Technical Note 136

Providing for Cyclists at Roundabouts

August 15

Queensland Government

Feedback: Please send your feedback regarding this document to: tmr.techdocs@tmr.qld.gov.au

1 Introduction

This Technical Note provides guidance for designers and is about improving the safety of cyclists at existing roundabouts. Roundabouts represent about 4% of all intersections on the Queensland state controlled road network and approximately 15% of all bicycle social crash costs at intersections on state controlled road. In 2013 the Queensland road network contained over 3,400 roundabouts.

The guidance contained in this Technical Note is targeted at brownfield sites, however some of the treatments may be applicable to greenfield roundabout projects. In some situations other intersection types besides roundabouts may be safer and more appropriate for cyclists, other intersection types should be considered first if possible.

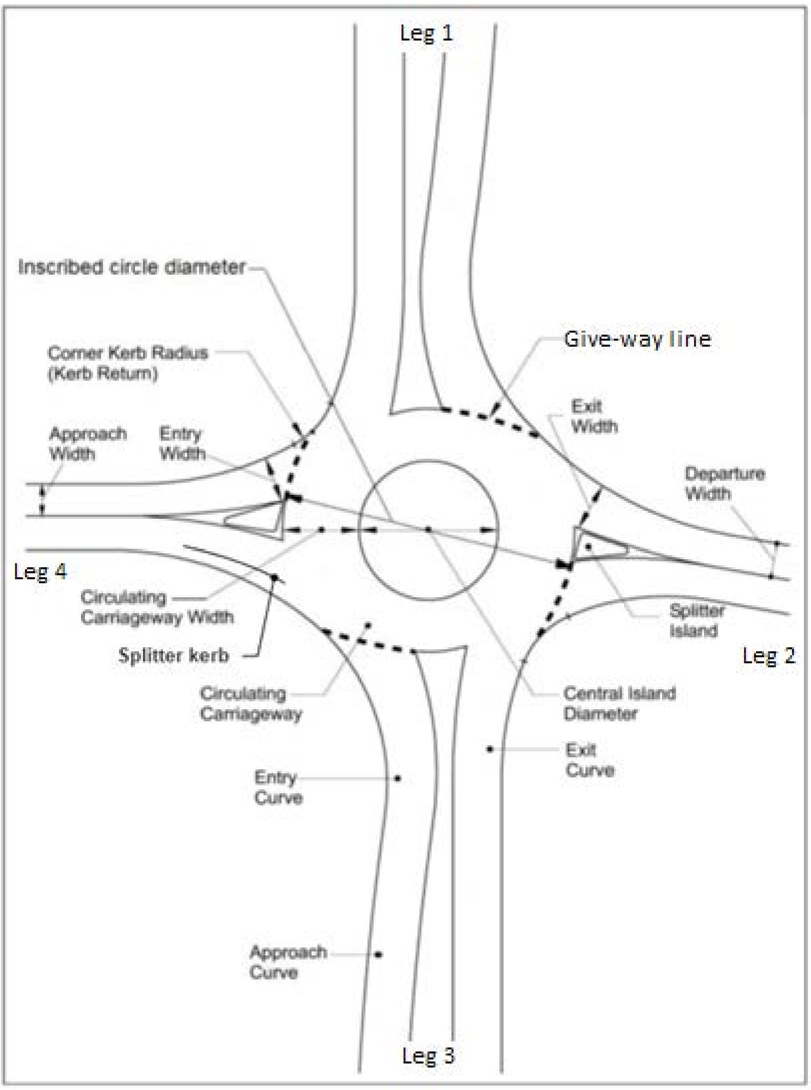
It is acknowledged that in many situations optimal solutions may not be practicable in the short term. Some suggested treatments have not been implemented in Queensland previously and should be trialled and evaluated.

This Technical Note supports the Department of Transport and Main Roads (TMR) *Cycling Infrastructure Policy and Queensland Cycle Strategy (QCS)*. These documents aim to make cycling safer and more convenient so more Queenslanders can take advantage of the most sustainable and enjoyable mode of travel.

Unless specifically noted, all content is supplementary to the TMR *Road Planning and Design Manual*, *Manual of Uniform Traffic Control Devices* (MUTCD) and *Austroads* guides.

Definitions are listed in Appendix A. Figure 1 details specific terminology associated with roundabouts.

Figure 1 Roundabout feature terminology



2 Background

To inform the development of these guidelines, a systematic research program was undertaken, including:

- Literature research, including national and international databases, search engines and websites,
- Review of Austroads *Research Report AP-R461-14 Assessment of the Effectiveness of On-road Bicycle Lanes at Roundabouts in Australia and New Zealand*[1],
- Review and analysis of prediction models for bicycle crashes at roundabouts, including recent research for TMR by ARRB[2,3], and Beca,[4]
- Supplementary review of foreign language research by the SWOV Institute for Road Safety Research, The Netherlands,
- Analysis of bicycle crash history at Queensland roundabouts.

2.1 Roundabouts and bicycle safety research findings

2.1.1 Overview

This section summarises a variety of national and international design guidelines and research relevant to provisions for bicycles at roundabouts. The literature research revealed that roundabouts have been shown to be effective in reducing the frequency and severity of motor vehicle crashes. However, the safety of roundabouts for bicycle riders remains a source of concern.

2.1.2 Layout considerations

Roundabout designs depend on the road environment where they will be installed. Roundabout geometric dimensions are typically governed by the selection of design vehicle, approach speed and traffic volume.

Research indicates entering speed is a key factor influencing roundabout safety. Entering speed influences both the time available to perceive and react to other users and also the severity of any resulting crash.

The selection and operation of the design vehicle can influence light vehicle speeds. Treatments such as aprons and mountable central islands may be required to ensure heavy vehicle access while keeping speeds safe. The frequency of use by heavy vehicles may govern appropriateness of mountable elements. The influence of mountable elements on heavy vehicle stability and underbody clearance, as well as motorcycle safety must be considered.[5, 6, 7]

There are two schools of roundabout geometry design which are known as either tangential or compact (also known as radial) geometry. The primary difference is the radius of entry and exit curves. Compact geometry supports priority crossings for cyclists and pedestrians as it requires lower approach and exit speeds.

The two approaches to roundabout design differ in their focus. Capacity is the primary focus of tangential roundabouts (named after the design road entry and exit geometry) minimising the delay to motor vehicles. Compact roundabouts focus on speed reduction and safety. English-speaking countries (United States, Australia and New Zealand) typically use tangential roundabouts, while countries from continental Europe (Sweden, Denmark, Germany, and Netherlands) use compact roundabouts. United Kingdom guidelines permit both types of geometry recommending their most appropriate contexts[8].

2.1.3 Bicycle operation at roundabouts

Guidelines on the provisions for cyclists are similar among jurisdictions. Most expect on-road cyclists to act as a vehicle in single-lane, typically low-speed, roundabouts. Some jurisdictions do not permit cyclists to travel on multi-lane roundabouts, and recommend segregated off-road cycle paths. Other jurisdictions do allow for the use of bicycle lanes in the circulating area, but caution against positioning cyclists at the edge of the road.

2.1.4 Impact on road safety (crash risk)

World-wide, the conversion of signalised and un-signalised intersections to roundabouts has improved overall safety outcomes. The reductions in injury crashes vary between jurisdictions, and probably reflect different design guidelines and road user expectations. Overall it is estimated that the conversion to roundabouts reduces all crashes by 36%[9]. Fatal crashes are reduced by 66%, and injury crashes are reduced by 46%. It is estimated that there is a small increase in Property Damage Only crashes. While there have been overall improvements in road safety, the effect has not been positive for all road user groups, and lower vehicle approach speeds should reduce the risk of crashes and injuries occurring at roundabouts for all users. Attaining appropriate entering speed can be achieve through horizontal curvature on approach, vertical speed control treatments such as road humps, lower posted speed limits or perceptual counter-measures. No evaluation has been published by Australian jurisdictions that have implemented lower posted speed limits approaching roundabouts. However, lower posted speed limits have been found to be effective at several Queensland high speed intersections[10]. Perceptual counter-measures have been shown to reduce vehicle speeds by 5-10 km/h, and reduce roundabout crashes on approach to roundabouts by about 60%[11].

2.1.5 Bicycle safety at roundabouts

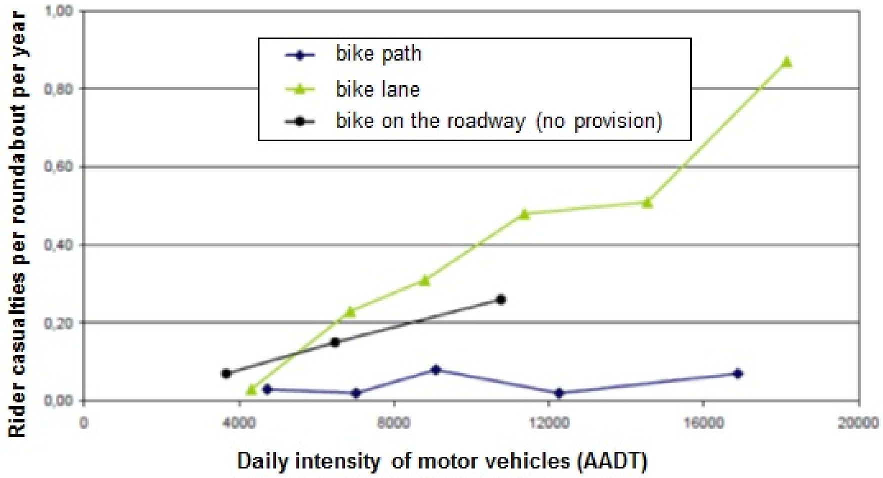
Overall, cyclists are considered vulnerable in comparison with occupants of motorised vehicles, due to their relative lack of occupant protection, slower speeds and smaller size. While roundabouts have increased the safety for motor vehicle occupants[12], compared with other junctions, the same cannot be said for cyclists. Research has found that traffic signals provide more protection to vulnerable road users than roundabouts[1,13]. In Queensland, roundabouts represent about 4% of all intersections on state controlled road and approximately 15% of bicycle social crash costs at intersections (using 2005-2009 crash data).

Cyclists in different countries appear to perceive the risk of roundabouts differently. Those who ride in the United Kingdom perceive roundabouts to be very risky, whereas cyclists in continental Europe view low-speed urban roundabouts in a more positive light.

There are several factors that may influence cyclist safety at roundabouts. One issue may be cyclists' position on the circulating roadway when travelling through the roundabout. Observational work conducted in Australia has found that cyclists tend to position themselves towards the outer edge of the circulating roadway, even if no bicycle lane is provided[1]. However, travelling on the outer edge of the roadway may lead to a reduction in the likelihood a driver will perceive the cyclist. This road position also limits potential crash avoidance manoeuvres that might be possible with a greater buffer distance. This may explain why the most common crash (25-40% of total crashes) involving cyclists at roundabouts is 'a driver entering the roundabout failing to yield to an already circulating cyclist'.

Limited research has examined geometric features that may influence bicycle crash rates at intersections. Compact roundabouts have been found to reduce bicycle-vehicle crashes, while crash rates at two lane roundabouts are higher than expected[14]. Research from Europe has found that the roundabouts with bicycle lanes are more risky for cyclists even compared to roundabouts with no cycling provision[15]. Roundabouts with segregated bicycle facilities have the lowest crash ratings for cyclists[16], refer Figure 2.

Figure 2: Rider casualties, traffic intensity and bicycle facility types (Dijkstra 2004)



While research from Sweden and the Netherlands has found segregated cycling paths at roundabouts can reduce cyclist crashes[3, 18, 19, 20, 21, 22], different priority rules at crossing points make comparisons with Australian roundabouts difficult. In Sweden specifically, vehicles do not have priority when exiting. Traffic regulations in the Netherlands also require larger vehicles to take more care when interacting with more vulnerable road users. In Australia the road rules do not require drivers to give way to pedestrians or cyclists crossing the road near a roundabout[23]. However, priority can be given to path users by implementing various forms of priority crossings. Priority crossings support bicycle network continuity and foster appropriate driver expectations. Priority crossing selection and design is discussed in Section 6.

It is important to recognise that people who ride bicycles are not a homogenous group. There are different types of cyclists, riding for different reasons and with differing perceptions of risk. As such, the fact that there are different types of cyclists using different types of roundabouts, in different ways, needs to be acknowledged. A roundabout design that is well-accepted by sports or commuting cyclists may be daunting and potentially unsafe for children and their parents.

The perceived safety of cycling is a significant barrier to more people taking up cycling as a regular transport mode. Geller[24] coined the term *interested but concerned* for the majority of the population who could cycle but don't due to safety concerns, and this is a key target market that needs to be engaged in order to achieve Queensland Cycle Strategy growth targets.

2.2 Mixed traffic vs bicycle lanes

Mixed traffic roundabouts are usually safe and appropriate in low speed, low volume environments. In The Netherlands, design advice for mixed traffic roundabout is for volumes up to 6,000 vehicles per day in the roundabout, typically with entering speeds of 30 km/h. Between 6,000 and 10,000 vehicles per day is advised for mixed traffic if none of the approach roads provides bicycle paths.

