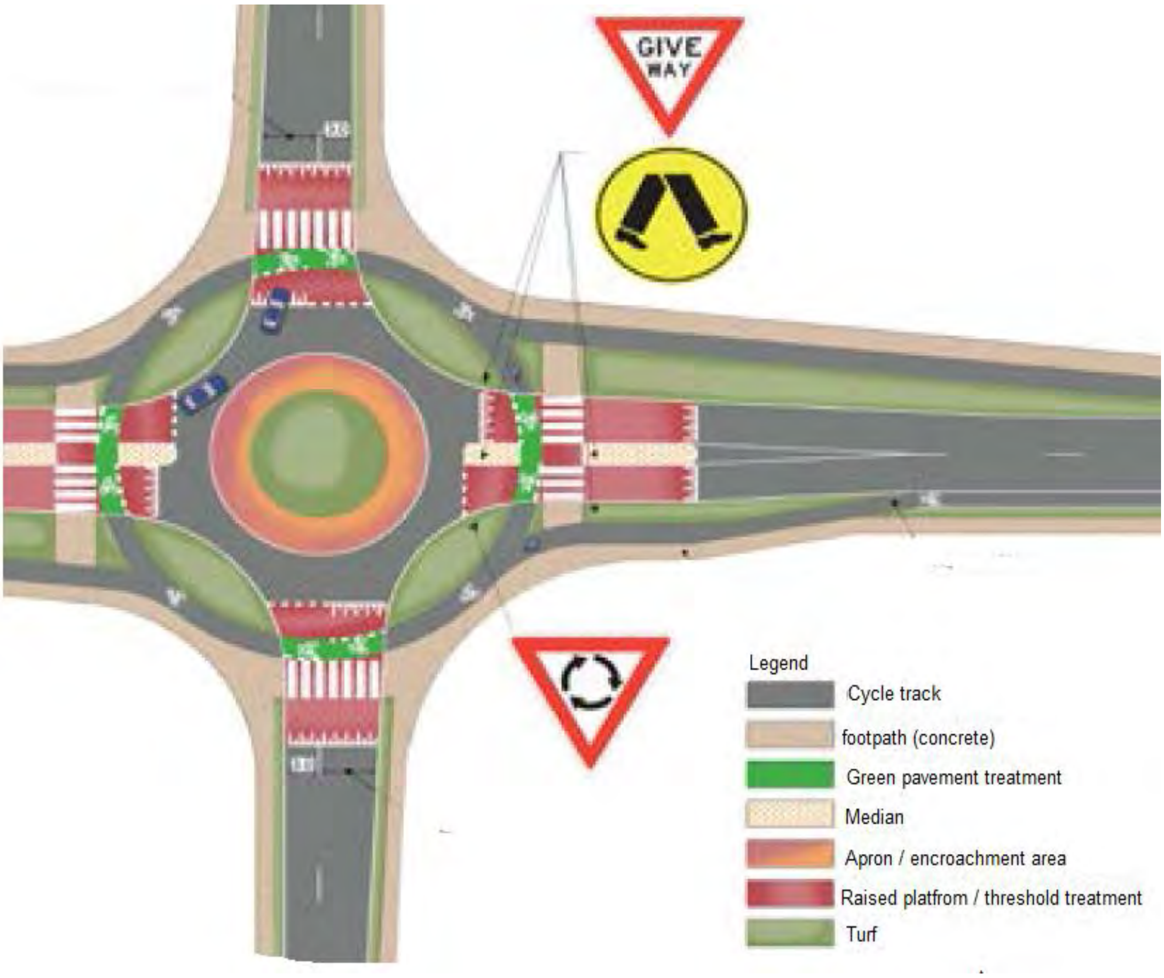
A flat-top road hump or raised table is a raised surface approximately 75 mm to100 mm high and typically with a 2 m to 6 m long platform ramped up from the normal level of the street. Ramp grades of 1:15 to 1:20 are generally regarded as bicycle friendly. The hump tapering at the road kerb (Figure 8.5) may cause a hazard for cyclists and a bypass for cyclists should be considered (Austroads 2016b).

A flat-top road hump near the roundabout also provides an opportunity to install a raised crossing for pedestrians and cyclists. An example of a raised crossing incorporating a pedestrian crossing is shown in Figure 8.6.

Figure 8.5: Example of a flat-top road hump

Source: Austroads (2016b).

Figure 8.6: Example of a raised pedestrian crossing at a roundabout



Source: Based on Queensland Department of Transport and Main Roads (2015c).

Wombat crossing

Wombat crossings are flat-top road humps with a marked pedestrian crossing on the raised flat surface, providing priority to pedestrians crossing the road.

The ramp grades need to be the same as indicated for flat-top humps.

On arterial roads, the use of vertical displacement treatments has not been adopted. The issues generally relate to the discomfort of vehicle passengers, noise, excessive wear and tear on vehicle suspension and increased emergency vehicle response times and patient comfort.

A study in New Zealand by Campbell, Jurisich and Dunn (2011), concluded that vertical displacement devices would most likely have an adverse effect on the noise levels generated as some heavy vehicles travel across the device. Other issues were identified but found to be usually of a minor nature.

Guidelines for the use of vertical displacement devices on arterial roads would need to be developed for use prior to being implemented.

Comments

Any vertical device should be located to allow the vehicle to complete the vertical movement caused by the device prior to commencing a turn movement into a roundabout.

8.1.6 Sight Distance

Current Austroads guidance seeks to have adequate sight distance available on the approach to a roundabout to enable a driver, to detect its presence, detect vehicles on the circulating lane or approaching the roundabout from the right and so avoid a collision. The distances are suggested to be determined using speeds of 50 km/h for an arterial road and 25 km/h to 30 km/h for a local residential street. Alternatively, it is suggested that the ARNDT model may be used to determine likely 85th percentile speeds (Austroads 2015a). The sight distances available at the locations examined in this report, were generally greater than required to meet Criterion 2 in Austroads (2015a). However, the sight distances required to meet Criterion 3, particularly on the on the urban local roads, was not available to meet the requirements in Austroads (2015a).

In the United Kingdom, Department for Transport (2016) suggests that limiting sight distance as shown in Figure 3.14 and Figure 3.15 can be helpful in reducing excessive approach speeds. The sight distance to the right is limited from the holding line and a point 15 m in advance of the holding line to the circulating lanes of the roundabout. This is a significant difference to the guidance contained in Austroads (2015a).

There is also some research that has found that restricted sight distances can reduce the vehicle approach speeds.

Turner, Roozenburg and Smith (2009) as part of the development of a roundabout crash prediction model examined the relationship between available sight distance and vehicle entering speeds, and concluded that as the visibility (sight distance) increases, vehicle speeds also increase and recommended that further investigation be undertaken on how vehicle speeds are affected by visibility.

Campbell, Jurisich and Dunn (2012) undertook a study of a roundabout and as part of the study examined the relationship between sightlines, approach speeds and driver behaviour. On one approach the sight distance was unimpeded and on three approaches there was adequate sight distance at the holding line, but was severely restricted 10 m prior to the holding line. Speeds surveys were undertaken and it was found that the unimpeded approach the 85th percentile speeds were found to be 30–32 km/h while at the other three approaches with restricted sight distance the 85th percentile speeds were found to be 25–28 km/h. The report concluded that excessive sight distance to the right can contribute to higher than desirable speeds and that obtaining a better understanding of the effects of sight distance restrictions on approach speeds could be valuable for the safe design of a roundabout and preventing crashes involving cyclists.

The concept of reducing sight distance at roundabouts has been shown in some research to result in lowering approach speeds but the development of design criteria would need further detailed investigation and is beyond the scope of this project.

8.1.7 Geometric Information

The type of roundabout that achieved the target speed of 30 km/h was a radial-type roundabout or very similar in layout to a radial-type of roundabout. Development of specific guidance is beyond the scope of this project, however, guidance can be obtained from information used in the Netherlands (Table 8.1). The information was sourced from de Groot (2007) and from information provided to the author by John Boender, Project Manager Traffic and Transport, CROW, Netherlands and Department for Transport (2016).

Table 8.1: Geometric information for a single-lane radial-type roundabout

Element	Netherlands	United Kingdom
	Design value (m)	Design value (m)
Central island radius	12.5 to 20.0	2.0 (min)
Circulating lane widths	5.0 to 6.0	6.0 (max)
Entry lane width	3.5 to 4.0	3.0 to 4.5
Entry kerb radius (left side)	8.0 to 12.0	10.0 to 20.0
Exit kerb radius (left side)	12.0 to 15.0	15.0 to 20.0
Exit lane width	4.0 to 4.5	Match the carriageway at exit

Source: de Groot (2007) and John Boender (personal communication) and Department for Transport (2016).

This information should only be used as a starting point in the development of a roundabout layout. In applying the principles, the site constraints or conditions will also influence specific details of the design.

The geometric parameters contained in Table 8.1 were using the ARNDT model (Section 7.1) and vehicle speeds on the approach and circulating lane were found be 30 km/h.

8.2 Single-lane Rural Arterial Road Roundabout

Only one single-lane rural arterial road roundabout was included in the project. Achieving the target speed of 30 km/h on this type of roundabout through the use of reverse curves is theoretically possible and would require at least four curves, based on limiting the speed differential to 20 km/h. This would need to be incorporated into the approach road over sufficient length to enable the development of superelevation for each of the curves. The approach reverse curves should be visible (each approach curve and the central island) to drivers from before the first approach curve. This may not be a practical treatment due to these requirements.

The alternative to providing reverse curves on the approach is to rely on drivers observing the roundabout ahead and slowing in response. Warning signs placed to alert drivers to the roundabout ahead and ensuring the roundabout is visible well before the entry would assist in alerting drivers of the need to slow down.

It is possible to establish the entry path curve radius to achieve a 40 km/h speed by ending the bicycle lane prior to the holding line, removing the splitter island and shifting the approach lane closer to the centreline of the road, and incorporating a 10 m radius on the left kerb return. The central island would need to be provided with an encroachment area to cater for the turning movements of larger trucks, such as a B-double to travel through the roundabout.

On these higher speed roads, the speeds may need to be reduced prior to the roundabout due to the large speed differential from the 100 km/h posted speed limit to the 30 km/h target speed. Methods to achieve a gradual speed reduction include the use of long median or reverse curves and are further outlined in AGRD Part 4B (Austroads 2015a).

At these types of roundabouts the use of an off-road facility as a bypass of the roundabout may not be effective as cyclists are likely to remain on the road in order to avoid the need to slow down and then accelerate to their desired operating speed. Grade separated treatments may provide an alternative but would need to be considered with other factors such as costs.

8.3 Multilane Roundabouts

The multilane roundabouts investigated in this project were located on both local roads and arterial roads.

The analysis indicated that the entry speeds were greater than the target speed of 30 km/h and because of the size of the roundabout and entry width due to the number of lanes, even when reducing the left kerb radius to 10 m (minimum to cater for larger vehicles) an entry path curve speed of 30 km/h could not be obtained. To improve the likelihood of achieving the desired entry path radius, the approach lanes could be offset by reducing the width of the exit lanes, but this also failed to achieve the target entry path speed.