Austroads *Research Report AP-R461-14* suggests design entry speeds around 25-30 km/h are "equitable" for cyclists to comfortably share the lane with motor vehicles.

There is general agreement in research that circulation bicycle lanes are inappropriate as they may lead to unsafe positioning of cyclists closest to entering traffic. Also drivers are frequently observed sweeping through approach bicycle lanes using the entry width to optimise their entry speed. Splitter kerbs have been used in many locations to separate cars and bicycles until equitable speeds are attained.

The termination of a bicycle lane does not mean cyclists must depart the road. Unless alternatives offer reduced delay many cyclists will likely remain on-road. Treatments that maintain cyclist network continuity and inform drivers to expect likely cyclist actions are important safety considerations particularly in mixed traffic environments. AASHTO states “motorist reaction times 35% higher when processing unexpected events” and “reinforced expectancies help drivers respond rapidly and correctly.”[25] It follows that safety should be improved by treatments that maintain bicycle conspicuity and network continuity will reduce cyclists making manoeuvres that may be unexpected to drivers.

3 Roundabout retrofitting rationale

The themes that emerged from the research and analysis were used to develop detailed retrofit treatments for this Technical Note. These treatments are structured in a modular data sheet format in order assist targeted safety treatments and retrofit specific problems. What works in one context may not work in another.

Table 3.1 presents the basic geometric groups. Section 5 presents data sheets that list the problems cyclists may encounter at these roundabout types and suggests possible retrofit treatments.

Table 3.2 presents a series of treatments grouped into treatment toolboxes presented in Section 6 to improve bicycle safety at roundabouts. These treatments can be used either in isolation or in combination with each other. It may be appropriate to include few treatments at first and implement additional controls if a need is identified through monitoring.

Additionally roadside objects (such as signage landscaping or artwork) should be reviewed considering safety. Flexible signs may improve vulnerable user safety and reduce maintenance costs from errant vehicle damage.

Steel access lids should supply sufficient friction particularly where turning, acceleration or deceleration is taking place. Concrete infill lids are one possible option for a durable friction treatment.

Treatments not listed here, either existing or innovative, should not automatically be considered unsafe. Engineering judgement should prevail until trial, monitoring and evaluation can assist with evidence based decision making.

Table 3.1 - Basic geometric groups (refer Section 5 for details)

Single lane approaches	Multiple lane approaches
B1 - Tangential geometry	B2 - Tangential geometry

Table 3.2 - Toolbox Treatments (refer Section 6 for details)

Awareness Toolbox	Speed Management Toolbox
A1 - Bicycle awareness zone	S1 - Approach speed limit
A2 - Setback give-way line	S2 - Perceptual treatments
A3 - Bicycle activated warning sign	S3 - Compact geometry
	S4 - Convert multi lane to single lane
	S5 - Convert multi lane to C-Roundabout
	S6 - Central island apron
	S7 - Outside Aprons
	S8 - Speed cushion with splitter kerb
	S9 - Splitter kerb
	S10 - Raised crossing
Transition Toolbox	**Conflict Management Toolbox**
T1 - Path following kerb line	C1 - Alternative route
T2 - Path on own alignment	C2 - Eliminate left turn slip lane
T3 - On-road-off-road transition	C3 - Non-priority crossing
	C4 - Unsignalised at-grade priority crossing
	C5 - Mid-block signals
	C6 - Replace the Roundabout with a signalised intersection
	C7 - Signalise the roundabout
	C8 - Grade Separation (Underpass)
	C9 - Grade Separation (Overpass)

4 Retrofit process

This section steps out the process to:

4.1 Identify candidate treatment sites

4.2 Select appropriate treatments

4.3 Prioritise and Implement

4.4 Monitor and evaluate

4.1 Identify candidate treatment sites

Table 4.1 provides an overview of risk identification methods. Proactive methods may highlight safety issues prior to a crash occurring. Reactive methods rely on crash history.

Table 4.1: Pro-active and Reactive risk identification methods

Proactive	Complaints from bicycle users
	Safety audit
	Crash prediction model
Reactive	Bicycle crash history
	All user crash history (car based proxy)

Currently there are no efficient tools for high level proactive network screening of roundabout safety for bicycles. A crash prediction model for bicycles at roundabouts has been calibrated for Queensland and is presented in Appendix B. The model is most suited for a first pass proactive assessment of the expected average bicycle crash rate at a roundabout. As the model does not include factors for geometric elements some engineering judgement may be required to determine features that may modify expected risks. Some effort is required to determine user volumes and turning movements for each roundabout.

It is suggested that roundabout safety should be investigated if:

- More than two bicycle crashes have been recorded in a five year period, or
- The crash prediction model indicates more than 0.2 crashes are expected annually (an average of one crash every five years), or
- Other methods highlight significant risks.

4.2 Select appropriate treatments

At sites with a pre-existing crash history, reviewing the detailed crash reports may provide additional insights to determine if infrastructure treatments would be effective in reducing crash occurrence. Austroads *Guide to Road Safety* Part 8 presents a complete discussion on crash analysis and treatment.

Table 4.2 suggests infrastructure treatments to improve bicycle safety in the context of the bicycle network and road environment. These suggestions are not definitive and engineering judgement is required in selection of treatments appropriate to the site being investigated. As evidence on the safety of bicycle lanes in within the circulation of the roundabout remains inconclusive this treatment has been excluded.

It is important to note that a roundabout is a system. Changes to one aspect of the roundabout affect other elements of the system. Each roundabout is different and a choice made for one location does not necessarily suit another. Decisions should be based on thorough data collection, analysis and consideration of local conditions and context for all users.

A thorough understanding of existing operating conditions and concerns may be assisted by attending site visits and consulting with local users, formal Bicycle User Groups, road racing groups, triathlon groups and less obvious groups such as walking volunteers, local aged care centres, schools, groups representing people with a disability, etc.

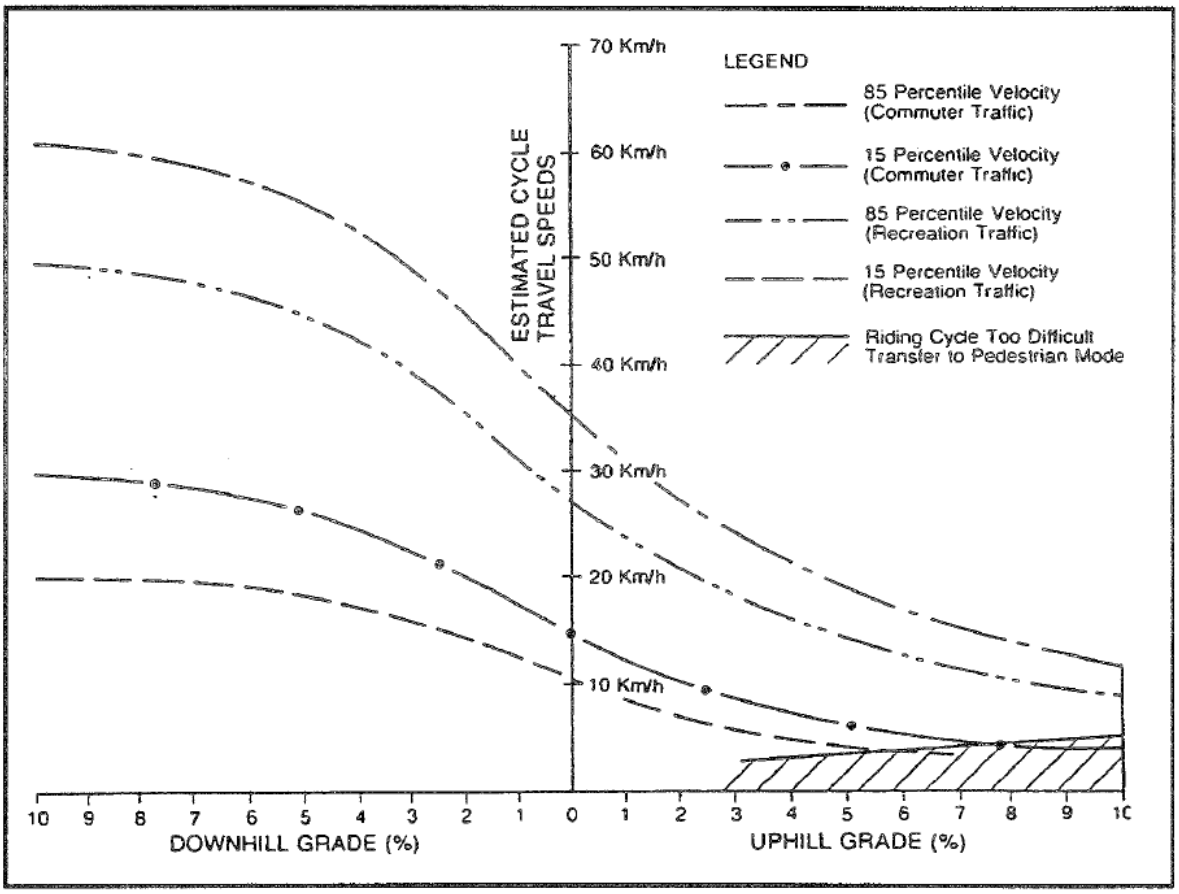
The Strava heatmap (http://labs.strava.com/heatmap/#6/142.69043/-21.44712/gray/bike) may provide some indication on recent bicycle usage in the area and alternative routes in use by cyclists. Attempts at calibrating the underlying bicycle volume data against permanent counter sites in Queensland revealed Strava typically represents about 5-10% of all riders. This proportion can vary significantly across sites. Strava is also thought to represent the activity of longer distance sports riders more than recreational riders undertaking short distance local trips, so the true pattern of bicycle usage on the network may vary from what is recorded by Strava. At this time Strava data cannot provide a reliable estimate of bicycle volumes, if bicycle volumes need to be determined accurately a manual traffic count should be undertaken as it more likely to represent the number of actual users.

Bicycle speeds can be significantly reduced when travelling uphill, bicycle speed on gradients may be approximated using Figure 4.2. Note that downhill speeds are terminal speeds, a coasting bicycle (no rider power input) may take up to one kilometre of downhill gradient to achieve terminal speed.

Table 4.2: Suggested treatments given traffic environment and bicycle network context

	Low volume single lane - Entry speed <40km/h	Medium volume multi lane - Entry speed <40km/h	High volume multi lane - Entry speed >=40km/h
Principal cycle network	S3 - Compact geometry S6 - Central island apron S7 - Outside Aprons S8 - Speed cushion with splitter kerb S9 - Splitter kerbs S10 - Raised crossing T2 - Path on own alignment T3 - On-road-off-road transition C3 - Unsignalised priority crossing	A3 - Bicycle activated warning sign S4 - Convert multi lane to single lane S5 - Convert multi lane to C-Roundabout S6 - Central island apron S7 - Outside Aprons S8 - Speed cushion with splitter kerb S9 - Splitter kerbs T1 - Path following kerb line T3 - On-road-off-road transition C1 - Alternative route C3 - Non-priority crossing C5 - Mid-block signals C6 - Replace the Roundabout with a signalised intersection C7 - Signalise the roundabout C8 - Grade Separation (Underpass) C9 - Grade Separation (Overpass)	A3 - Bicycle activated warning sign S6 - Central island apron S7 - Outside Aprons S9 - Splitter kerbs T1 - Path following kerb line T3 - On-road-off-road transition C1 - Alternative route C3 - Non-priority crossing C5 - Mid-block signals C6 - Replace the Roundabout with a signalised intersection C7 - Signalise the roundabout C8 - Grade Separation (Underpass) C9 - Grade Separation (Overpass)
Not on principal cycle network	S3 - Compact geometry S6 - Central island apron S7 - Outside Aprons S8 - Speed cushion with splitter kerb S9 - Splitter kerbs C2 - Non-priority crossing C4 - Unsignalised at-grade priority crossing	S4 - Convert multi lane to single lane S5 - Convert multi lane to C-Roundabout S6 - Central island apron S7 - Outside Aprons S8 - Speed cushion with splitter kerb S9 - Splitter kerbs T1 - Path following kerb line T3 - On-road-off-road transition C1 - Alternative route C3 - Non-priority crossing C5 - Mid-block signals C6 - Replace the Roundabout with a signalised intersection C7 - Signalise the roundabout C8 - Grade Separation (Underpass) C9 - Grade Separation (Overpass)	S6 - Central island apron S7 - Outside Aprons S9 - Splitter kerbs T1 - Path following kerb line T3 - On-road-off-road transition C1 - Alternative route C3 - Non-priority crossing C5 - Mid-block signals C6 - Replace the Roundabout with a signalised intersection C7 - Signalise the roundabout C8 - Grade Separation (Underpass) C9 - Grade Separation (Overpass
Generic – for all situations	S1 - Approach speed limit S2 - Perceptual treatments A1 - Bicycle awareness zone A2 - Setback give-way line C2 - Eliminate left turn slip lane Review roadside objects (Remove, relocate or replace with more forgiving alternative)		

Figure 4.2: Bicycle Operating Speeds
(Source: National Capital Development Commission 1983)



4.3 Prioritise and Implement

Treating the "worst first" is the suggested retrofit prioritisation approach. However it is highly desirable to seek out opportunistic integration of roundabout safety treatments with other works such as resurfacing.

Risks to bicycle riders are likely to be higher on roundabouts where:

- Motor vehicle speeds significantly exceed on-road bicycle speeds (>20 km/h speed differential),
- Motor vehicle volumes are higher (AADT),
- Motor vehicles frequently sweep across lanes (observed via site visits or aerial photography),
- Bicycle numbers are higher (exposure),
- The roundabout is in close proximity to a school (<1 km),
- Alternative routes for bicycles are non-existent or not desirable.

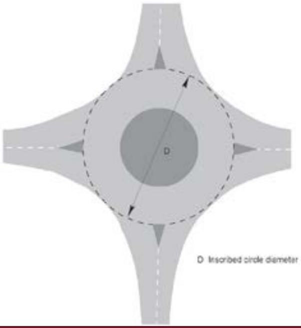
Risks are likely to be higher particularly where a number of these conditions exist in combination.

Funding for improvements may be available through capital works programs or grants programs such as Blackspot or Safer Roads Sooner. Obtaining funding is usually in competition with other project bids and is subject to program priorities.

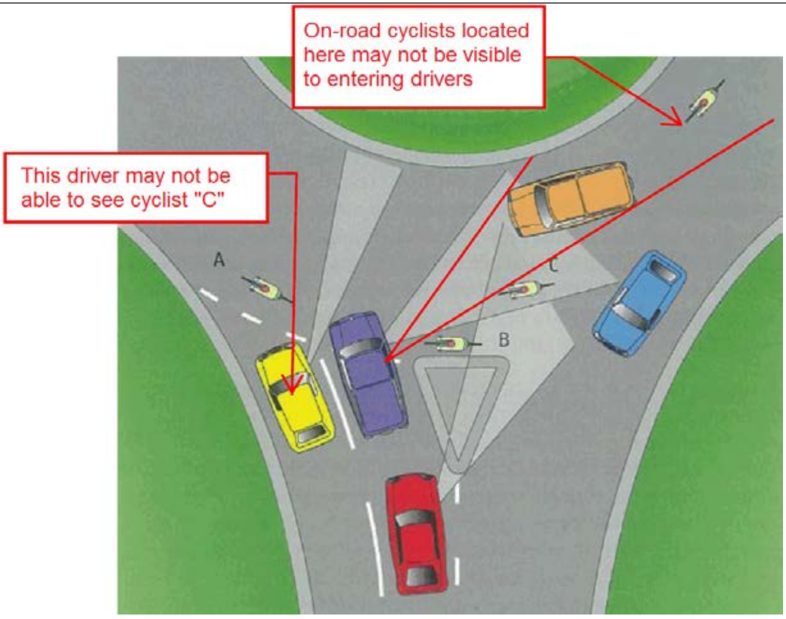
4.4 Monitor and evaluate

It is important for each project to include a monitoring and evaluation plan particularly where the treatment may be innovative or new to the locality. This plan should initiate the collection and analysis of appropriate before and after data on traffic and safety patterns. Some relevant information for a before/after analysis would include entering speed, traffic volumes, bicycle volumes, lateral positioning and detailed crash records. Similar information may also need to be collected at a nearby control site to rule out other systemic changes that may occur over time. TMR is currently developing a pilot project evaluation framework which will further inform monitoring and evaluation requirements.

5 Basic Geometric Groups

B1 - Single Lane Approaches (Tangential geometry)	
	
Guidelines	
• As per *Road Planning and Design Manual*[27]	
Consider bicycle treatments where	• Combined AADT of all approaches exceeds 6000, and • Approach speed limit exceeds 40 km/h.
Avoid	• In urban areas near schools. • Locations frequented by the elderly or people with disabilities. • Elliptical central islands.
Advantages	• Low angle of incidence reduces motor vehicle collision severity. • 5 m wide approach lanes can allow cyclists to queue jump during congested periods.
Disadvantages	• Limited motor vehicle speed control at crossing conflict points, speeds greater than 50 km/h result in high probability of a fatal crash if a vulnerable road user is involved. • 5 metre lane width flare at entry can be difficult for cyclists to claim the lane. • Late motor vehicle deceleration can prohibit cyclist integration on approach. • Entering driver attention may be focused on vehicles about to enter on the adjacent approach if they expect high speed potentially conflicting vehicles, cyclists present on the circulation lane may be overlooked when driver attention is focused elsewhere. • Drivers may misjudge cyclist speed or perceive there is enough road width available to push past.
Other Considerations	• Early acceleration allowed by generous exit geometry allows drivers to quickly attain their desired speed but reinforces driver expectation that the intersection is over, just when path users are about to cross. • This expectation might increase the probability of rear end crashes associated with a downstream priority crossing and reduce driver likelihood of giving way.
Possible Retrofit Treatments	• Refer Table 4.2 for suggested treatments by context. • Apply selected facilities from the “Awareness Toolbox”. • Apply selected facilities from the “Speed management Toolbox”. • Apply selected facilities from the “Transition Toolbox”. • Apply selected facilities from the “Conflict Management Toolbox”. • Bicycle lanes should be terminated on approach at a point where equitable car-bicycle speeds are achieved.
Additional References	• Austroads *Guide to Road Design* Part 4B. • Austroads *Guide to Traffic Management* Part 6.

B2 - Multiple Lane Approaches (Tangential geometry)



Typical Arcs of Concentration or drivers entering a roundabout (modified to show potential dynamic visibility obstructions)
Source: Franklin Cyclecraft

Guidelines

- As per *Road Planning and Design Manual*

Consider bicycle treatments where	• Bicycles and pedestrians are known to use the roundabout.
Avoid	• In urban areas near schools. • Locations frequented by the elderly or people with disabilities. • On principal bicycle network. • Elliptical central islands.
Advantages	• Reduced need to stop for motor vehicles. • Low angle of incidence reduces motor vehicle collision severity.
Disadvantages	• Permits vehicular speeds at conflict points above threshold for human crash tolerance. • Drivers can sweep across lanes to compromise intended geometric speed control. • Lane width flare at entry can be difficult for on-road cyclists to claim the lane. • Difficult to cross the road particularly for children, elderly and people with a vision impairment. • Drivers look for gaps in circulation traffic and high speed vehicles about to enter on adjacent approach, drivers not focused on bicycles are less likely to perceive them. • Cyclists potentially overlooked in a busy traffic environment. • Cyclists potentially obscured from sight by other vehicles (multiple threat).
Possible Retrofit Treatments	• Refer Table 4.2 for suggested treatments by context. • Apply selected facilities from the “Awareness Toolbox”. • Apply selected facilities from the “Speed management Toolbox”. • Apply selected facilities from the “Transition Toolbox”. • Apply selected facilities from the “Conflict Management Toolbox”. • Bicycle lanes should be terminated on approach at a point where equitable car-bicycle speeds are achieved.
Additional References	• As per Austroads *Guide to Road Design* Part 4B. • Austroads *Guide to Traffic Management* Part 6.

6 Treatment Details

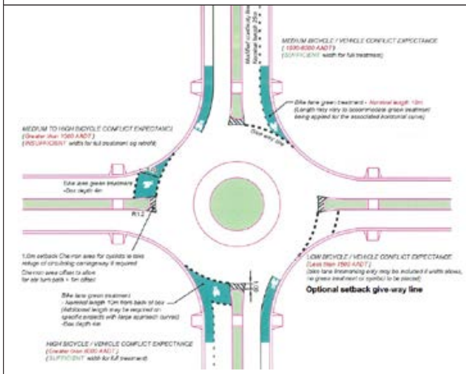
6.1 Awareness Toolbox

A1 - Bicycle awareness zone

River Street, Mackay, QLD (Edited Photo: Mark McDonald)

Guidelines	
• As per *TRUM Volume 1 Part 10, Section 6.5-1*	
Where to Use	• On approaches and within the circulation of roundabouts with mixed traffic. • At the transition zones on approaches to roundabouts. • Symbol must be located in the centre of the lane.
Avoid	• As a standalone treatment. • Locating the symbol near the left hand edge.
Advantages	• Reminds drivers of cyclist presence in queue and circulation. • Does not increase entering lane width assisting control of motor vehicle entering speed.
Disadvantages	• Pavement markings may be obscured by queued vehicles. • May not be appealing to “interested but concerned” user groups.
Other considerations	• People do not see what they are not looking for, treatments to raise driver awareness and expectations should support safety. • Symbols located in the centre of the lane may receive less wheel wear and last longer.
Additional References	• Austroads *Guide to Traffic Management* Part 6.

A2 - Setback give-way line



Sunshine Coast Council Standard Plans LM20 to LM22 (modified)

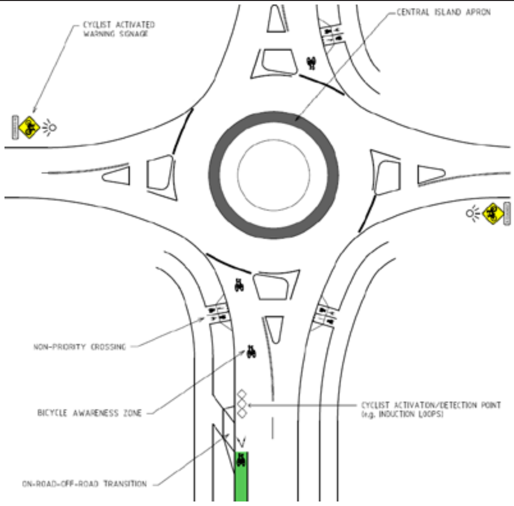
David Low Way at Mahogany Dr (Photo:TMR aerial imagery)

Innovative treatment currently in use on Sunshine Coast. SHALL be evaluated.

Where to Use	• Where higher order treatments are not warranted or unsuitable. • Identified sport and commuter routes, including pelotons. • Demand for right turn cycle movement. • Roundabout is known to be difficult for cyclists to negotiate. • Identified cycle routes to support driver awareness of cyclist presence. • Where sight distance criteria for roundabouts can be maintained. • Where the speed limit is 60 km/h or less on all approaches.
Avoid	• As a standalone treatment (eg. provide alternative options and traffic speed mitigating treatments for less experienced cyclists).
Advantages	• Sets hold line back from circulation potentially reducing DCA101 crashes. • Assists cyclists attain good road position. • Pavement marking will not be obscured by queued vehicles. • Reminds drivers of cyclist presence in queue and circulation. • Treatments legitimise presence of on-road cyclists. • Consistent with intersection conflict zone treatments.
Disadvantages	• May not be appealing to "interested but concerned" riders. • Does not assist pedestrians. • Bicycle lanes on approaches are continued to the hold line (Limiting control of driver entering speed). • The time for drivers to enter the roundabout from the give way line and cross the circulating traffic is longer. This may increase crashes where drivers misjudge the gap required (evaluation required on gap acceptance and driver holding behaviour).
Other Considerations	• *MUTCD* Part 2, 5.4.2b) will be amended to read: *(b) At a roundabout, to indicate the safe position for a vehicle to be held before entering. The line shall be placed across the entering road. The line may be along the edge of the circulating roadway (see Figures 2.7 and 2.8) or set back up to 5 metres from the edge of circulating roadway to reduce to reduce the likelihood of a "multiple threat" incident. The line may be staggered on multiple lane approaches.* *If the line is set back from the edge of the circulating roadway a supplementary give-way line shall be used to describe the edge of the circulating roadway.* • Not circulatory lanes therefore does not conflict with research. • Consistent treatment with intersection conflict zone marking style. • Extend splitter island and place crossing 6 m from give way line to allow path users to cross behind a holding vehicle. • Limited trials in Noosa without formal evaluation. • People do not see what they are not looking for, treatments to raise driver awareness and expectations can support safety. • Evaluation should include at least how road users are actually using the facility (concerns the treatment may be used like a bicycle storage area at signals), motor vehicle speeds and before/after crash history.
Additional References	• *Manual of Uniform Traffic Control Devices* (MUTCD). • *Sunshine Coast Council Standard Plans LM20 to LM22.*

A3 - Bicycle activated warning sign

Noosa Parade, Noosa Heads
(Photo: Dool, GTA Consultants)



Example layout, loops activating warning on adjacent approach
(Source: GTA Consultants)

Guidelines

- *TMR TN137 Bicycle activated warning signs*[29]

Where to Use	• On one or more approaches to a roundabout with mixed traffic. • Where other treatments have not been effective in modifying driver behaviour. • Where paths cannot be fully implemented. • Multilane roundabouts where the crossing task is extremely difficult and higher order treatments are not possible (for example, grade separation, signalisation).
Avoid	• High volume cycling routes (if the warning light illuminates continuously it potentially loses impact value). • As a standalone treatment.
Advantages	• Warns approaching drivers of circulating cyclists. • Only active when a potential conflict is likely. • Treatment legitimises cyclist presence on-road.
Disadvantages	• Cost of installation and maintenance. • Potential vandalism target. • Potential target of theft (solar cells). • May not be appealing to "Interested but concerned" user groups.
Other considerations	• Shall be implemented with approved sign faces (MUTCD or TC signs). • Consider activation methods that do not require cyclists to stop to trigger the device. • Activation method must be robust, reliable and limit false positives. • A pavement symbol may be required on road so cyclists know where to ride to activate the device. • Consider power system backup to limit system failure. • People do not see what they are not looking for, treatments to raise driver awareness and expectations can support safety.
Complementary Retrofit Treatments	• Selected facilities from the "Awareness Toolbox". • S1 - Approach speed limit. • S2 - Perceptual treatments. • S6 - Central island apron. • S8 - Speed cushion with splitter kerb.