If the desired capacity, allowing for traffic growth, could be achieved, these roundabouts could be modified to single-lane roundabouts which would provide a greater opportunity to achieve the target entry speed. However, multilane roundabouts are provided on the more important transport routes where the objective is to provide a high level of service, particularly for freight vehicles, and to provide for traffic growth, not to simply achieve adequate capacity. Modification to a single-lane roundabout is achievable on arterial roads and local roads but does depend on the traffic flows to be catered for.

In the case of multilane roundabouts separating bicycles from motor vehicles would seem to be necessary.

An off-road path may remove cyclists from the circulating lanes, but where the path crosses the approach legs of the roundabout, the type of crossing for cyclists needs to be considered. The crossing may be a simple uncontrolled crossing, requiring cyclists to give way to passing traffic or a controlled crossing such as traffic signals could be provided. This project did not consider the advantages/disadvantages of the types of crossings that could be utilised.

As indicated previously in this section reduction of the entry speeds to 30 km/h at multilane roundabouts may not be feasible. However the use of reverse curves with gradually smaller radii to gradually decrease vehicle speeds on the approaches could achieve a slower entry speed.

8.3.1 C-roundabout

A C-roundabout treatment has been developed and trialled in New Zealand (Figure 8.7). The C roundabout was developed for multilane roundabouts and aims to achieve a maximum path radius of 30 m to 40 m. The C-roundabout relies on large vehicles being able to straddle the approach lanes and circulating lanes[5].

The entry path curve speeds were found to be ≤ 30 km/h based on speed surveys at C-roundabouts (Asmus, Campbell & Dunn 2012).

The application of a C-roundabout would rely on the road rules in each jurisdiction allowing larger vehicles to occupy two circulating lanes.

This treatment would need further trialling and evaluation prior to incorporation into design guides.

Figure 8.7: Example of a C-roundabout

Source: Austroads (2014a).

5 The Australian Road Rules (National Transport Commission 2012) allows larger vehicles to occupy two approach lanes for the purposes of undertaking a left or right-turning manoeuvre only.

8.3.2 Merge Zones

Where a bicycle lane ends or merges with the through-traffic lane on the approach to roundabouts and the cyclist is to remain on-road, sharing the lane with motor vehicles, the motor vehicle speeds need to be the same as, or less than, the target speed of 30 km/h. If the motor vehicle speeds cannot be reduced through horizontal curve treatments, then treatments such as those used in local area traffic management schemes, e.g. flat-top road humps could be installed to reduce speeds. de Groot (2007) suggests that the merge be undertaken 20 m to 30 m prior to the circulating lanes. This would allow cyclists to ‘claim the lane’ as they proceed into the roundabout.

An alternative approach would be to provide priority to cyclists through the road rules. Further expansion of the application and acceptance of this type of change is beyond the scope of this project.

Where a merge zone is created, it needs to be evident to motor vehicle drivers that bicycles are joining the traffic lane. To assist cyclists in these locations, sharrow markings, an advisory shared road marking (Figure 8.8) have been implemented in some jurisdictions. For example in South Australia, guidance on the use of these markings has been developed in *Advisory Bicycle Pavement Marking: Shared Lane Marking* (*Sharrow*) (Department of Transport, Planning and Infrastructure 2015).

The sharrow is an advisory marking and, whilst alerting drivers to the presence of cyclists does not provide any priority to the cyclist. If this marking was included in road rules to establish priority to cyclists in this space, it would be expected to enhance the cyclists capability to travel in the centre of the lane, effectively ‘claiming the lane’.

Figure 8.8: Example of a sharrow marking

Source: Department of Planning, Transport and Infrastructure (2015).

Department of Transport, Planning and Infrastructure (2015) indicates that a shared lane marking (sharrow) may be used to:

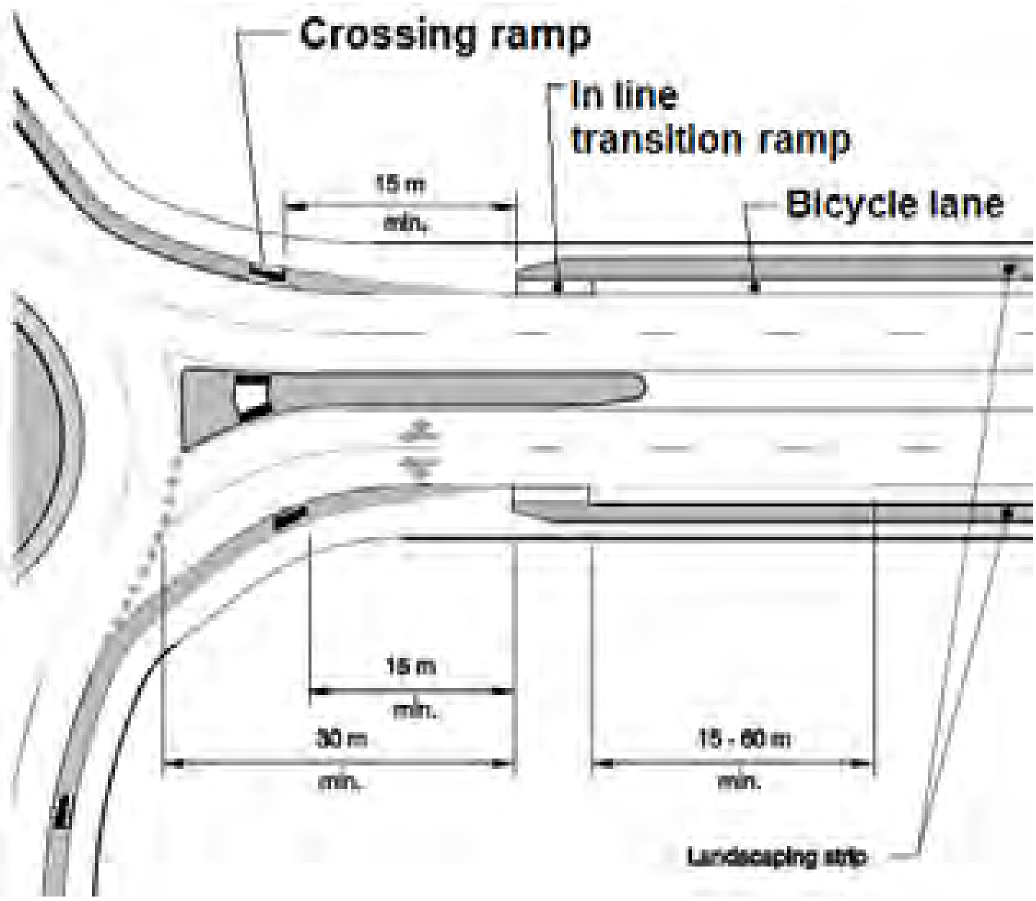
- assist cyclists with lateral positioning on roads with on-street parallel parking in order to reduce the chance of being hit by an opening door of a parked vehicle
- assist cyclists with lateral positioning on roads that are too narrow for a motor vehicle and a bicycle to travel side by side in the same direction
- assist cyclists with navigating a designated bicycle route
- alert road users that they are on a designated bicycle route
- alert road users of the lateral location that cyclists are likely to occupy within the roadway
- encourage safe passing of cyclists by motorists.

8.3.3 Off-road Path Connection

The provision of an off-road path requires a transition that facilitates the movement onto and off the road pavement. Examples of these treatments are shown in Figure 8.9 and Figure 8.10. The cyclist should be alerted to, or be able to view, the off-road path connection ahead to avoid sudden changes of lane by the cyclist.

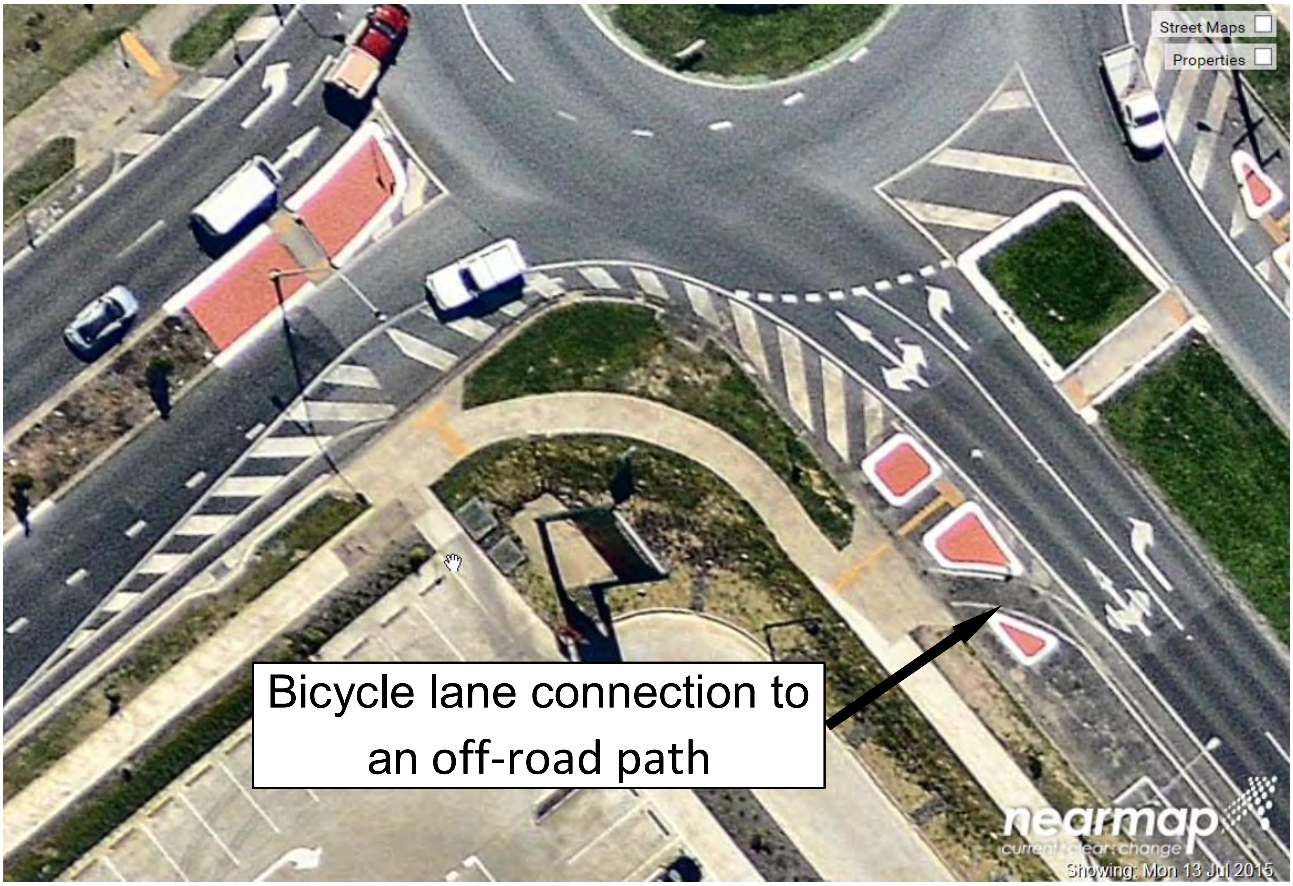
The off-road path connection should be located well in advance of the roundabout so that, if the cyclist decides to continue on-road, the manoeuvre into the through lane can be completed without disrupting the traffic flow close to the entry into the roundabout.