6.2 *Speed Management Toolbox*

S1 - Approach speed limit

Guidelines

- As per *MUTCD* Part 4 Sections 3.6 and 4.5.2

Where to Use	• The deceleration zone on approach to the roundabout. • Immediately prior to the termination of the bicycle lane/shoulder on the approach to the roundabout, about 15-60 m from the give-way line.
Avoid	• Implementing as a standalone treatment.
Advantages	• Supports equitable speeds prior to the merge point of the bicycle and traffic lanes. • Supports appropriate entry speeds. • Slower entry speeds and circulation may improve gap acceptance. • Supports appropriate speeds at crossings (priority, non-priority). • 30 km/h zones in residential areas have been proven to save lives and save money[12] • Assists crossing for young elderly and people with a disability.
Disadvantages	• 24/7 traffic speed reductions. • Potentially reduced compliance if drivers perceive the reduced speed zone is too long or too slow.
Other Considerations	• Use pavement stencils to support signage. • Re-establish speed zone after the departure crossing point. • Ability to enforce.
Additional References	• Dool, van den D, Job, S. Pedestrian Safety - can we handle the next phase? Walk21 Global Conference. Sydney. GTA Consultants. 2014.[30]

S2 - Perceptual treatments

"Dragons teeth" Source: RMS Technical Directions[31]

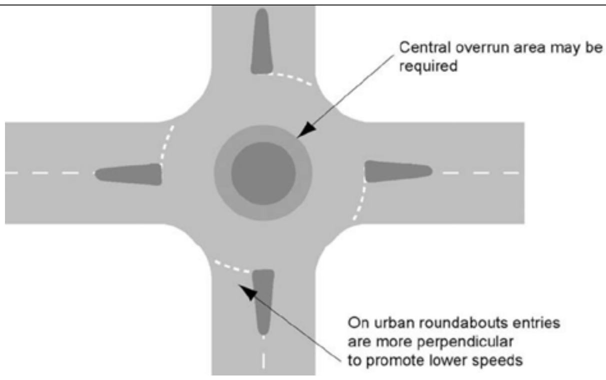
Extended chevron island on Approach, Ferguson Rd (Photo:TMR aerial imagery)

Non standard treatments SHALL be evaluated if trialled in Queensland

Guidelines

- As per *MUTCD* Part 2

Where to Use	• Immediately prior to the end of the bicycle lane/shoulder on the approach to the roundabout. • On approach to a change in speed limit or speed environment.
Avoid	• As a standalone treatment.
Advantages	• Induces appropriate speeds prior to the merge point of the bicycle and traffic lanes. • Induces appropriate speeds prior to the crossing (priority, non-priority). • Slower entry speeds in circulation may improve gap acceptance. • Assists crossing for young elderly and people with a disability.
Disadvantages	• 24/7 traffic speed reductions. • Maintenance.
Other Considerations	• Many forms of perceptual treatments have been trialled nationally and overseas. • Evaluations typically indicate minor reductions in motor vehicle speed (2-13 km/h). • "Dragons teeth" used in NSW school zones, are a non-standard treatment in Queensland, potential for driver confusion unless complementary community awareness communications are undertaken. • Some concerns have been raised that perceptual treatments on approach to crossings may distract driver attention away from path users crossing the road. • Ensure adequate slip resistance is available over treatment life, some treatments may not be appropriate on curved approaches. • Standard treatments currently contained in MUTCD are preferred (for example, visually narrow traffic lane width with extended painted chevron island on approach to splitter island).
Additional References	• UK Village Gateways research and guidelines[32, 33]. • NSW school zones safety research[34, 35]. • RMS Technical Directions[31] • Charlton and, Baas, 2006. *Speed change management for New Zealand roads*. Land Transport New Zealand Research Report 300[36].

S3 - Compact (radial) geometry	
 *Source: Highways England, Design Manual for Roads and Bridges, TD-16/07*[8]	
Innovative treatment: SHALL be evaluated if trialled in Queensland	
Guidelines	
• As per *Road Planning and Design Manual*	
Where to Use	• Local and collector roads in urban areas. • Two way AADT on any approach is less than 8000, and • Where the speed limit is 60 km/h or less on all approaches.
Avoid	• Rural Areas. • Elliptical central islands.
Advantages	• Slower approach speed and circulation speed, may change focus of driver attention possibly improving detection of bicycles. • Perpendicular entry and exits slow vehicles throughout the circulation. Supports crossing safety. • Less flare on entries/exits allows more flexibility in siting crossings. • Low cyclist-car speed differential in circulation. • ARNDT crash modelling predicts lower crash costs compared to tangential geometry in appropriate speed environment. Refer Appendix B.
Disadvantages	• Less capacity than Tangential geometry • May increase single vehicle crash likelihood if high motor vehicle approach speeds persist.
Other Considerations	• Entry kerb radius = 10 m minimum, 20 m desirable for heavy vehicle access (Radii<15 m reduce traffic capacity, Radii>20 m result in only small traffic capacity improvements). • Exit kerb radius = 15-20 m. • Lane widths at the give way line (measured normal to the kerb) should be not less than 3 m or more than 4.5 m. • Where inscribed circle diameter is between 28 m and 36 m. • Raised platforms may influence motor vehicle approach speeds and reduce single vehicle loss of control issues in the circulation. • Check for semi-trailer swept path, harden encroachment areas. • Central island apron may be required to permit heavy vehicle access and control light motor vehicle speed.
Complementary Retrofit Treatments	• Selected facilities from the "Awareness Toolbox". • S1 - Approach speed limit. • S2 - Perceptual treatments. • S6 - Central island apron. • S7 - Outside Aprons. • S8 - Speed cushion with splitter kerb. • S9 - Splitter kerbs. • S10 - Raised crossing.
Additional References	• Austroads *Guide to Road Design* Part 4B. • Austroads *Guide to Traffic Management* Part 6. • Highways England, *Design Manual For Roads And Bridges*, Td 16/07[8].

S4 - Convert multi lane to single lane

River Street, Mackay, QLD (Photo Mark McDonald)

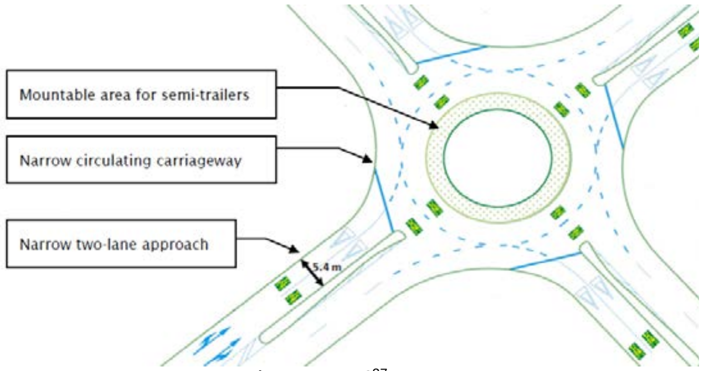
Requires support by traffic modelling

Guidelines

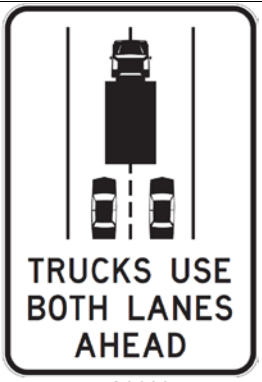
- As per *Road Planning and Design Manual*

Where to Use	• 10 yr design horizon traffic flows permit single lane on all legs.
Avoid	• High cost conversion methods.
Advantages	• Limits complexity and conflicts within the roundabout improving perceived safety for vulnerable users. • Limits motor vehicle speed entering the roundabout improving safety for all users.
Disadvantages	• May be seen as a reduction in motor vehicle level of service. • Reduces capacity.
Other Considerations	• Consider bolt down kerb (or similar) to reduce drainage retrofit costs.
Alternative Retrofit Treatments	• S5 - Convert multi lane to C-Roundabout. • C6 - Replace the Roundabout with a signalised intersection. • C7 - Signalise the roundabout. • C8 - Grade Separation (Underpass). • C9 - Grade Separation (Overpass).
Complementary Retrofit Treatments	• Selected facilities from the “Awareness Toolbox”. • S1 - Approach speed limit. • S2 - Perceptual treatments. • S3 - Compact geometry. • S6 - Central island apron. • S7 - Outside Aprons. • S8 - Speed cushion with splitter kerb. • S9 - Splitter kerbs. • S10 - Raised crossing.
Additional References	• Austroads *Guide to Road Design* Part 4B. • Austroads *Guide to Traffic Management* Part 6.

S5 - Convert multi lane to C-Roundabout (cyclist roundabout)



Source: NZ Transport Agency research report 510[37]



TC2039

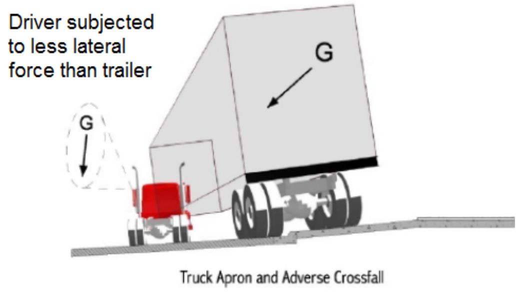
Innovative treatment: SHALL be evaluated if trialled in Queensland

Guidelines

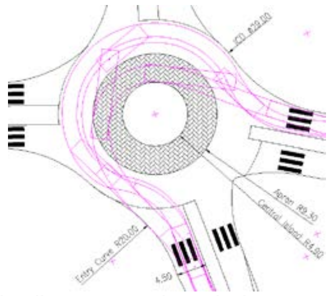
- As per *Road Planning and Design Manual*

Where to Use	• Two way AADT on any approach is greater than 12000; and • Where the speed limit is 60 km/h or less on all approaches.
Avoid	• As a standalone treatment. • Elliptical central island.
Advantages	• Heavy vehicle access maintained while limiting light vehicle entry speeds to improve pedestrian and bicycle safety. • Minimised crossing width for pedestrians. • Potentially low cost retrofit.
Disadvantages	• Off peak vehicular speeds may still exceed above threshold for human crash tolerance. • Constrained entry lane width may result in cyclists queuing with traffic during peak hours. • Difficult to cross the road particularly for children, elderly and people with a vision impairment. • Narrow lane widths may increase potential for motor vehicle sideswipe crashes.
Other considerations	• Queensland road rule 111 permits vehicles greater than 7.5 m long turning **less than halfway** or **more than halfway** to straddle entry lanes for up to 50 m on approach the roundabout. The road rules do not explicitly permit lane straddling for **halfway** movements. • Shall be supported with TC2039 signage. • The width of the two approach lanes needs to be about 5 m to 5.4 m total. • The higher the proportion of heavy vehicles, the more likely they negatively impact on the capacity of the approach.
Alternative Retrofit Treatments	• S4 - Convert multi lane to single lane. • C6 - Replace the Roundabout with a signalised intersection. • C7 - Signalise the roundabout. • C8 - Grade Separation (Underpass). • C9 - Grade Separation (Overpass).
Complementary Retrofit Treatments	• Selected facilities from the “Awareness Toolbox”. • S1 - Approach speed limit. • S2 - Perceptual treatments. • S6 - Central island apron. • S7 - Outside Aprons. • S8 - Speed cushion with splitter kerb. • S9 - Splitter kerbs.
Additional References	• Austroads *Guide to Road Design* Part 4B. • NZ Transport Agency research report 510[37].