Figure 8.9: Example of an on-road/off-road transition



Source: Queensland Department of Transport and Main Roads (2015c).

Figure 8.10: Example of a bicycle lane transition to an off-road path



Source: Modified nearmap© (2015), 'QLD', map data, nearmap©, Sydney, NSW.

A further consideration for off-road paths is the crossing of the approach roads. At these crossing points conflict areas are created. Priority can be provided to cyclists utilising treatments such as traffic signals or other pedestrian crossings, which may incorporate a raised platform, forming a wombat crossing. Alternatively, depending on traffic and cyclist volumes, the crossing may remain uncontrolled with the cyclist not having priority.

8.4 Conclusions

The crash analysis identified roundabouts where a high number of crashes involving bicycles had occurred. The majority of these roundabouts, 12 of the 17 examined, were located on urban local roads with a 50 km/h or 60 km/h speed zoning.

At the roundabouts selected for this project, the types of crashes involving cyclists that occurred over the analysis period showed that 88% of the total number of these crashes were of the adjacent direction type, either cross or right-turning movement. The key contributing factors identified for these crashes was the speed at which vehicles may be travelling on the entry to the roundabout. For this project a 30 km/h target speed was adopted, however further investigation of the relationship between vehicle speeds and bicycle crash outcomes is needed.

The layouts of the roundabouts were mostly tangential style, with one, in an inner urban area being similar to the radial-type of layout. The tangential type of roundabout created entry path curves which would allow speeds higher than the target speed of 30 km/h. The estimated entry curve speeds at all of the roundabouts examined were greater than the 30 km/h target speed. The treatment option identified for all the roundabouts was to reduce the curve radius along the travel path to no more than 20 m for both the entry curve and the circulating curve, based on the methods available to estimate these speeds.

The actual vehicle speeds were not included in the scope of the project and curve speeds were assessed using methods contained in the design guides, the horizontal curve equation and the ARNDT model. The horizontal curve equation relies on values of side friction being known for the urban local road network. The ARNDT model is based on rural roads and therefore its application for urban local roads may need validation to confirm its application at these locations. The speeds estimated from both estimation methods, whilst acknowledging their limitations, were found to be sufficiently close to provide an indication of the vehicle speeds. The speeds where possible, were also compared against speed survey results obtained in Austroads (2014a) which indicated that the estimated speeds were close to the measured speeds. This indicated that the use of these vehicle speed estimates would provide an indication of the likely vehicle speeds at the roundabouts.

However, there does appear to be a gap in the information for estimating vehicle speeds for urban local road roundabouts.

Using these speed assessment methods, at a single-lane urban local road roundabout, the target speed of 30 km/h could be achieved with a radial-type alignment using geometric parameter contained in Table 8.1. Geometric details for radial-type roundabouts needs to be developed, and a suitable starting point would be to use the information obtained from the United Kingdom and the Netherlands (Table 8.1).

Where the speeds cannot be reduced using methods such as horizontal curves, the installation of vertical displacement devices such as flat-top road humps could be used to reduce vehicle speeds, particularly on local roads.

On the singe-lane rural arterial road roundabout examined, speeds could not be reduced to 30 km/h and separation of bicycles from the motor traffic would be needed. This separation could be provided by an off-road path. This does however create conflicts where the path crosses the approaches to the roundabout and cyclists may not leave the road during times of low traffic flows.

On multilane roundabouts it is more difficult to reduce speeds due to the width of the entry and the possibility of motor vehicles crossing circulating lanes. In these situations, providing an off-road bicycle shared path would enable cyclists an alternative to travel outside of the roundabout. This does create conflict points where the path crosses the approaches to the roundabout and appropriate treatments would need to be assessed. While using curvature to control speed, designers need to ensure that the appropriate design or check vehicle can negotiate the proposed roundabout (entry/circulating/exit curvature) without too much additional widening (encroachment area) to allow for the turning manoeuvre, or swept path of the vehicle. Provision of encroachment areas on the inside of entry curves and central island of the roundabout to allow for larger vehicles, may provide opportunity for smaller vehicles such as cars to adopt a ‘straighter’ drive line, leading to entry/circulating speeds above the desired speed to improve safety.

The concept of reducing sight distance on the approach to a roundabout has shown that approach speeds can be reduced by restricting the available sight distance, but further investigation is required to develop design criteria.

9. Suggested Amendments to Austroads Guides

The investigation found that the majority of the crashes occurred on urban local road roundabouts, with most of these located on roads with a 50 km/h speed limit. Most of the crashes occurred on the circulating lane involving a motor vehicle, about to undertake a turning or straight through movement, entering the circulating lane and colliding with a cyclist already on the circulating lane.

The analysis of the roundabouts included estimating the approach and circulating speeds of motor vehicles travelling through each roundabout and assessing the available sight distance. The method of estimating vehicle speeds was undertaken using the ARNDT model (AGRD Part 4B) and the horizontal curve equation (Austroads 2009b). There are limitations with each method as the ARNDT model was developed for rural arterial roads and its application to urban local roads would require validation and the horizontal curve equation does not take into account other approach curves on the travel path.

The geometric analysis found that the urban local road roundabouts allowed vehicles to enter the circulating lanes and continue through the roundabout at a faster speed than the target speed (< 30 km/h). Reducing this speed was identified as a possible countermeasure to reduce the number of bicycle crashes. Geometric methods to reduce the entry and circulating speed were examined and it was found that reducing the entry curve radius to align with the target speed, the entry curve radius needed to be < 20 m. To achieve this radius the approach alignment needed to have a straighter, or a radial-type alignment.

Sight distances were assessed and it was found that most locations on an urban local road met the requirements for Criterion 2, but did not meet the requirements for Criterion 3. At the arterial road locations, the sight distance requirements, Criterion 2 and Criterion 3, were met on four of the five roundabouts. Criterion 3 sight distance is not a mandatory requirements and so it was considered that sight distance requirements were met. There is some research available that indicates that by limiting the available sight distance on the approach, vehicle speeds on the approach are reduced, however, further research is required and criteria developed for application in a design process.

Where bicycle lanes have been installed on the approach roads and merged with the traffic lane, advisory treatments such as a sharrows, have been used to assist cyclists to establish a suitable position on the entry lane. The use of a sharrow is a supporting treatment to enhance a cyclists capability to move to the centre of the approach lane.

On the arterial road roundabouts examined, five roundabouts, with locations and characteristics ranging from an urban multilane roundabout to a rural single-lane roundabout. The crashes that predominantly had occurred involved a motor vehicle entering the circulating lane colliding with a cyclist or a side-swipe type crash, both left- and right-turning, involving a motor vehicle and cyclist on the circulating lane.

Geometric options to reduce vehicle speeds to the target speed, required treatments that slowed motor vehicles prior to the roundabout, e.g. incorporating a series of reverse curves to slow vehicles prior to the entry and incorporating of small radius (e.g. < 20 m) onto the entry curve and increasing the central island size to achieve the smaller entry curve radius. The incorporation of only a small radius entry curves or larger central island, did not achieve the target speed through the roundabout. The treatment identified to reduce the cyclist crashes was to separate the cyclists from the motor traffic with the use of off-road paths. When using encroachment areas to achieve the desired travel path curvature while catering for the larger vehicles, the encroachment area should be designed to make it unattractive for smaller vehicles, e.g. cars, to traverse.

The suggested amendments to the *Guide to Road Design: Part 4B: Roundabouts* (Austroads 2015a) and *Guide to Road Design: Part 6A: Pedestrian and Cyclist Paths* (Austroads 2009a), and *Cycling Aspects of Austroads Guides* (Austroads 2014b) are contained in the following sections. A brief examination of the *Guide to Traffic Management: Part 6: Intersections, Interchanges and Crossing*s (Austroads 2013a) was also undertaken to complement the suggested amendments to AGRD Part 4B and AGRD Part 6A.

9.1 Guide to Road Design

9.1.1 Part 4B: Roundabouts

The *Guide to Road Design: Part 4B: Roundabouts* (Austroads 2015a) provides guidance with a strong focus on the higher speed arterial road type roundabouts. Many roundabouts are located on local roads and the guidance for these locations needs to be expanded. The suggested amendments relate to the design principles, design speeds and geometric details however may not be able to be implemented until further investigation is undertaken and until appropriate design criteria developed.

The section numbers referred to below relate to the section number in the guide.

Section 2.2: Design Principles

The design principles should include the situation where bicycles and motor vehicles share the road space and the design speed of the roundabout should be no more than the target speed of less than 30 km/h. (Note: the design methods available to obtain this speed need to be developed).

Where the target speed cannot be achieved consideration should be given to providing a separate facility for cyclists away from the circulating lanes.

Section 4: Geometric Design

The current guidance has a focus on the higher speed arterial road roundabout, with speeds in the order of 50 km/h. Specific guidance on geometric methods to achieve entry and circulating speeds of less than 30 km/h are not contained in the guide. This type of information needs to be developed and included in the guide. The structure of the section could be the same as the current structure in Section 4 with geometric parameters developed from the information obtained from countries such as the Netherlands. This type of information would be more likely to relate to urban local road roundabouts, where most of the bicycle crashes have occurred.

On urban local roads, if vehicle speeds are desired to be reduced below that achieved through the geometric design of the roundabout, then the use of vertical displacement devices should be included as an option to reduce approach speeds. A cross-reference to the *Guide to Traffic Management: Part 8: Local Area Traffic Management* (Austroads 2016b) should be included.

9.1.2 Section 5.3: Cyclists

Section 5.3 contains guidance on the considerations needed for cyclists, however the speeds identified in Austroads (2015b) related to vehicle speeds and pedestrian crashes and so further investigation of vehicle speeds and cyclist crashes is needed to identify an appropriate design speed.

The current guidance refers to 20 km/h (AGRD Part 4B (Austroads 2015a)) being suitable for cyclists to share the road with general traffic. The guidance information needs further investigation of the appropriate speed where sharing of the road space to provide an adequate level of safety.

Section 5.3.4: Roads with Shared Traffic, should be amended to refer to the target speed and *Figure 5.1: Bicycle route through single-lane roundabout – no bicycle facility*, should provide an example of a layout to achieve vehicle speeds of less than 30 km/h for the entry and circulating speeds.

Section 5.3.5: Multilane Roundabouts should be amended to recommend that if vehicle speeds on the approach and circulating lanes cannot be reduced to the target speed of 30 km/h, then separated facilities are to be provided, e.g. grade-separated crossing or offroad paths. Achieving the target speed is unlikely when vehicles are able to track across the lanes, effectively increasing the travel path curve radius.

Section 5.3.6: Bicycle Paths and Shared Paths at Roundabouts should include additional information on and examples of acceptable methods, including any design information, to provide the connection from the on-road bicycle lane to an off-road path.

9.1.3 Part 6A: Pedestrian and Cyclist Paths

Part 6A provides guidance on off-road paths, which excludes road crossings. The guidance for off-road paths caters for pedestrians and cyclists, separately or when the path is shared.

As such, there were no sections identified for amendment.

9.2 Guide to Traffic Management

9.2.1 Part 6: Intersections Interchanges and Crossings

The *Guide to Traffic Management: Part 6: Intersections, Interchanges and Crossings* (Austroads 2013a) provides guidance on the types of intersection, the selection of an intersection and traffic management considerations relating to an intersection.

Section 2.3: Intersection Selection

Section 2.3.2: Selection Process outlines a process to determine the most appropriate type of intersection. The considerations strongly emphasise network performance with recognition that the presence of a bicycle network may also influence the type of intersection. The process should be amended to consider the safety objectives, particularly relating to bicycle safety, followed by the network objectives.

Section 2.3.3: Assessment of Intersections, *Table 2.2: Intersection control options and selection criteria* indicates the presence of cyclists as a key factor in the selection. The information needs to include reference to suitable treatments for cyclists, depending on motor vehicle speeds. Treatments such as grade-separation or, if an off-road path is selected, consideration be given to providing a suitable crossing of the approach legs of the roundabout.

Section 4.4: Road Space Allocation and Lane Management

Section 4.4.2: Cyclists indicates that specific provision for cyclists is not required where vehicle speeds are low, i.e. ≤ 50 km/h. At roundabouts, reference should be made to the target speed following further investigation to determine an appropriate speed for locations where motor vehicles and cyclists may conflict.

The location of the merge zone and advisory treatments, such as sharrows or bicycle awareness zones (refer to Queensland Department of Transport and Main Roads 2015b) to assist cyclists to establish a suitable position on the entry lane position needs to be included. This would be strengthened if the sharrow marking was included in the road rules giving priority to the cyclist.

Options are provided for consideration where cyclists travel through a large single-lane or multilane roundabout with no provision of specific facilities, which may be acceptable under some circumstances, or an on-road facility (Figure 4.6). The guidance should relate to the design speed of the roundabout and, if the design speed is > 30 km/h, separated off-road facilities should be considered. The provision of off-road facilities would also need to consider costs for installation and maintenance, particularly in rural or remote areas.

Risks to cyclists is outlined with some criteria to be used including the proportion of cyclists expected to use the intersection, the functional classification and the overall traffic management strategy. This indicates a risk assessment approach to the selection of treatments, which may be appropriate to assist in priortising works. The appropriate treatment for reducing speeds or separating cyclists away from the circulating lanes of the roundabout should be indicated.

9.3 Cycling Aspects of Austroads Guides

Cycling Aspects of Austroads Guides (Austroads 2014b) provides information and links to information on bicycle facilities in the Austroads Guides. The sections suggested for amendment include the suggested amendments to the AGRD Part 4B (Austroads 2015a) and *Guide to Traffic Management: Part 6* (Austroads 2013a) and are outlined below.

If the suggestions contained in Section 9.1 and Section 9.2 are adopted then the following update would be required.

9.3.1 Section 5.5: Roundabouts

Reference to the provision of an on-road bicycle lane at larger single-lane or multilane roundabouts should be removed.

Reference to local road roundabouts and speeds of ≤ 50 km/h be amended to be ≤ 30 km/h.

At multilane roundabouts, the target motor vehicle speed of ≤ 30 km/h may not be able to be achievable and, when this occurs a separated facility should be provided for cyclists.

In *Section 5.5.2: Local Roads – No Bicycle Facility* reference to low traffic speeds at roundabouts being ≤ 50 km/h should be amended to ≤ 30 km/h.

In *Section 5.5.3: Bicycle Lanes at Single-lane Roundabouts* Figure 5.21 indicates bicycle lanes being provided up to the holding lines of the roundabout. This was found to allow higher motor vehicle speeds at the entry. To achieve the desired entry speed, the entry width needs to be kept as narrow as possible, which requires the bicycle lane to end prior to the holding line. Figure 5.21 needs to show the narrower entry and bicycle lanes ending prior to the holding line.

Figure 5.22 and Figure 5.23 show a single-lane roundabout with bicycle lanes alongside the circulating lanes. This type of treatment has been removed from *Guide to Road Design: Part 4B: Roundabouts* (Austroads 2015a) and this should be reflected in this guide.

Figure 5.24, Figure 5.25 and Figure 5.26 show a multilane roundabout with bicycle lanes alongside the circulating lanes. At multilane roundabouts it is suggested that separated off-road facilities be provided and this figure should be amended to show off-road facilities.

9.4 Other Recommendations

During the assessment of the roundabouts, the sight distance required in the *Guide to Road Design: Part 4B: Roundabouts* (Austroads 2015a) for Criterion 2 was met but the requirements for Criterion 3 were not met.

Some research on sight distances at roundabouts indicated that restricting the sight distance relating to Criterion 3 has resulted in reducing approach speeds. This requires further investigation including the development of design criteria and it is recommended that a further investigation on the effects of sight distance on the safety performance at a roundabout, and the investigation includes sight distance and approach speeds.

References

American Association of State Highway and Transportation Officials 2011, *Policy on the geometric design of highways and streets*, 6th edn, AASHTO, Washington, DC, USA.

American Association of State Highway and Transportation Officials 2012, *Guide for the development of bicycle facilities*, 4th edn, AASHTO, Washington, DC, USA.

Asmus, D, Campbell, D & Dunn, R 2012, *Evaluation of the C-roundabout: an improved multi-lane roundabout design for cyclists,* research report no. 510, NZ Transport Agency, Wellington, New Zealand.

Austroads 2009a, *Guide to road design part 6A: pedestrian and cyclist paths*, AGRD06A-09, Austroads, Sydney, NSW.

Austroads 2009b, *Impact of LATM treatments on speed and safety*, APT-123-09, Austroads Sydney, NSW.

Austroads 2010, *Guide to road design part 4A: unsignalised and signalised intersections*, AGRD04A-10, Austroads, Sydney, NSW.

Austroads 2013a, *Guide to traffic management part 6: intersections, interchanges and crossings*, AGTM06-13, Austroads, Sydney, NSW.

Austroads 2013b, *Design vehicles and turning path templates guide*, AP-G34-13, Austroads, Sydney, NSW.

Austroads 2013c, *Improving the performance of safe system infrastructure: stage 1 interim report*, AP-T256-13, Austroads, Sydney, NSW.

Austroads 2014a*, Effectiveness of on-road bicycle lanes at roundabouts*, AP-R416-14, Austroads, Sydney, NSW.

Austroads 2014b, *Cycling aspects of Austroads Guides*, AP-G88-14, Austroads, Sydney, NSW.

Austroads 2015a, *Guide to road design part 4B: roundabouts*, AGRD04B-15, Austroads, Sydney, NSW.

Austroads 2015b, *Improving the performance of safe system infrastructure: final report*, AP-R498-15, Austroads, Sydney, NSW.

Austroads 2015c, *Guide to road safety part 8: treatment of crash locations*, AGRS08-15, Austroads, Sydney, NSW.

Austroads 2016a, *Guide to road design part 3: geometric design*, AGRD03-16, Austroads, Sydney, NSW.

Austroads 2016b, *Guide to traffic management part 8: local area traffic management*, AGTM08-16, Austroads, Sydney, NSW.

Bahouth, G, Graygo, J, Digges, K, Schulman, C & Baur, P 2014, 'The benefits and tradeoffs for varied high-severity injury risk thresholds for advanced automatic crash notification systems', *Traffic Injury Prevention*, vol. 15, supplement 1, pp. S134-40.

Boender, J 2000, 'The new Dutch guidelines on roundabouts', *International symposium on highway geometric design, 2nd, 2000, Mainz, Germany*, Road and Transportation Research Association, Cologne, Germany, pp. 184-91.

Brilon, W 2014, 'Roundabouts: a state of the art in Germany, *International conference on roundabouts*, *4th*, *Seattle, Washington*, Transportation Research Board, Washington, DC, USA, 15 pp.

Bureau of Infrastructure, Transport and Regional Economics 2015, *Australian cycling safety: casualties, crash types and participation levels*, BITRE, Canberra, ACT.

Campbell, D, Jurisich, I & Dunn, R 2006, *Improved multi-lane roundabout designs for cyclists*, research report no. 287, Land Transport New Zealand, Wellington, NZ.

Campbell, D, Jurisich, I & Dunn, R 2011, 'Improved safety features for multi-lane roundabouts', *International conference on roundabouts*, *3rd*, *2011*, *Carmel, Indiana*, Transportation Research Board, Washington, DC, USA, 16 pp.

Campbell, D, Jurisich, I & Dunn, R 2012, *Improved multi-lane roundabout designs for urban areas*, research report no. 476, NZ Transport Agency, Wellington, New Zealand.

Davis, G 2001, 'Relating severity of pedestrian injury to impact speed in vehicle-pedestrian crashes: simple threshold model', *Transportation Research Record*, no. 1773, pp. 108-13.

de Groot, R 2007, *Design manual for bicycle traffic*, CROW, Ede, The Netherlands.

Department for Transport 2016, *Design manual for roads and bridges*, DfT, London, UK, viewed 22 September 2016, <http://www.standardsforhighways.co.uk/dmrb/>.

Department of Transport, Planning and Infrastructure 2015, *Advisory bicycle pavement marking: shared lane marking* (*Sharrow*), operational instructions 9.4, DPTI, Adelaide, SA.

Jensen, SU 2013, 'Safety effects of converting intersections to roundabouts', *Transportation Research Record,* no. 2389, pp. 22-9.

Land Transport New Zealand 2007, *New Zealand on-road tracking curves for heavy vehicles*, RTS 18, Land Transport New Zealand, Wellington, NZ.

National Transport Commission 2012, *Australian road rules*, February 2012 version, NTC, Melbourne, Vic.

Queensland Department of Transport and Main Roads 2015a, *Supplement manual of uniform traffic control devices (MUTCD): part 3: works on roads*, TMR, Brisbane, Qld.

Queensland Department of Transport and Main Roads 2015b, *Traffic and road use management manual (TRUM)*, TMR, Brisbane, Qld.

Queensland Department of Transport and Main Roads 2015c, *Technical note 136: providing for cyclists at roundabouts*, TMR, Brisbane, Qld.

Queensland Department of Transport and Main Roads 2016, *ARNDT*, TMR, Brisbane, Qld, viewed 22 September 2016, <http://www.tmr.qld.gov.au/business-industry/Road-systems-and-engineering/Software/ARNDT.aspx>.

Rodergerdts, L, Bansen, J, Tiesler, C, Knudsen, J, Myers, E, Johnson, M, Moule, M, Persaud, B, Lyon, C, Hallmark, S, Isebrands, H, Crown, RB, Guichet, B & O'Brien, A 2010, *Roundabouts: an informational guide*, 2nd edn, National Cooperative Highway Research Program (NCHRP) report no. 672, Transportation Research Board, Washington, DC, USA.