S6 - Central island apron



Source: *Ourston Roundabout Engineering Inc.*



VPATH Semi trailer swept path analysis on compact geometry

Guidelines

- As per *Road Planning and Design Manual*

Where to Use	• In order to ensure that light vehicles encounter sufficient entry deflection. • Primarily in single lane roundabouts.
Avoid	• Where adverse crossfall and truck turning speeds are incompatible. • Where heavy vehicles with low underbody clearance could be expected.
Advantages	• Promotes safe system speeds for light vehicles.
Disadvantages	• Not directly supportive of cyclist presence on road. • Fine construction tolerances required to be safe and effective. • Future resurfacing needs to “mill and fill” to ensure apron remains effective.
Other considerations	• Must be capable of being traversed by the trailers of large goods vehicle, but be unattractive to cars e.g. by having a slope and/or a textured surface. • Nose must be visible to drivers and motorcyclists on approach (ASD). Colour should contrast with surroundings. • Roundabouts with aprons should be lit, vegetation should not shadow apron. • Nose should be reflectorized in case lighting is not operative. • **Motorcycles:** • Vertical edges ≥50 mm are not motorcycle friendly[6, 7] refer SETRA (2000) & Baxter (1997). Vertical edges should be <30 mm (“AA” on TMR Standard Drawing 1033). • Should have a semi mountable profile at edge of apron. • These standards should be adhered to after maintenance (eg. resurfacing). • **Articulated vehicles:** • Swept path analysis may assist in estimation of adverse crossfall and potential underbody clearance problems. • Check adverse crossfall and truck turning speeds are compatible (Refer AGRD4A Appendix C, Table C3).
Alternative Retrofit Treatments	• S5 - Convert multi lane to C-Roundabout. • C6 - Replace the Roundabout with a signalised intersection. • C7 - Signalise the roundabout. • C8 - Grade Separation (Underpass). • C9 - Grade Separation (Overpass).
Complementary Retrofit Treatments	• Selected facilities from the “Awareness Toolbox”. • S1 - Approach speed limit. • S2 - Perceptual treatments. • S3 - Compact geometry. • S4 - Convert multi lane to single lane. • S7 - Outside Aprons. • S8 - Speed cushion with splitter kerb. • S9 - Splitter kerbs. • S10 - Raised crossing.
Additional References	• Austroads *Guide to Road Design* Part 4B. • Austroads *Guide to Traffic Management* Part 6. • *West Australian Coroners investigation 30/03* (http://web.archive.org/web/20061019013540/http://www.coronerscourt.wa.gov.au/_files/monson%20mcgee%20finding.pdf). • Ourston Roundabout Engineering Inc. *Accommodating Trucks on Single and Multilane Roundabouts*. TRB National Roundabout Conference 2008[5].

S7 - Outside Aprons

Outside Aprons. Note cobbles not preferred due to maintenance, durability and constructability
Source: CROW Guide to Turbo Roundabouts[38]

Innovative treatment: SHALL be evaluated if trialled in Queensland

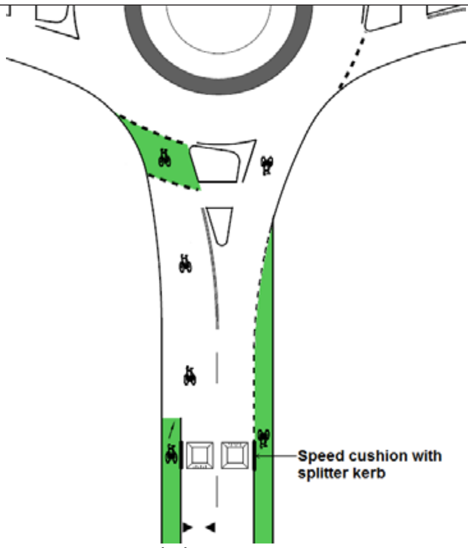
Guidelines

- As per Austroads *Guide to Traffic Management* Part 8

Where to Use	• In order to ensure that light vehicles encounter sufficient entry deflection.
Avoid	• Where adverse crossfall and truck turning speeds are incompatible (refer AGRD4A Appendix C, Table C3). • At the crossing point for pedestrians and cyclists. • Adjacent to bicycle lane on the exit of the roundabout.
Advantages	• Promotes safe system speeds for light vehicles.
Disadvantages	• Not directly supportive of cyclist presence on road. • Fine construction tolerances required to be safe and effective. • Future resurfacing needs to “mill and fill” to ensure apron remains effective. • Cyclists pressured out of traffic stream may be destabilised.
Other considerations	• Must be visible to drivers and motorcyclists on approach. • Must be capable of being mounted by the trailers of large goods vehicle, but be unattractive to cars e.g. by having a slope and/or a textured surface. • No vertical edge. • Should have a semi mountable edge profile. • Lane width should not be constrained to less than 4.5 m wide. • Treatment must be adequately durable and slip resistant. • Discontinue at crossing points. • West Australian design practice only permits flush widening as a result of a Coroners recommendation in late 1990s, further details currently unavailable.
Additional References	• Austroads *Guide to Road Design* Part 4B. • Austroads *Guide to Traffic Management* Part 6. • CROW *Guide to Turbo Roundabouts*[38].

S8 - Speed cushion with splitter kerb

Speed cushion and splitter kerb used in combination. Yarra VIC
Photo: Jon Giles



Example layout
Source GTA Consultants (modified)

Guidelines

- As per Austroads *Guide to Traffic Management* Part 8

Where to Use	• Immediately prior to the end of the bicycle lane/shoulder on the approach to the roundabout, about 15-60 m from the give-way line. • Prior to path crossing points. • In all traffic lanes not separated by medians (eg dual approach lanes, opposing lanes on single carriageway roads).
Avoid	• At or near the crossing point (they may be a trip hazard for people using the crossing). • On routes that may attract pelotons (check with local road riding clubs). • Speed cushion without splitter kerbs (drivers are known to seek to minimise discomfort by partially avoiding vertical displacement through driving in the bicycle lane).
Advantages	• Relatively quick and cheap to retrofit. • Low maintenance. • Induces appropriate speeds suitable for mixed traffic. • Induces safe system speeds prior to crossing points. • Reduces crossing difficulty for young, elderly and people with a disability. • Slower entry speeds in circulation may improve gap acceptance on adjacent legs. • Traversable by emergency vehicles and buses with minimal vertical displacement.
Disadvantages	• 24/7 traffic speed reductions.
Other considerations	• May generate some noise but less than a full width platform or a mid-block situation. • Co-locate with lighting, reflectorize or contrast colour with pavement to ensure splitter kerbs are visible in low light conditions. • For improved detection on approach consider flexible guide posts, flexible bollards or chevron markings on approach.
Additional References	• *Road Planning and Design Manual.* • Austroads *Guide to Road Design* Part 4B. • Austroads *Guide to Traffic Management* Part 6. • *MUTCD* Part 13.

S9 - Splitter kerbs

Approach (Photo: Iain Cummings)

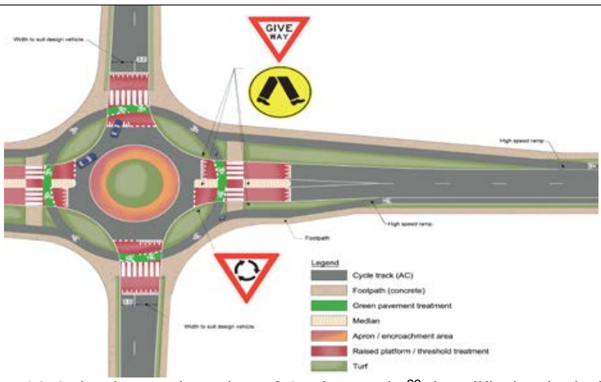
Depart (Photo: Iain Cummings)

Guidelines

- As per *Road Planning and Design Manual*

Where to Use	• To provide a separated bypass treatment between non-conflicting legs. • To induce horizontal deflection to motor vehicle path of travel to achieve appropriate speeds prior to mixed traffic slow encroachment into the bicycle lane on the exit of the roundabout. • Where vertical deflection devices may not be appropriate. • On all entries and exits of the roundabout, drivers entering on a leg without a splitter kerb may be surprised if one is located on the exit.
Avoid	• Extending up to the give-way line. • Permitting on-street parking nearby as it may block access to or from the facility.
Advantages	• Increased separation between cyclists and vehicles until safe mixing speed is achieved. • Reduced pedestrian crossing distance. • Protects cyclists from motor vehicle encroachment on approaches and departures.
Disadvantages	• If the splitter kerb extends all the way to the give-way line it may lead cyclists to adopt a road position that has a minimal buffer distance to traffic entering on the adjacent leg. • Not all cyclists will use the lane behind the kerb, larger groups of cyclists (particularly sports riders) will use a traffic lane.
Other considerations	• Must be visible to drivers and motorcyclists on approach (ASD). • Co-locate with lighting, reflectorize or contrast colour with pavement to ensure splitter kerbs are visible in low light conditions. • Ensure straight path of travel for bicycles to access the space behind the splitter kerb. • For improved detection of narrow splitter kerb consider flexible guide posts, flexible bollards or chevron markings on approach. • Wider splitter kerb may permit placement of a D4-1 hazard marker sign, check this does not interfere with visibility of children or people using wheelchairs at the crossing point • Bicycle lane width should be at least 1.8 m between kerb faces. More width may be required if path of travel is curved while cyclists are also looking for gaps to enter the roundabout. • Terminate the splitter kerb once motor deflection is achieved. • Bolt down splitter kerb is a relatively cheap, fast and light to install as a retrofit treatment or trial. Leading edge may become loose if frequently impacted by motor vehicles. May verify proof of concept or highlight any issues that need to be resolved before progressing to a more permanent solution.
Additional References	• Austroads *Guide to Road Design* Part 4B. • Austroads *Guide to Traffic Management* Part 6.

S10 - Raised crossing

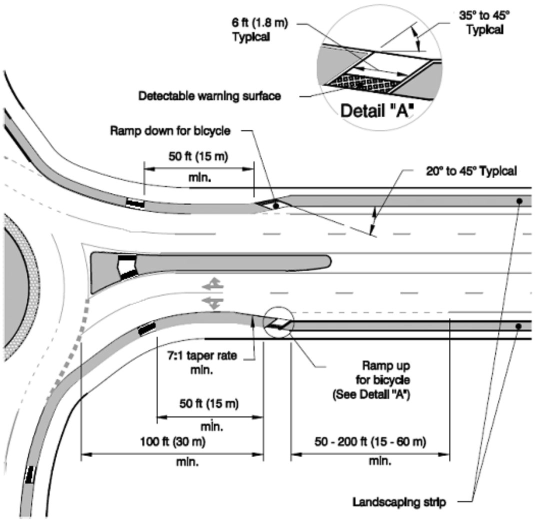


Source: TN128 Selection and Design of Cycle Tracks[39] *(modified to include signage)*

Guidelines	
• As per *MUTCD* Part 9, Part 10 and TN128 *Selection and Design of Cycle Tracks*	
Where to Use	• Within 20 m of the roundabout circulation. • Where 85th percentile traffic speeds do not exceed 60 km/h at the crossing point. • Where control of motor vehicle approach speeds cannot be controlled through horizontal deflection. • On principal bicycle network or high pedestrian activity areas. • Local and collector roads in urban areas.
Avoid	• Where low clearance heavy vehicles cannot be accommodated. • Leading edge not perpendicular to traffic approaching the roundabout.
Advantages	• Provides path users with safest facility with no reduction in convenience or priority. • Induces safe system speeds at the crossing points (80% CRF) • Slower entry speeds may improve gap acceptance for traffic on adjacent legs. • Assists crossing for children, elderly and people with a disability.
Disadvantages	• 24/7 traffic speed reductions.
Other Considerations	• Leading edge and trailing edge of the platform should not have a vertical lip. • Slope of leading edge should be between 1:10 and 1:15 to achieve a v85 of 25-30 km/h (1:15 desirable on bus routes). • A trailing edge slope of 1:50 will increase passenger comfort and reduce dynamic loading on pavement due to suspension bounce. • A platform height of 75 mm may be required on routes where low floor buses operate • Locating the leading edge 5-10 m in advance of the crossing reduces motor vehicle speed at the crossing to reduce crash likelihood and crash severity. • May impact drainage flow path, may require new drainage pits or a treatment to bridge the existing drainage channel. • Noise of wheel impact to hump.
Alternative Retrofit Treatments	• C6 - Replace the Roundabout with a signalised intersection. • C7 - Signalise the roundabout. • C8 - Grade Separation (Underpass). • C9 - Grade Separation (Overpass).
Complementary Retrofit Treatments	• Selected facilities from the “Awareness Toolbox”. • S1 - Approach speed limit. • S2 - Perceptual treatments. • S4 - Convert multi lane to single lane. • S6 - Central island apron. • S7 - Outside Aprons. • S10 - Raised crossing. • T2 - Path on own alignment. • T3 - On-road-off-road transition.
Additional References	• *Road Planning and Design Manual.* • Austroads *Guide to Road Design* Part 4B. • Austroads *Guide to Traffic Management* Part 8. • NCHRP report 562[40] report 674[41].