Schreiber, M, Ortlepp, J & Bakaba, JE 2014, 'Road safety of cyclists at intersections', *Transport research arena*, *5th, 2014, Paris, France,* Transport Research Arena, Paris, France.

Silvano, AP, Ma, X & Koutsopoulos, HN 2015, 'When do drivers yield to cyclists at unsignalized roundabouts? Empirical evidence and behavioral analysis', *Transportation Research Board annual meeting, 94th, 2015, Washington, DC,* Transportation Research Board, Washington, DC, USA, 11 pp.

Turner, SA, Roozenburg, AP & Smith, AW 2009, *Roundabout crash prediction models*, research report no. 386, NZ Transport Agency, Wellington, New Zealand.

Transportation Association of Canada 1999, *Geometric design guide for Canadian roads: part 1 and 2*, TAC, Ottawa, Canada.

Transport for London 2014, *International cycling infrastructure best practice study*, TfL, London, UK.

Transport for London 2015, *London cycling design standards*, TfL, London, UK, viewed 22 September 2016, <https://tfl.gov.uk/corporate/publications-and-reports/streets-toolkit>.

ViaStrada 2016, *German roundabout design*, ViaStrada, Christchurch, New Zealand.

VicRoads 2005, *Providing for cyclists at roundabouts,* cycle notes no. 15, VicRoads, Kew, Vic.

VicRoads 2013, *Crash stats user guide*, VicRoads, Kew, Vic, viewed 22 September 2016, <http://data.vicroads.vic.gov.au/metadata/crashstats_user_guide_and_appendices.pdf>.

Appendix A Crash Data

A.1 Crashes by Year, Month, Day and Time

Table A 1: Bicycle crashes at roundabouts – by year and location

Year	Crashes by location																			
	ACT		NSW		NT		QLD		SA		TAS		VIC		WA		NZ		Total	
	No	%	No	%	No	%	No	%	No	%	No	%	No	%	No	%	No	%	No	%
2009	4	9%	137	21%	4	21%	106	25%	50	19%	7	22%	116	20%	42	17%	82	17%	548	20%
2010	7	17%	121	18%	4	21%	94	22%	42	16%	2	6%	108	18%	44	18%	90	18%	512	18%
2011	8	19%	126	19%	4	21%	101	23%	49	19%	7	22%	133	23%	69	27%	104	21%	600	22%
2012	16	38%	141	22%	2	11%	75	17%	61	23%	9	28%	106	18%	47	19%	101	21%	558	20%
2013	7	17%	132	20%	5	26%	54	13%	61	23%	7	22%	124	21%	47	19%	111	23%	549	20%
Total	42	100%	657	100%	19	100%	430	100%	263	100%	54	100%	587	100%	249	100%	487	100%	2766	100%

Table A 2: Bicycle crashes at roundabouts – by month and location

Month	Crashes by location																			
	ACT		NSW		NT		QLD		SA		TAS		VIC		WA		NZ		Total	
	No	%	No	%	No	%	No	%	No	%	No	%	No	%	No	%	No	%	No	%
Jan	1	2%	56	9%	0	0%	31	7%	23	10%	2	6%	41	7%	16	6%	36	7%	208	7%
Feb	8	19%	56	8%	0	0%	40	9%	25	9%	4	13%	60	10%	22	9%	45	9%	258	10%
Mar	5	12%	72	11%	1	5%	52	12%	26	10%	5	16%	64	11%	32	13%	47	10%	304	11%
Apr	0	0%	57	9%	3	16%	34	8%	22	8%	2	6%	48	8%	18	7%	43	9%	227	8%
May	3	7%	64	10%	2	11%	37	9%	28	11%	3	9%	62	11%	28	11%	53	11%	280	10%
Jun	3	7%	50	8%	3	16%	29	7%	24	9%	2	6%	61	10%	17	7%	41	8%	230	9%
Jul	2	5%	52	8%	3	16%	43	10%	24	9%	3	9%	43	7%	25	6%	47	10%	232	8%
Aug	4	10%	55	8%	2	11%	34	8%	12	5%	2	6%	44	7%	18	7%	34	7%	205	8%
Sep	7	17%	62	9%	1	5%	24	6%	22	8%	5	16%	40	7%	13	5%	40	8%	214	7%
Oct	3	7%	50	8%	2	11%	40	9%	20	8%	3	9%	39	7%	22	9%	32	7%	211	8%
Nov	2	5%	48	7%	0	0%	29	7%	15	6%	1	3%	41	7%	25	10%	41	8%	202	8%
Dec	4	10%	35	5%	2	11%	37	9%	22	8%	0	0%	44	7%	23	9%	29	6%	196	7%
Total	42	100%	657	100%	19	100%	430	100%	263	100%	32	100%	587	100%	249	100%	487	100%	2766	100%

Table A 3: Crashes at roundabouts – by day of week and location

Day of the week	Crashes by location																			
	ACT		NSW		NT		QLD		SA		TAS		VIC		WA		NZ		Total	
	No	%	No	%	No	%	No	%	No	%	No	%	No	%	No	%	No	%	No	%
Sun	3	7%	63	10%	3	16%	30	7%	27	10%	54	13%	42	7%	34	7%	35	7%	228	8%
Mon	6	14%	92	14%	6	32%	60	14%	39	15%	8	25%	99	17%	74	16%	66	14%	414	15%
Tue	10	24%	118	18%	4	21%	64	15%	49	19%	4	22%	108	18%	78	17%	94	19%	491	18%
Wed	6	14%	114	17%	3	16%	85	20%	51	19%	4	13%	102	17%	86	18%	92	19%	503	18%
Thu	5	12%	120	18%	1	5%	71	17%	38	14%	4	13%	91	16%	78	17%	90	18%	465	17%
Fri	8	19%	83	13%	1	5%	71	17%	35	13%	3	13%	90	15%	67	14%	65	13%	391	14%
Sat	4	10%	67	10%	1	5%	49	11%	24	9%	5	16%	55	9%	49	11%	45	9%	274	10%
Total	42	100%	657	100%	19	100%	430	100%	263	100%	32	100%	587	100%	249	100%	487	100%	2766	100%

Table A 4: Bicycle crashes at roundabouts – by time of day and location

Time of day	Crashes by location																			
	ACT		NSW		NT		QLD		SA		TAS		VIC		WA		NZ		Total	
	No	%	No	%	No	%	No	%	No	%	No	%	No	%	No	%	No	%	No	%
Before 7am	6	9%	79	12%	3	16%	0	0%	23	7%	2	6%	45	8%	35	12%	34	7%	262	8%
7–10am	14	31%	203	31%	7	37%	0	0%	86	34%	7	26%	195	33%	86	33%	159	33%	227	27%
10–3pm	10	26%	122	19%	2	11%	0	0%	45	18%	9	28%	119	20%	37	17%	107	22%	451	16%
3–7pm	12	25%	203	31%	7	37%	0	0%	88	33%	12	30%	175	30%	76	33%	139	29%	712	26%
After 7pm	0	8%	50	8%	0	0%	0	0%	21	8%	2	11%	53	9%	12	4%	43	9%	181	7%
Unknown	0	0%	0	0%	0	0%	430	100%	0	0%	0	0%	0	0%	3	1%	5	1%	438	16%
Total	42	100%	657	100%	19	100%	430	100%	263	100%	32	100%	587	100%	249	100%	487	100%	2766	100%

A.2 Crashes by Type and Severity

Table A 5: Bicycle crashes at roundabouts – by crash type groupings and location

Crash group	Crashes by location																			
	ACT		NSW		NT		QLD		SA		TAS		VIC		WA		NZ		Total	
	No	%	No	%	No	%	No	%	No	%	No	%	No	%	No	%	No	%	No	%
Pedestrian	0	0%	5	1%	0	0%	0	0%	0	0%	0	0%	0	0%	1	0%	1	0%	7	0%
Adjacent direction (intersection)	28	67%	483	73%	10	53%	271	63%	56	21%	22	69%	477	81%	197	79%	300	62%	1844	67%
Opposing direction	2	5%	40	6%	1	5%	28	7%	1	0%	2	6%	19	3%	7	3%	36	7%	125	5%
Same direction	4	10%	58	9%	3	16%	75	17%	4	2%	4	13%	56	10%	33	13%	127	26%	364	13%
Manoeuvring	4	10%	33	5%	0	0%	35	8%	0	0%	0	0%	11	2%	1	0%	2	0%	86	3%
Overtaking	0	0%	0	0%	0	0%	0	0%	1	1%	0	2%	2	0%	0	0%	15	3%	18	1%
On path	0	0%	2	0%	0	0%	1	0%	0	0%	0	0%	1	0%	0	0%	4	1%	8	0%
Off path, on straight	0	0%	18	3%	2	11%	14	3%	1	1%	2	4%	19	3%	10	3%	1	0%	45	2%
Off path, on curve	4	4%	9	1%	0	0%	4	1%	0	0%	2	6%	0	0%	0	0%	1	0%	20	1%
Other	0	0%	8	1%	3	16%	2	0%	200	75%	0	0%	2	0%	0	0%	0	0%	215	8%
Total	42	100%	657	100%	19	100%	430	100%	263	100%	32	100%	587	100%	249	100%	487	100%	2766	100%

Table A 6: Vehicles from adjacent directions – breakdown by crash type and location

Crash type	Crashes by location													
	ACT		NSW		QLD		SA		TAS		VIC		WA	
	No	%	No	%	No	%	No	%	No	%	No	%	No	%
Cross traffic	21	50%	407	62%	140	33%	44	17%	18	56%	367	63%	135	54%
Right far	1	2%	24	4%	20	5%	3	1%	0	0%	25	4%	13	5%
Left far	0	0%	0	0%	1	0%	0	0%	1	3%	1	0%	1	0%
Right near	4	10%	28	4%	60	14%	3	1%	1	3%	32	5%	14	6%
Two right turning	0	0%	2	0%	2	0%	0	0%	1	3%	1	0%	0	0%
Right/left far	0	0%	0	0%	1	0%	0	0%	0	0%	1	0%	0	0%
Left near	2	5%	18	3%	39	9%	6	2%	2	6%	40	7%	13	5%
Right/left near	0	0%	0	0%	0	0%	0	0%	0	0%	1	0%	0	0%
Other adjacent	0	0%	4	1%	8	2%	0	0%	0	0%	9	2%	21	9%
Total(1)	28	67%	483	73%	271	63%	56	21%	24	71%	477	81%	197	79%

1 Percentages are of the total number of crashes – refer to Table A 5.

Note: Northern Territory and New Zealand were not included as crash type was not provided and not comparable to the other states respectively.

Table A 7: Vehicles from same direction – crash type and location

Crash type	Crashes by location													
	ACT		NSW		QLD		SA		TAS		VIC		WA	
	No	%	No	%	No	%	No	%	No	%	No	%	No	%
Rear end	0	0%	16	2%	6	1%	1	0%	1	3%	11	2%	7	3%
Left rear	0	0%	2	0%	2	0%	0	0%	0	0%	2	0%	2	1%
Right rear	0	0%	1	0%	3	1%	0	0%	0	0%	2	0%	0	0%
Lane side swipe	2	5%	15	2%	18	4%	2	1%	2	6%	15	3%	8	3%
Lane change – left	1	2%	1	0%	0	0%	0	0%	0	0%	1	0%	1	0%
Right turn side swipe	0	0%	5	1%	15	3%	0	0%	0	0%	4	1%	2	1%
Left turn side swipe	1	2%	18	3%	31	7%	1	0%	1	3%	18	3%	13	5%
Other same direction	0	0%	2	0%	0	0%	0	0%	1	3%	3	1%	0	0%
Total(1)	4	9%	60	9%	75	17%	4	1%	9	15%	56	10%	33	13%

1 Percentages are of the total number of crashes – refer to Table A 5.

Note: Northern Territory and New Zealand were not included as crash type was not provided and not comparable to the other states respectively.

Table A 8: Crash groups by crash severity – ACT

Crash group	Crash severity – ACT			
	Injury		PDO[1]	
	Count	%	Count	%
Pedestrian	0	0%	0	0%
Vehicle from adjacent directions (intersection)	28	67%	35	65%
Vehicles from opposing directions	2	5%	1	2%
Vehicles from same direction	4	10%	12	22%
Manoeuvring	4	10%	6	11%
Overtaking	0	0%	0	0%
On path	0	0%	0	0%
Off path, on straight	0	0%	0	0%
Off path, on curve	4	10%	0	0%
Other	0	0%	0	0%
Total	42	100%	54	100%

1 *PDO – 'Property Damage Only' crashes.*

Table A 9: Crash groups by crash severity – NSW

Crash group	Crash severity – NSW					
	Fatal		Injury		Non-casualty	
	Count	%	Count	%	Count	%
Pedestrian	0	0%	5	1%	0	0%
Vehicle from adjacent directions (intersection)	0	0%	483	74%	0	0%
Vehicles from opposing directions	0	0%	40	6%	0	0%
Vehicles from same direction	0	0%	58	9%	2	100%
Manoeuvring	0	0%	33	5%	0	0%
Overtaking	–	–	–	–	–	–
On path	1	50%	2	0%	0	0%
Off path, on straight	1	50%	17	3%	0	0%
Off path, on curve	0	0%	9	1%	0	0%
Other	0	0%	8	1%	0	0%
Total	2	100%	655	100%	2	100%

Table A 10: Crash groups by crash severity – NT

Crash group	Crash severity – NT			
	Minor injury		Serious injury	
	Count	%	Count	%
Pedestrian	0	0%	0	0%
Vehicle from adjacent directions (intersection)	6	67%	4	40%
Vehicles from opposing directions	1	11%	0	0%
Vehicles from same direction	1	11%	2	20%
Manoeuvring	0	0%	0	0%
Overtaking	0	0%	0	0%
On path	0	0%	0	0%
Off path, on straight	1	11%	1	10%
Off path, on curve	0	0%	0	0%
Other	0	0%	3	30%
Total	9	100%	10	100%

Table A 11: Crash groups by crash severity – QLD

Crash group	Crash severity – QLD							
	Fatal		Hospitalisation		Medical treatment		Minor injury	
	Count	%	Count	%	Count	%	Count	%
Pedestrian	0	0%	0	0%	0	0%	0	0%
Vehicle from adjacent directions (intersection)	2	50%	137	69%	87	60%	45	55%
Vehicles from opposing directions	0	0%	9	5%	15	10%	4	5%
Vehicles from same direction	0	0%	29	15%	25	17%	21	26%
Manoeuvring	0	0%	17	9%	12	8%	6	7%
Overtaking	0	0%	0	0%	0	0%	0	0%
On path	0	0%	0	0%	0	0%	1	1%
Off path, on straight	2	50%	4	2%	5	3%	3	4%
Off path, on curve	0	0%	2	1%	0	0%	2	2%
Other	0	0%	2	1%	0	0%	0	0%
Total	4	100%	200	100%	144	100%	82	100%

Table A 12: Crash groups by crash severity – SA

Crash group	Crash severity – SA					
	Minor		PDO(1)		Serious	
	Count	%	Count	%	Count	%
Pedestrian	0	0%	0	0%	0	0%
Vehicle from adjacent directions (intersection)	53	22%	127	60%	3	17%
Vehicles from opposing directions	1	0%	3	1%	0	0%
Vehicles from same direction	4	2%	30	14%	0	0%
Manoeuvring	0	0%	5	2%	0	0%
Overtaking	1	0%	2	1%	0	0%
On path	0	0%	0	0%	0	0%
Off path, on straight	1	0%	3	1%	0	0%
Off path, on curve	0	0%	0	0%	0	0%
Other	185	76%	40	19%	15	83%
Total	245	100%	210	100%	18	100%

1 *PDO – 'Property Damage Only' crashes.*

Table A 13: Crash groups by crash severity – TAS

Crash group	Crash severity – TAS							
	First aid		Minor injury		PDO(1)		Serious injury	
	Count	%	Count	%	Count	%	Count	%
Pedestrian	0	0%	0	0%	0	0%	0	0%
Vehicle from adjacent directions (intersection)	3	75%	18	69%	12	55%	1	50%
Vehicles from opposing directions	1	25%	1	4%	2	9%	0	0%
Vehicles from same direction	0	0%	4	15%	5	23%	0	0%
Manoeuvring	0	0%	0	0%	1	5%	0	0%
Overtaking	0	0%	0	0%	1	5%	0	0%
On path	0	0%	0	0%	0	0%	0	0%
Off path, on straight	0	0%	1	4%	0	0%	1	50%
Off path, on curve	0	0%	2	8%	1	5%	0	0%
Other	0	0%	0	0%	0	0%	0	0%
Total	4	100%	26	100%	22	100%	2	100%

1 *PDO – 'Property Damage Only' crashes.*

Table A 14: Crash groups by crash severity – VIC

Crash group	Crash severity – VIC					
	Fatal		Serious injury		Minor injury	
	Count	%	Count	%	Count	%
Pedestrian	0	0%	0	0%	0	0%
Vehicle from adjacent directions (intersection)	1	100%	110	80%	366	82%
Vehicles from opposing directions	0	0%	2	1%	17	4%
Vehicles from same direction	0	0%	15	11%	41	9%
Manoeuvring	0	0%	3	2%	8	2%
Overtaking	0	0%	0	0%	2	0%
On path	0	0%	1	1%	0	0%
Off path, on straight	0	0%	6	4%	13	3%
Off path, on curve	0	0%	0	0%	0	0%
Other	0	0%	1	1%	1	0%
Total	1	100%	138	100%	448	100%

Table A 15: Crash groups by crash severity – WA

Crash group	Crash severity – WA									
	Fatal		Hospitalisation		Medical treatment		PDO[(1)] major		PDO[(1)] minor	
	Count	%	Count	%	Count	%	Count	%	Count	%
Pedestrian	1	50%	0	0%	0	0%	0	0%	0	0%
Vehicle from adjacent directions (intersection)	1	50%	45	74%	151	81%	17	74%	148	76%
Vehicles from opposing directions	0	0%	2	3%	5	3%	0	0%	6	3%
Vehicles from same direction	0	0%	9	15%	24	13%	5	22%	34	18%
Manoeuvring	0	0%	1	2%	0	0%	0	0%	2	1%
Overtaking	0	0%	0	0%	0	0%	0	0%	0	0%
On path	0	0%	0	0%	0	0%	0	0%	0	0%
Off path, on straight	0	0%	4	7%	6	3%	1	4%	4	2%
Off path, on curve	0	0%	0	0%	0	0%	0	0%	0	0%
Other	0	0%	0	0%	0	0%	0	0%	0	0%
Total	2	100%	61	100%	186	100%	23	100%	194	100%

1 *PDO – 'Property Damage Only' crashes.*

Table A 16: Crash groups by crash severity – NZ

Crash group	Crash severity – NZ					
	Fatal		Serious injury		Minor injury	
	Count	%	Count	%	Count	%
Pedestrian	0	0%	0	0%	1	0%
Vehicle from adjacent directions (intersection)	1	50%	53	67%	246	61%
Vehicles from opposing directions	0	0%	4	5%	32	8%
Vehicles from same direction	0	0%	18	23%	109	27%
Manoeuvring	0	0%	0	0%	2	0%
Overtaking	1	50%	3	4%	11	3%
On path	0	0%	1	1%	3	1%
Off path, on straight	0	0%	0	0%	1	0%
Off path, on curve	0	0%	0	0%	1	0%
Other	0	0%	0	0%	0	0%
Total	2	100%	79	100%	406	100%

A.3 Crashes by Light, Surface and Atmospheric Conditions

Table A 17: Lighting conditions by location

Lighting conditions	Crashes by location																			
	ACT		NSW		NT		QLD		SA		TAS		VIC		WA		NZ		Total	
	No	%	No	%	No	%	No	%	No	%	No	%	No	%	No	%	No	%	No	%
Daylight	34	80%	483	74%	15	79%	337	78%	212	82%	25	79%	439	75%	208	84%	402	83%	2155	78%
Dawn/dusk	4	15%	99	15%	2	11%	53	12%	0	0%	2	6%	68	12%	14	6%	22	5%	264	10%
Dark – street lights on	2	5%	69	10%	1	5%	39	9%	0	0%	3	9%	55	9%	20	8%	60	12%	249	9%
Dark – street lights off/not present	2	5%	6	1%	1	5%	1	0%	0	0%	1	3%	3	1%	4	2%	3	1%	21	1%
Dark – street light condition unknown	0	0%	0	0%	0	0%	0	0%	51	18%	0	0%	14	2%	0	0%	0	0%	65	2%
Other/unknown	0	0%	0	0%	0	0%	0	0%	0	0%	1	3%	8	1%	3	1%	0	0%	12	0%
Total	42	100%	657	100%	19	100%	430	100%	263	100%	32	100%	587	100%	249	100%	487	100%	2766	100%

Table A 18: Surface conditions by location

Surface conditions	Crashes by location																			
	ACT		NSW		NT		QLD		SA		TAS		VIC		WA		NZ		Total	
	No	%	No	%	No	%	No	%	No	%	No	%	No	%	No	%	No	%	No	%
Dry	34	81%	571	87%	19	100%	388	90%	233	89%	29	91%	423	72%	224	90%	398	82%	2319	84%
Wet	7	17%	84	13%	0	0%	42	10%	30	11%	2	6%	67	11%	23	9%	89	18%	344	12%
Other/unknown	1	2%	2	0%	0	0%	0	0%	0	0%	1	3%	97	17%	2	1%	0	0%	103	4%
Total	42	100%	657	100%	19	100%	430	100%	263	100%	32	100%	587	100%	249	100%	487	100%	2766	100%