6.3 *Transition Toolbox*

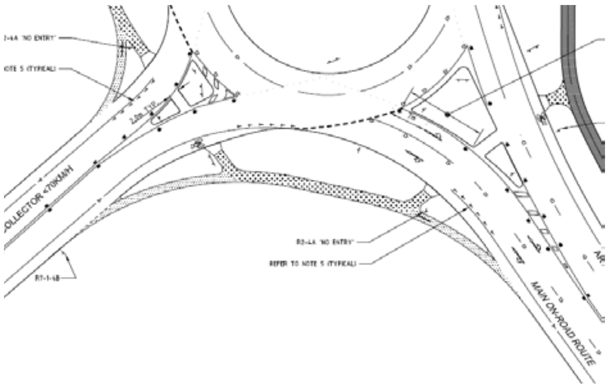
T1 - Path following kerb line



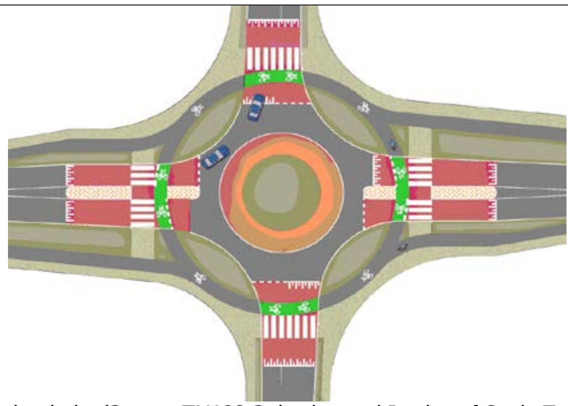
Source: NCHRP 672[42] (modified)

Guidelines	
• As per *Road Planning and Design Manual*	
Where to Use	• In constrained corridor width. • Where pedestrian and cyclist volumes are relatively low.
Avoid	• Conflicts with poles, signs and other roadside furniture that may be obstructing the path.
Advantages	• Keeps cyclists visible to traffic. • Limited changes required for most retrofitting.
Disadvantages	• Potential for path user conflict if path width too narrow. • Cyclists or pedestrians waiting to cross the road may block other path users travelling longitudinally.
Other considerations	• May require treatments to reduce potential path user conflict. • May require increased path width (2.5-3.0 m) to adequately cater for increased demand and potential path user conflict. • May require treatment or relocation of potential hazards or obstructions on the path. • Path should be suitably smooth and free of trip hazards for bicycles and pedestrians.
Alternative Retrofit Treatments	• T2 - Path on own alignment.
Complementary Retrofit Treatments	• Selected facilities from the “Awareness Toolbox”. • S1 - Approach speed limit. • S2 - Perceptual treatments. • S4 - Convert multi lane to single lane. • S6 - Central island apron. • S7 - Outside Aprons. • S10 - Raised crossing. • T3 - On-road-off-road transition. • C3 - Non-priority crossing. • C4 - Unsignalised at-grade priority crossing. • C5 - Mid-block signals.
Additional References	• Austroads *Guide to Road Design* Part 4B and Part 6. • Austroads *Guide to Traffic Management* Part 6. • TN133 *Guidance on the widths of shared paths and separated bicycle paths*.

T2 - Path on own alignment



Motor vehicular priority (Source: ACT Design Standard DS13)



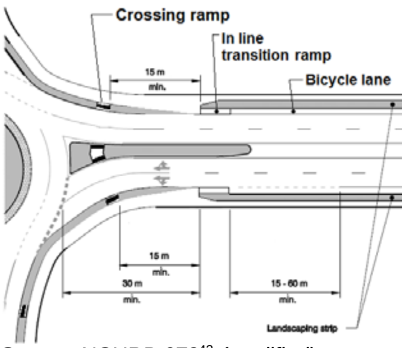
Path priority (Source TN128 Selection and Design of Cycle Tracks)

Guidelines

- As per *Road Planning and Design* Manual

Where to Use	• Where corridor width permits improved geometry.
Avoid	• Landscaping that obscures intervisibility between the road and path.
Advantages	• Cyclists or pedestrians waiting to cross the road will not block other path users. • May permit separated bicycle and pedestrian paths increasing path capacity. • Provides option for riders to exit road if undesirable traffic conditions exist. • May avoid some potential conflicts with utilities and road furniture. • Transition slope to/from road can be very flat providing maximum comfort.
Disadvantages	• Land area. • Likely to be new construction.
Other considerations	• May require path width (2.5-3.0 m) to adequately cater for increased demand and potential path user conflict. • Path alignment should be relatively direct, no unnecessary curves should be included in the alignment. • Some additional signage or surface contrast may be required warn pedestrians of wrong way movements, such as walking out onto the bicycle lane. • If motor vehicles are given priority at the crossing, path geometry should include tight turns to access the crossing to highlight lack of priority to path users. • If path users are given priority at the crossing, path geometry is ideally circular and raised at the road crossings to support path priority.
Alternative Retrofit Treatments	• T1 - Path following kerb line.
Complementary Retrofit Treatments	• Selected facilities from the “Awareness Toolbox”. • S1 - Approach speed limit. • S2 - Perceptual treatments. • S4 - Convert multi lane to single lane. • S6 - Central island apron. • S7 - Outside Aprons. • S10 - Raised crossing. • T3 - On-road-off-road transition. • C3 - Non-priority crossing. • C4 - Unsignalised at-grade priority crossing. • C5 - Mid-block signals.
Additional References	• Austroads *Guide to Road Design* Part 4B, Part 6. • Austroads *Guide to Traffic Management* Part 6. • *ACT Design Standard DS13*[44]. • TN128 Selection and Design of Cycle Tracks[39] • TN133 Guidance on the widths of shared paths and separated bicycle paths[43].

T3 - On-road-off-road transition



Source: NCHRP 672[42] (modified)

In line transition ramp (invert graded to be self-cleaning), Bowen Tce Brisbane (Photo: Mark McDonald)

Guidelines

- As per *Road Planning and Design Manual*

Where to Use	• To provide access to an adjacent path where undesirable traffic conditions might exist on road. • At the bicycle lane termination or where the bicycle lane is added. • On approaches between 15 to 60 m from give-way line. • On exits as soon as practicable (ideally added lane).
Avoid	• Sharp transitions in ramp construction (rounding permissible). • ALL BICYCLES G9-60 signs as they may create false expectations for drivers regarding cyclist path of travel. • Vertical lips in ramp construction. • Locating the ramp so cyclists re-enter into a mixed traffic lane.
Advantages	• Option for riders to exit road if undesirable traffic conditions exist. • Leads riders towards safe crossing opportunities, more riders will be attracted to this option if priority crossings are provided.
Disadvantages	• Not all cyclists will use the path, larger groups of cyclists (particularly sports riders) will use a traffic lane.
Other considerations	• “High speed ramp” as shown in AGRD3 Figure 4.25 is preferred. However this may collect drainage debris where longitudinal road gradient is flat. • An in-line ramp at 1:10 slope is a potential alternative design. • May require supplementary treatments to path to manage path user conflict. • Ideally separated from crossing ramps. However may be co-located with crossing ramps in locations with low pedestrian volumes.
Alternative Retrofit Treatments	• S8 - Speed cushion with splitter kerb. • S9 - Splitter kerbs. • C6 - Replace the Roundabout with a signalised intersection. • C7 - Signalise the roundabout. • C8 - Grade Separation (Underpass). • C9 - Grade Separation (Overpass).
Complementary Retrofit Treatments	• Selected facilities from the “Awareness Toolbox”. • S1 - Approach speed limit. • S2 - Perceptual treatments. • S3 - Compact geometry. • S4 - Convert multi lane to single lane. • S6 - Central island apron. • S7 - Outside Aprons. • S10 - Raised crossing. • T1 - Path following kerb line. • T2 - Path on own alignment. • C3 - Non-priority crossing. • C4 - Unsignalised at-grade priority crossing.
Additional References	• Austroads *Guide to Road Design* Part 3. • Austroads *Guide to Traffic Management* Part 6.

6.4 *Conflict Management Toolbox*

C1 - Alternative route

Primary Route

Alternative Route (less desirable than primary)

Assess and compare the risk on both the primary and the alternative route

Where to use	• Where local streets or parks offer a direct, competitive and lower risk alternative to a high capacity, high speed roundabouts. • The alternative route is coherent system and maintains good access to origins, destinations and services. • On the Principle Bicycle Network, where cycle volumes are expected to be high.
Avoid	• As a localised bypass to an individual roundabout. • Routes that have poor CPTED properties. • Routes that incur significant delay in either time or distance. • Routes that are heavily used or could create conflict with other path users.
Advantages	• Bicycles are separated from heavy traffic. • Local back streets offer good personal security and passive surveillance. • Desirable to all types of rider.
Disadvantages	• Suitably safe and convenient option may not always be available. • Some parks and underpasses may be perceived to have poor personal security and passive surveillance which may deter use. • May incur additional costs to make the alternative route safe or fully accessible. • Other corridors may require the approval of other agencies which could delay or block implementation of a suitable solution.
Other Considerations	• Local backstreets may require traffic calming or intersection modifications. • May require wayfinding signage to ensure the route is legible. • May require modifications to signals if the alternative route crosses a major road. • Ensure gradients on alternative route are desirable. • Some treatment of the roundabout may still be necessary to mitigate risk for cyclists who don't use the alternative route. • The Strava heatmap (http://labs.strava.com/heatmap/#6/142.69043/-21.44712/gray/bike) may provide some indication on current bicycle usage in the area and possible alternative routes currently in use (Strava may represent activity of sports riders more than traffic shy recreational riders).
Additional References	• *Road Planning and Design Manual*. • Austroads Guide *to Road Design*. • Austroads *Guide to Traffic Management*. • *Queensland Police CPTED guidelines*[45].

C2 - Eliminate left turn slip lane

Ferguson Rd and Oateson Skyline Dr (Photo:TMR aerial imagery)

Requires support by traffic modelling

Guidelines

- As per *Road Planning and Design Manual*

Where to Use	• Consider removing slip lanes at roundabouts where they are not absolutely necessary. • Where traffic queue regularly blocks access to the slip lane. • Urban locations where many pedestrians and cyclists could be expected.
Avoid	• Removal of a slip lane if traffic safety is potentially compromised (for example, without slip lane traffic backs up onto adjacent motorway).
Advantages	• Reduces number of conflict points and intersection complexity. Drivers are potentially less likely to overlook cyclists. • Makes crossing the road easier. Particularly for children, elderly and people with a vision impairment. • May reduce motor vehicle delays on other legs as more gaps will occur between conflicting vehicle movements.
Disadvantages	• Some additional delay for motor vehicles on the relevant entry.
Other Considerations	• Provision of new or upgraded roads nearby may have reduced the traffic carrying importance of the site. • Removal of slip lane may be supported by traffic modelling, some slip lanes provide little benefit in peak hours as access is blocked by motor vehicle queues.
Alternative Retrofit Treatments	• C6 - Replace the Roundabout with a signalised intersection. • C7 - Signalise the roundabout. • C8 - Grade Separation (Underpass). • C9 - Grade Separation (Overpass).
Complementary Retrofit Treatments	• Selected facilities from the “Awareness Toolbox”. • S1 - Approach speed limit. • S10 - Raised crossing. • C4 - Unsignalised at-grade priority crossing.
Additional References	• Austroads *Guide to Road Design* Part 4B. • Austroads *Guide to Traffic Management* Part 6. • NCHRP report 674[41]

C3 - Non-priority crossing

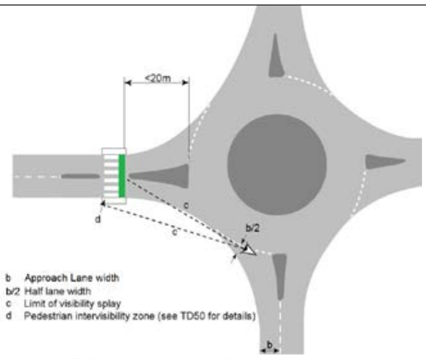
Yellow line indicates path user sight line, 3rd approaching car potentially not visible to path user.
Robina Parkway at Gooding Dr, QLD (Photo:TMR aerial imagery)

Guidelines

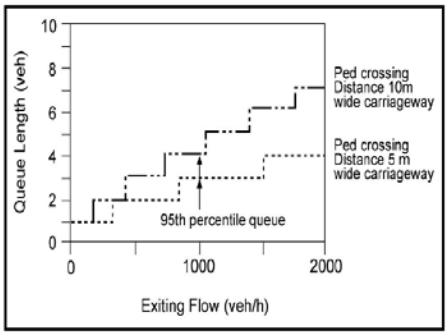
- As per *MUTCD* Part 10 and *TRUM* Vol 1 Part 6 S3.4-1

Where to Use	• Where gaps in traffic are available to cross the road. • Where priority crossings are unsuitable.
Avoid	• Where children, elderly or people with disabilities are known to cross the road regularly. • Where higher order crossing facilities are feasible. • Vegetation or landscape terrain that obscures intervisibility between the road and path.
Advantages	• Minimal motor vehicle delay.
Disadvantages	• Traffic queue on approach may not permit path users to cross. • Locates crossing in motor vehicle acceleration zone, driver expectation of acceleration may reduce ability to stop if necessary. • Higher traffic speed increases the probability of a crash being fatal for the vulnerable road user. • Experienced cyclists will remain on-road to retain priority and reduce delay. • Non-priority crossings place onus of responsibility on people potentially least able to judge the situation. Under 12s cannot judge traffic speed well, people with a vision impairment struggle to judge traffic movements in free flow conditions. • Lead vehicle may obscure visibility to a following vehicle in an adjacent lane increasing difficulty of judging a safe gap. (multi lane multiple threat).
Other Considerations	• Analyse crossing appropriateness using TRUM Vol 1 Part 6 S3.4-1, include both bicycle volumes and pedestrian volumes (existing and projected volumes). • Refuge is desirably 3 metres wide, a bicycle with a baby trailer is 3 m long. Refer *MUTCD* Part 10 Fig7 • Tight turn geometry on path to access the crossing reduces approach speed and highlights lack of crossing priority. • A give-way line should be included where a bicycle path enters at grade. Give-way line not required where TGSI is used (shared path). • Consider Give-way pavement symbol instead of small sign on pole, refer *MUTCD* Part 9. • Hold rail located on a flat gradient may assist comfort and prompt crossing for cyclists, refer details *TRUM* Vol 1 Part 6 S3.4-1 Figure 4-B
Alternative Retrofit Treatments	• S4 - Convert multi lane to single lane. • C6 - Replace the Roundabout with a signalised intersection. • C7 - Signalise the roundabout. • C8 - Grade Separation (Underpass). • C9 - Grade Separation (Overpass).
Complementary Retrofit Treatments	• Selected facilities from the "Awareness Toolbox". • S1 - Approach speed limit. • S9 - Splitter kerbs.
Additional References	• *Road Planning and Design Manual.* • Austroads *Guide to Road Design* Part 4. • Austroads *Guide to Traffic Management* Part 6.