Table A 19: Atmospheric conditions by location

Atmospheric conditions	Crashes by location																			
	ACT		NSW		NT		QLD		SA		TAS		VIC		WA		NZ		Total	
	No	%	No	%	No	%	No	%	No	%	No	%	No	%	No	%	No	%	No	%
Clear	33	79%	549	84%	17	89%	392	91%	241	92%	30	94%	420	72%	0	0%	413	85%	2095	76%
Raining	6	14%	52	8%	0	0%	32	7%	21	8%	2	6%	49	8%	0	0%	63	13%	225	8%
Other/unknown	3	7%	56	8%	2	11%	6	1%	1	0%	0	0%	118	20%	249	100%	11	2%	446	16%
Total	42	100%	657	100%	19	100%	430	100%	263	100%	32	100%	587	100%	249	100%	487	100%	2766	100%

A.4 Crashes by Speed Zones

Table A 20: Speed zones by location

Speed zone	Crashes by location																			
	ACT		NSW		NT		QLD		SA		TAS		VIC		WA		NZ		Total	
	No	%	No	%	No	%	No	%	No	%	No	%	No	%	No	%	No	%	No	%
0–50 km/h	0	0	483	73%	7	37%	134	31%	184	70%	22	69%	319	54%	0	0%	427	88%	1576	57%
60 km/h	0	0	150	23%	9	47%	280	65%	73	27%	9	28%	218	37%	0	0%	13	3%	752	27%
70 km/h	0	0	17	3%	1	5%	12	3%	2	1%	1	3%	11	2%	0	0%	17	3%	61	2%
80–00 km/h	0	0	5	1%	2	11%	4	1%	4	2%	0	0%	17	3%	0	0%	30	6%	62	2%
Unknown	42	100%	2	0%	0	0%	0	0%	0	0%	0	0%	22	4%	249	100%	0	0%	315	11%
Total	42	100%	657	100%	19	100%	430	100%	263	100%	32	100%	587	100%	249	100%	487	100%	2766	100%

A.5 Crashes by Demographics

Table A 21: Gender and age of cyclists Involved in crashes by location

Cyclist demographics	Crashes by location																			
	ACT		NSW		NT		QLD		SA		TAS		VIC		WA		NZ		Total	
	No	%	No	%	No	%	No	%	No	%	No	%	No	%	No	%	No	%	No	%
Male																				
0–20	1	2%	63	10%	2	11%	56	13%	12	5%	4	12%	42	7%	17	7%	74	15%	271	10%
21–40	3	7%	216	32%	6	32%	125	29%	79	30%	9	28%	171	29%	70	28%	95	19%	770	28%
41–60	7	17%	193	29%	7	37%	127	29%	74	28%	11	33%	158	27%	74	30%	113	23%	760	28%
61+	3	7%	52	8%	1	5%	38	9%	17	6%	1	3%	55	9%	19	8%	39	8%	225	78%
Unknown age	4	10%	19	2%	0	0%	0	0%	7	2%	0	0%	2	0%	1	0%	15	3%	39	1%
Subtotal: male	18	43%	536	81%	16	84%	338	79%	188	71%	25	76%	427	72%	181	73%	336	69%	2065	75%
Female																				
0–20	0	0%	10	2%	0	0%	15	3%	5	2%	3	9%	14	2%	5	2%	22	5%	73	3%
21–40	5	12%	55	8%	1	5%	38	9%	33	13%	2	6%	78	13%	28	11%	59	12%	299	11%
41–60	0	0%	40	6%	2	11%	32	7%	32	12%	3	9%	60	10%	18	7%	54	11%	241	9%
61+	0	0%	7	1%	0	0%	7	2%	5	2%	0	0%	7	1%	2	1%	11	2%	39	1%
Unknown age	1	2%	6	1%	0	0%	0	0%	0	0%	0	0%	1	0%	1	0%	3	1%	12	0%
Subtotal: female	6	14%	108	18%	3	16%	92	21%	75	29%	7	24%	160	27%	54	21%	149	31%	664	23%
Unknown age & gender	18	43%	3	1%	0	0%	0	0%	0	0%	0	0%	0	0%	14	6%	2	0%	37	2%
Total	42	100%	657	100%	19	100%	430	100%	263	100%	32	100%	587	100%	249	100%	487	100%	2766	100%

A.6 Crashes by Road User Type

Table A 22: Other road users involved by location

Other road users involved	Crashes by location																			
	ACT		NSW		NT		QLD		SA		TAS		VIC		WA		NZ		Total	
	No	%	No	%	No	%	No	%	No	%	No	%	No	%	No	%	No	%	No	%
Motorbike/moped	0	0%	2	0%	0	0%	1	0%	0	0%	0	0%	0	0%	6	2%	0	0%	9	0%
Light vehicle	22	52%	506	77%	16	84%	391	94%	243	95%	28	88%	547	95%	226	92%	460	94%	2439	89%
Heavy vehicle	0	0%	74	11%	1	6%	25	6%	1	1%	2	6%	12	2%	5	2%	24	5%	144	5%
Other/unknown	20	48%	75	12%	2	10%	13	0%	19	4%	2	6%	28	3%	12	4%	3	1%	181	6%
Total	42	100%	657	100%	19	100%	430	100%	263	100%	32	100%	587	100%	249	100%	487	100%	2766	100%

A.7 Crashes by Helmet Conditions

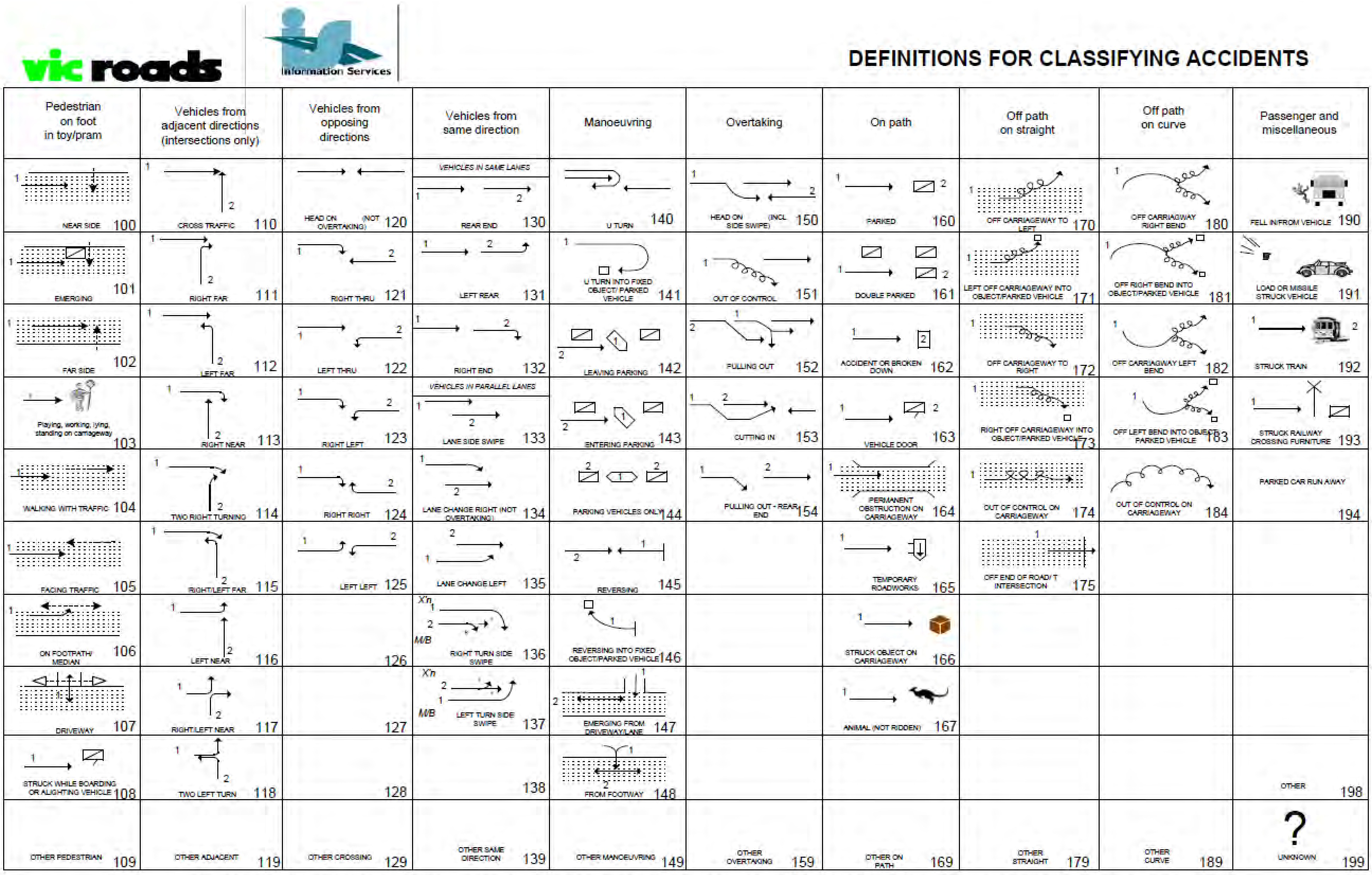
Table A 23: Helmet conditions in Victoria and Queensland

Helmet condition	Crashes by location					
	VIC		QLD		Total	
Worn	494	83%	379	87%	873	85%
Not worn	21	4%	26	6%	47	5%
Not applicable	3	1%	3	1%	6	1%
Unknown	69	13%	22	7%	91	10%
Total	587	100%	430	100%	1017	100%

Appendix B Definitions for Coding Accidents

The crash diagrams have been prepared using the Victorian coding system which is shown in Figure B 1.

Figure B 1: Definitions for coding accidents – Victoria



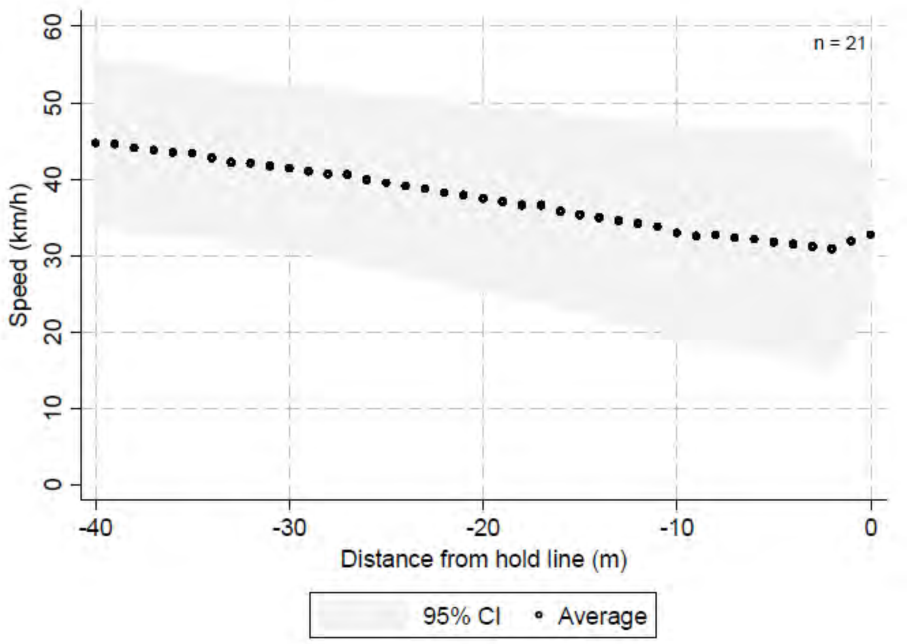
1. DEFINITION FOR CLASSIFYING ACCIDENTS (DCA) SHOULD BE DETERMINED BY FIRST SELECTING A COLUMN USING THE TEXT ABOVE EACH COLUMN AND THEN BY DIAGRAMATIC SUB-DIVISION
2. THE SUB-DIVISION CHOSEN SHOULD BE DESCRIBE THE GENERAL MOVEMENT OF VEHICLES INVOLVED IN THE INITIAL EVENT. IT DOES NOT ASSIGN A CAUSE TO THE ACCIDENT
3. SUPPLEMENTARY CODES HAVE BEEN DEFINED FOR MOST SUB-DIVISION. THESE CODES GIVE FURTHER DETAIL OF THE INITIAL EVENT.
4. THE NUMBER 1, 2 INDENTIFY INDIVIDUAL VEHICLES INVOLVED WHEN THE DCA IS LINKED WITH OTHER VEHICLE/DRIVER INFORMATION.
5. THESE CODES WERE USED FOR 1987 ACCIDENTS AND REPLACE THE ROAD MOVEMENT (RUM) CODE.

Source: VicRoads (2013).

Appendix C Surveyed Roundabout Speeds

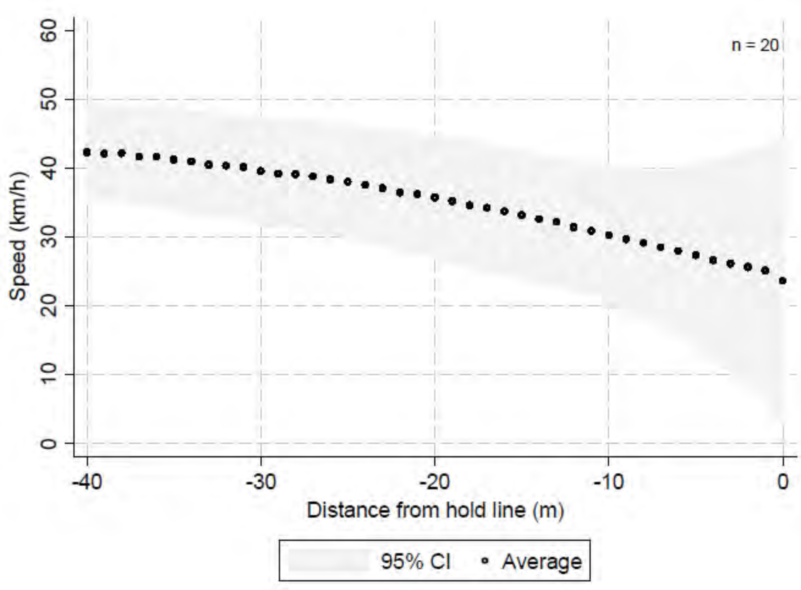
As part of Austroads (2014a), limited speed surveys were undertaken at roundabouts in Queensland. Three of the roundabouts were included in this project and the results obtained at these locations are shown in Figure C 1 to Figure C 6.

Figure C 1: Seaworld Drive – Waterways Drive – northern approach



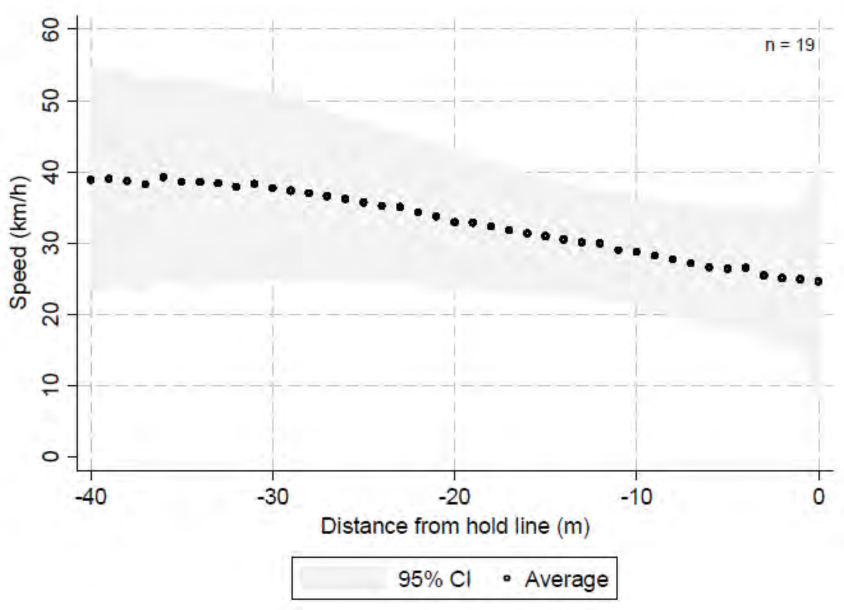
Source: Austroads (2014a).

Figure C 2: Seaworld Drive – Waterways Drive – eastern approach



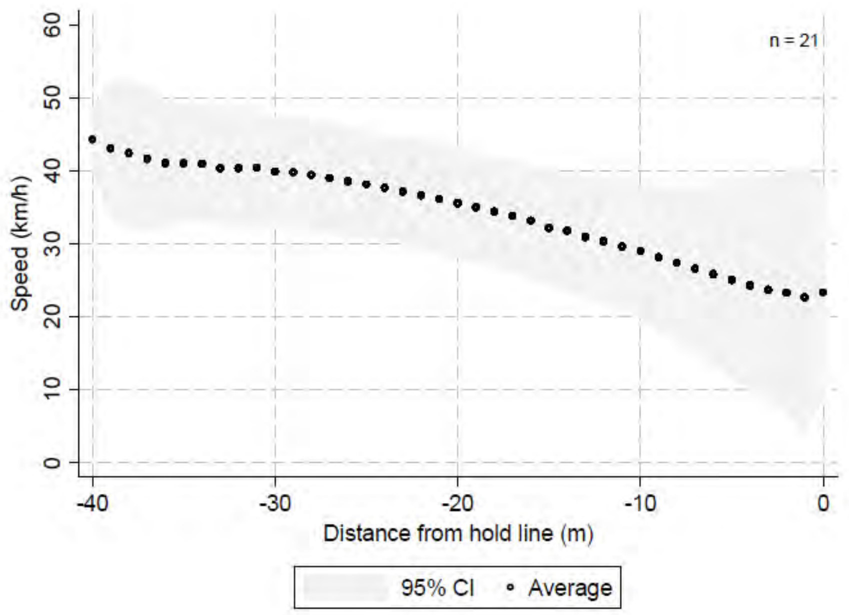
Source: Austroads (2014a).

Figure C 3: Seaworld Drive – Waterways Drive – western approach



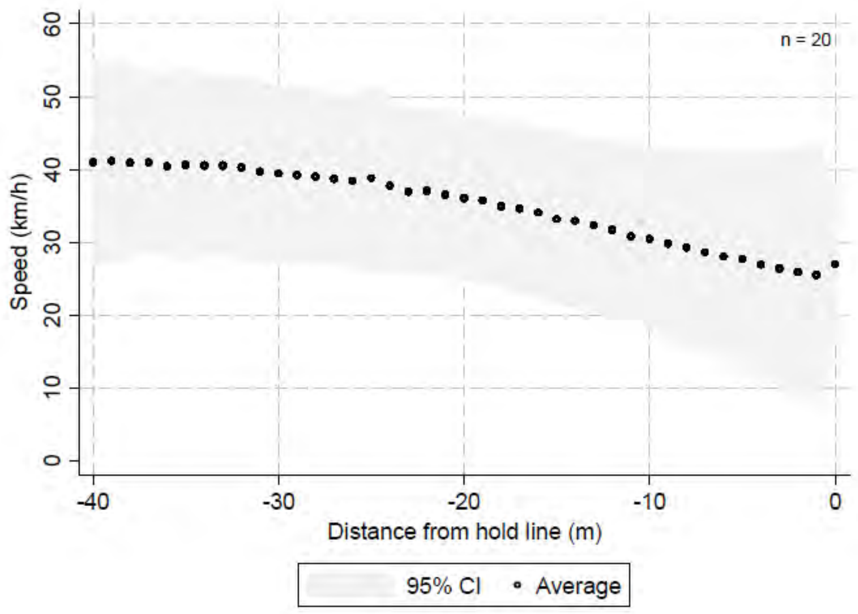
Source: Austroads (2014a).

Figure C 4: Old Burleigh Road – Queensland Avenue – northern approach



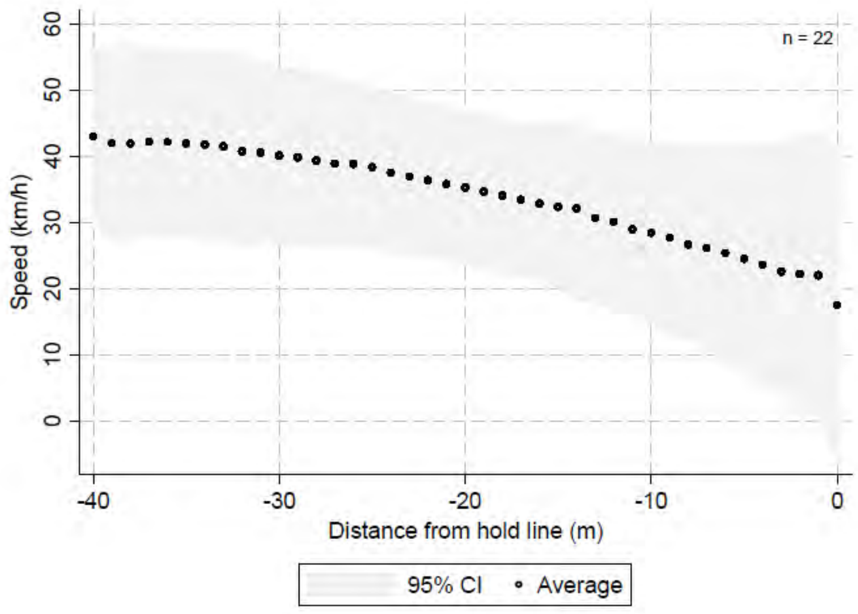
Source: Austroads (2014a).

Figure C 5: Old Burleigh Road – Queensland Avenue – western approach



Source: Austroads (2014a).

Figure C 6: Cotlew Street – Wardoo Street – southern approach



Source: Austroads (2014a).

Austroads

Level 9, 287 Elizabeth Street
Sydney NSW 2000 Australia

Phone: +61 2 8265 3300

austroads@austroads.com.au
www.austroads.com.au