C4 - Unsignalised at-grade priority crossing



Intervisibility splay (modified from original)
(UK Design Manual For Roads And Bridges, Td 16/07[8])



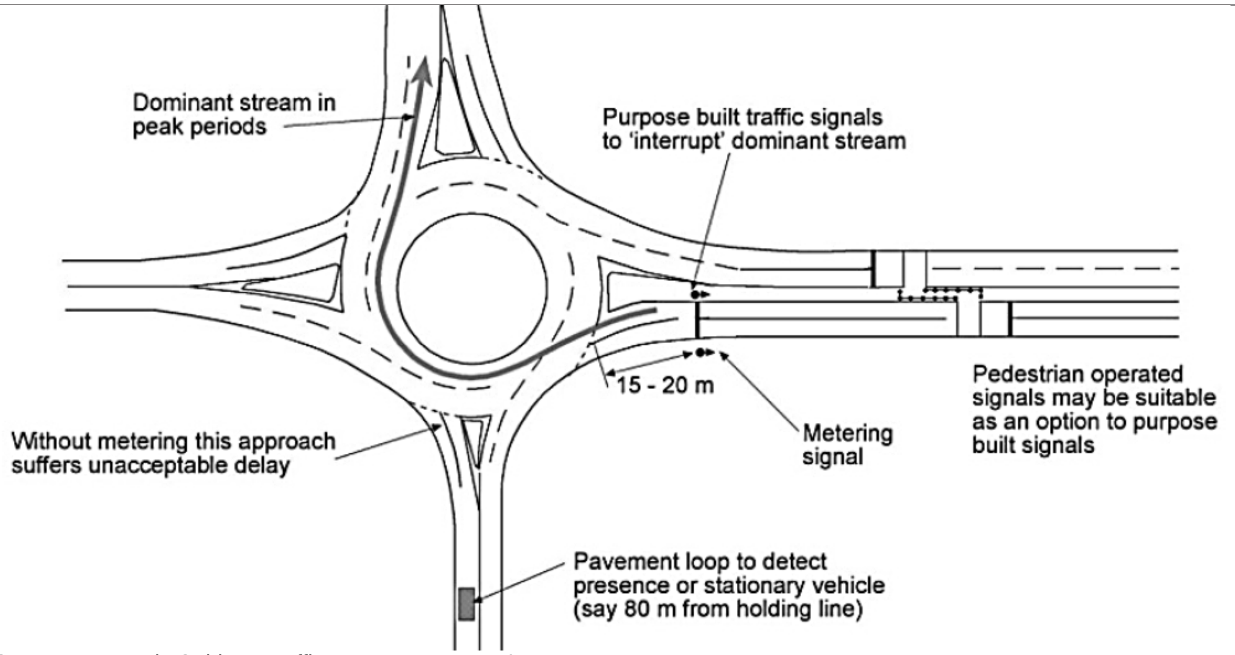
Number of motor vehicles queued at ***pedestrian crossing***
(Figure 4.8 Austroads guide to traffic management part 6)

Guidelines

- As per *MUTCD* Part 10 and *TRUM* Vol 1 Part 6 S3.4-1

Where to Use	• *MUTCD* Part 10 s6.3b 85th percentile speed measured at the point where the crossing is to be placed, shall not exceed 60 km/h. • Where *TRUM* Vol 1 Part 6 S3.4-1 indicates a pedestrian crossing as a possible treatment. • Located 6-20 m from the give-way line. • On single entry and exit lanes.
Avoid	• On higher speed roundabouts where traffic queued in the circulation may increase motor vehicle crash risk or severely reduce network performance. • Vegetation or landscape terrain that obscures intervisibility between the road and path.
Advantages	• Reduced delay for path users. • Increased connectivity for path users. • Assists people with a vision impairment to cross the road. • Crossings may randomise dominant traffic legs (similar to metering).
Disadvantages	• At grade priority crossings may lead to a “False sense of security” for path users, if drivers are not attentive they may not stop.
Other Considerations	• Analyse crossing appropriateness using *TRUM* Vol 1 Part 6 S3.4-1, Include both bicycle volumes and pedestrian volumes (existing or projected volumes). • Traffic approaching the roundabout is already slowing to stop, increasing likelihood of drivers actually giving way. • Provide green surface treatment for bicycle crossing adjacent to the pedestrian crossing. • Locate bicycle crossing downstream of pedestrian crossing. • A mounted cyclist travelling at 10 km/h is 2.3 times faster than a pedestrian, this reduces crossing time, motor vehicle delay and queue length. AGTM6 Figure 4.8 may indicate overly conservative numbers of queue vehicles at priority crossings predominantly used by bicycle riders.
Alternative Retrofit Treatments	• C1 - Alternative route. • C5 - Mid-block signals. • C6 - Replace the Roundabout with a signalised intersection. • C7 - Signalise the roundabout. • C8 - Grade Separation (Underpass). • C9 - Grade Separation (Overpass).
Complementary Retrofit Treatments	• Selected facilities from the “Awareness Toolbox”. • S1 - Approach speed limit. • S4 - Convert multi lane to single lane. • S8 - Speed cushion with splitter kerb. • S9 - Splitter kerbs. • S10 - Raised crossing.
Additional References	• *Road Planning and Design Manual.* • Austroads *Guide to Road Design* Part 4. • Austroads *Guide to Traffic Management* Part 6. • NCHRP report 674[41].

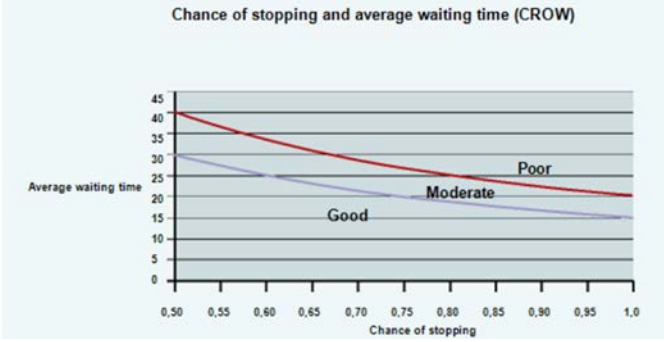
C5 - Mid-block signals



Source: Austroads Guide to Traffic Management Part 6

Guidelines	
• *TRUM* Vol 1 Part 6 S3.4-1	
Where to Use	• Urban areas near schools. • Locations frequented by the elderly or people with disabilities. • As part of a total traffic network operational improvement program. • Where bicycle and pedestrian routes and desire lines align well with the crossing point. • Where two or more lanes of traffic need to be crossed. • Where gaps in traffic are insufficient to safely cross.
Avoid	• Significant detour distances (>500 m) or significant time delay before the call progresses to hold traffic. • Low volume crossing demand.
Advantages	• May meter traffic entering the roundabout supporting flow on other legs that may be critical to network performance.
Disadvantages	• Excessive delay may result in cyclists remaining on-road, providing limited safety benefit.
Other considerations	• Intelligent crossing (pedestrian and cyclist detection) may reduce motor vehicle delay when the crossing is cleared earlier than normally expected. • Approach detection on bicycle paths may reduce cyclist waiting delay.
Alternative Retrofit Treatments	• S4 - Convert multi lane to single lane. • C1 - Alternative route. • C6 - Replace the Roundabout with a signalised intersection. • C7 - Signalise the roundabout. • C8 - Grade Separation (Underpass). • C9 - Grade Separation (Overpass).
Complementary Retrofit Treatments	• Selected facilities from the "Awareness Toolbox". • S1 - Approach speed limit. • S10 - Raised crossing.
Additional References	• *Road Planning and Design Manual.* • Austroads *Guide to Traffic Management* Part 6.

C6 - Replace the Roundabout with a signalised intersection



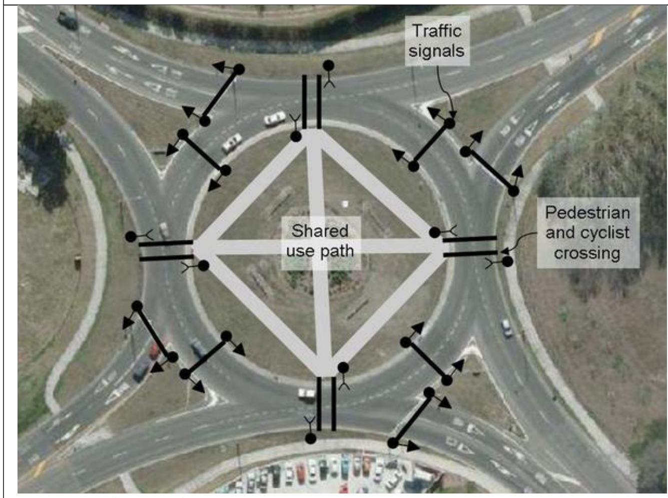
Source: TMR TN128 Selection and Design of Cycle Tracks

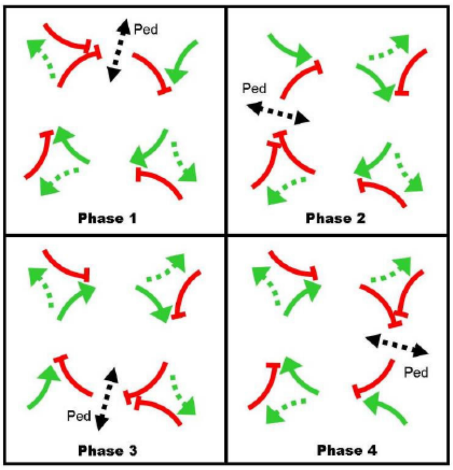
Guidelines

- *Road Planning and Design Manual*

Where to Use	• Urban areas near schools. • Locations frequented by the elderly or people with disabilities. • As part of a total traffic network operational improvement program.
Advantages	• Reduced land requirement at the intersection point. • Increased control of motor vehicle flows, favouring of priority routes.
Disadvantages	• Increased motor vehicle storage upstream. • Potential increased delay for all road users, especially off-peak. • Potential increase in crash severity for motorists (impact angle of incidence if a motorist runs red light). • Signalised slip lanes increase bicycle/pedestrian delay. • Un-signalised slip lanes are challenging for children, elderly and people with disabilities. Motor vehicle speed to likely exceed human tolerance to impact force.
Other considerations	• Installation costs. • Operating costs (system). • Operating costs (vehicles, users). • Crossings should be provided on all legs of the intersection. • Intelligent crossing (pedestrian and cyclist detection) may reduce motor vehicle delay when the crossing is cleared earlier than normally expected. • Approach detection on bicycle paths may reduce cyclist waiting delay. • Short signal cycle-times or double cycling of pedestrian and bicycle phases to reduce delay. • Filtered right turn movements across multiple lanes have been shown to increase crashes due to the dynamic visibility obstructions inherent in seeing through the traffic stream, smaller road users such as motorcyclists and cyclists are easily obscured by other vehicles.
Alternative Retrofit Treatments	• C1 - Alternative route. • C7 - Signalise the roundabout. • C8 - Grade Separation (Underpass). • C9 - Grade Separation (Overpass).
Complementary Retrofit Treatments	• Selected facilities from the “Awareness Toolbox”. • S1 - Approach speed limit.
Additional References	• *TMR TN128 Selection and Design of Cycle Tracks*[39]. • Austroads *Guide to Road Design.* • Austroads *Guide to Traffic Management.*

C7 - Signalise the roundabout



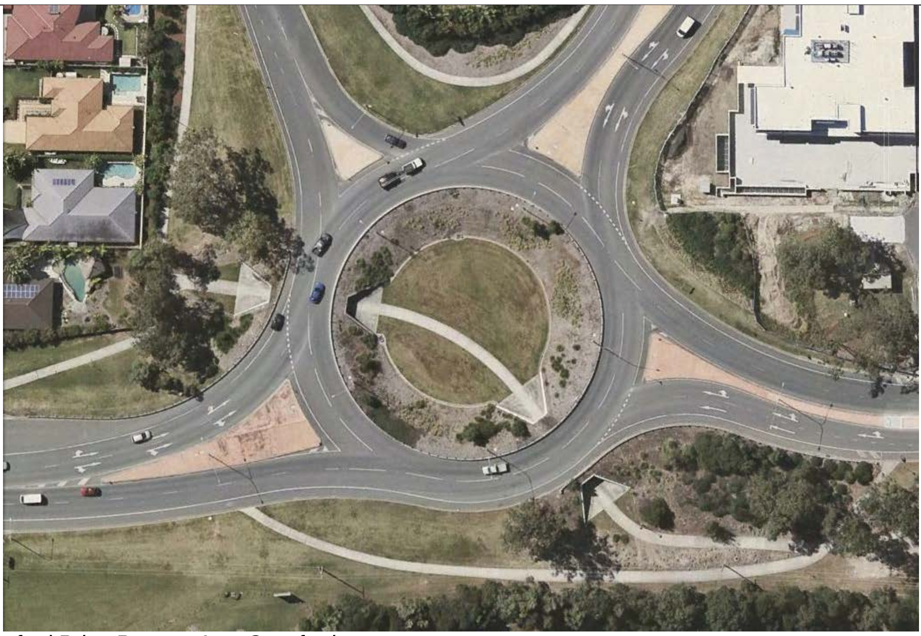


Source: Via Strada

Guidelines

- *TMR TN128 Selection and Design of Cycle Tracks*, *Road Planning and Design Manual* and Austroads *guides*.

Where to Use	• Urban areas near schools. • Locations frequented by the elderly or people with disabilities. • As part of a total traffic network operational improvement program.
Avoid	• Where alternative lower cost treatments are feasible and are expected to operate safely.
Advantages	• Permits control and favouring of priority routes. • Retains low impact angle of incidence for motor vehicles limiting crash severity. • Virtually no change in land requirement. • Potentially minimal traffic impact during retrofit construction. • Makes a challenging road environment accessible for children, elderly and people with disabilities.
Disadvantages	• Increased motor vehicle storage upstream. • Potential increased delay for all road users, especially off-peak.
Other considerations	• Installation costs. • Operating costs (system). • Operating costs (vehicles, users). • Intelligent crossing (pedestrian and cyclist detection) may reduce motor vehicle delay when the crossing is cleared earlier than normally expected. • Approach detection on bicycle paths may reduce cyclist waiting delay. • Short signal cycle-times or double cycling of pedestrian and bicycle phases to reduce delay. • Crossings need to be regularly activated to ensure drivers do not overlook the presence of the crossings.
Alternative Retrofit Treatments	• S4 - Convert multi lane to single lane. • C1 - Alternative route. • C6 - Replace the Roundabout with a signalised intersection. • C8 - Grade Separation (Underpass). • C9 - Grade Separation (Overpass).
Complementary Retrofit Treatments	• Selected facilities from the “Awareness Toolbox”. • S1 - Approach speed limit. • S2 - Perceptual treatments.
Additional References	• Austroads *Guide to Traffic Management* Part 6.

C8 - Grade Separation (Underpass)	
 *Tamborine-Oxenford Rd at Regatta Ave, Oxenford* *Source: TMR aerial imagery,*	
Consider grade separation in early design stages of capital works and greenfield developments	
Guidelines	
• As per *TRUM* Vol 1 Part 6 S3.4-1 and *Road Planning Design Manual*	
Where to Use	• Where topography supports an underpass. • Where good approach geometry is available and sightlines extend entire length of the underpass before the user enters the underpass. • Where the *TRUM* Vol 1 Part 6 S3.4-1 (including bicycle volumes) indicates that mid-block signals are warranted, but an at-grade crossing cannot be installed due to high traffic volume roads (e.g. arterial roads, freeways and motorways). • Across major roads where alternative crossing facilities are not feasible. • On PCNP or where extremely high pedestrian volumes occur, and/or • Where it can be provided as part of an adjacent development that would generate a high demand to cross at that location.
Avoid	• Where alternative lower cost treatments are feasible and are expected to operate safely.
Advantages	• Eliminates conflicts with motor vehicles. • Causes no delays to motor vehicle traffic. • Less height change compared to overpass, less physical effort for users. • Ability to use the central island to provide direct connection for multiple directions.
Disadvantages	• High capital cost as a retrofit treatment. • Jacking construction method may only permit small underpass dimensions. • Cut and cover construction method is likely to impact traffic during construction. • Can be subject to poor patronage (except at schools or where fencing is used) due to the level difference and longer travel distance. • May require changes in access points to encourage use (e.g. bus stop locations, school gates). • May reduce perception of personal security. • Prone to vandalism (maintenance cost). • Occasionally flooded (maintenance cost).
Other considerations	• Lighting as per AS1158.3.1. • May require fencing and signage to encourage use.
Additional References	• Austroads *Guide to Road Design* Part 6. • *Queensland Police CPTED guidelines*[45]. • *TMR Bridge design and assessment criteria*[46].

C9 - Grade Separation (Overpass)

Toowong Pedestrian and Bicycle overpass
Source: TMR aerial imagery,

Guidelines

- As per *Road Planning and Design Manual*

Where to Use	• Where topography supports an overpass. • Where the *TRUM* Vol 1 Part 6 S3.4-1 (including bicycle volumes) indicates that mid-block signals are warranted, but an at-grade crossing cannot be installed due to high traffic volume roads (e.g. arterial roads, freeways and motorways). • Across major roads where alternative crossing facilities are not feasible. • On PCNP or where extremely high pedestrian volumes occur, and/or • Where it can be provided as part of an adjacent development that would generate a high demand to cross at that location.
Avoid	• Where alternative lower cost treatments are feasible and are expected to operate safely.
Advantages	• Eliminates conflicts with motor vehicles. • Causes no delays to motor vehicle traffic.
Disadvantages	• High capital cost. • Can be subject to poor patronage (except at schools or where fencing is used) due to the level difference and longer travel distance. • May require fencing and signage to encourage use. • May require changes in access points to encourage use (e.g. bus stop locations, school gates). • Service more than one side of the roundabout may require more than one bridge or a significant Hovenring (http://hovenring.com/) style structure. • Crash barriers likely required to protect both traffic and the structure from impacts.
Additional References	• Austroads *Guide to Road Design* Part 6. • *TMR Bridge design and assessment criteria*[46]. • TMR Policy - *Reduction of Risk from Objects Thrown From Overpass Structures onto Roads*[47].

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Appendix A - Definitions

ASD: Approach Sight Distance. Distance it takes a driver to see a pavement marking and stop before the marking.

Bicycle facility: Any type of explicit bicycle infrastructure provision including bicycle path, bicycle lane, or cycle track.

Bicycle lane: An on-road special purpose lane for the exclusive use of bicycles.

Bicycle path/Exclusive bicycle path: A dedicated two-way facility for bicycle riders that is considered road related area under the Australian road rules.

Bicycle route: A route may comprise a number of different types of bicycle facilities or route signage to connect key origins and destinations.

Compact (Radial) Geometry: Approach geometry that is largely radial to the central island and includes entry/exit curve radii around 15-20m.

CRF: Crash Reduction Factor. Estimated influence a treatment may have in reducing the number of crashes. Usually only relevant to one or two specific crash types.

Cycle track: A bicycle path, physically separated from pedestrians and motor vehicles that provides priority at intersections with roads.

Cycle track (one-way): A bicycle path that only permits one-way movements. Defined as road related area under QRR.

Cycle track (two-way): A bicycle path that permits two-way movements. Defined as road related area under QRR.

CPTED: Crime Prevention through Environmental Design.

Danger Reduction: Reduce the danger that is present; Reduce the likelihood of a crash occurring; Reduce the consequences if a crash does occur.

DCA: Definitions for Coding Accidents. A system of classifying crashes, using ‘collision diagrams’,

based on the traffic movements leading up to the crash. Participant intent, as well as actual movement can be used in determining the DCA crash type however the relative fault of the participants is not

relevant. Refer Austroads Guide to Road Safety Part 8 Figure 5.1

DCA101: Through vehicle collision with another through vehicle. At a roundabout, an entering vehicle collision with circulating vehicle.

ICD: Inscribed Circle Diameter. Diameter of the outer edge of the circulating roadway of a roundabout.

Intersection: Without altering the QRR definition this guide also defines an intersection as the meeting one path with at least one other road, path or driveway.

MUTCD: Manual of Uniform Traffic Control Devices.

Off-road: A path located outside the road corridor, possibly through a park, reserve, easement, within a public transport corridor or other public or private land not open to motor vehicle traffic.

On-road: Where bicycles are operated in a general purpose traffic lane, special purpose lane, auxiliary lane, a lane shared with parked cars or road shoulder.

QRR: Queensland Road Rules

Road: As per the definition in Schedule 4 of the Transport Operations (Road Use Management) Act 1995

Road related area: As per section 13 of the Transport Operations (Road Use Management—Road Rules) Regulation 2009

Separator: An area that divides a bicycle facility or path from the footpath, nature strip or roadway.

Shared path: A pedestrian and bicycle facility that gives pedestrians priority under QRR.

Tangential Geometry: Entry geometry designed to direct vehicles into the roundabout circulation tangential to the central island.

Transition: A bicycle path connection, possibly a ramp, between road and road related area

(or vice versa), such as a Bend-in Transition.

TRUM: Traffic and Road Use Management Manual.

Appendix B – Crash Prediction Model

B1 - Background

Turner (2012) showed how covariate cycle crash models could be developed for Queensland using a wider sample set across New Zealand and for traffic signals in Adelaide However, some care does need to be taken in using these models based on the small number of sites that were available in Queensland at the time of the study. Ideally data needs to be collected for a larger sample set of sites so that the Queensland crash models are more reflective of local conditions. Some further refinement of the research would help to identify how the Queensland cycle crash rates differ from other jurisdictions. **However, these models are accepted for use as proactive risk assessment tools until more refined models become available.**

At roundabouts the entry speed was found to be a key factor in entering versus circulating cycle crashes (where cyclists circulating). This is thought to be due to the reduced time that drivers have to scan the roundabout before entering, when there are higher speeds, and the higher likelihood drivers will not perceive the cyclists, especially when there are a lot of motor-vehicles using the roundabout. A combination of reduced approach visibility and suitable geometry has been shown to reduce approach speeds at roundabouts.

The following sections present the cycle versus motor-vehicle crash models developed for entering versus circulating (cyclists circulating) and 'other' cyclists crash types at urban roundabouts. The crash prediction models for roundabouts were originally developed in New Zealand by Turner et al. (2009b). Thirty four models were developed in total, only the preferred models are presented here.

The models indicate that the number of crashes increases with increasing circulating and entering vehicle speeds, and with the presence of a downhill gradient. There was no increase observed for multiple circulating lanes, although this factor may well be taken into account in the entering and circulating speed variable, as larger roundabouts often have higher travel speeds. In other research (Turner and Roozenberg, 2006) on higher (rural) speed limit roundabouts, it was found that motor-vehicle crash rates were 35% higher than for lower speed roundabouts. It is reasonable to assume that at least a 35% increase would be expected for cycle related crashes.

B1.1 Entering versus Circulating Cyclist Crash Model

The A_{UCAR1} model includes entering motor vehicle volumes, circulating cyclist volumes and the mean speed of the entering motor vehicles.

$$A_{UCAR1} = 3.88 \times 10^{-5} \times Q_e^{0.43} \times C_c^{0.38} \times S_E^{0.49}$$

where:

A_{UCAR1}	=	annual number of entering v circulating cyclist crashes
Q_e	=	entering flow on the approach
C_c	=	circulating cyclist flow perpendicular to the entering motor vehicle flow
S_E	=	free mean speed of vehicles as they enter the roundabout.

B1.2 'Other' Cyclist Crash Model

The A_{UCAR2} model excludes crashes where the cyclist is circulating and the motor vehicle is entering, as this is covered by the previous model. Further disaggregation of cycle crashes was not possible given the low numbers of some cycle crash types.

$$A_{UCAR2} = 2.07 \times 10^{-7} \times Q_a^{1.04} \times C_a^{0.23}$$

where:

A_{UCAR2} = annual number of 'other' crashes involving cyclists

Q_a = approach flow (sum of entering and exiting motor vehicle flows)

C_a = cyclist approach flow (sum of entering and exiting cyclist flows).

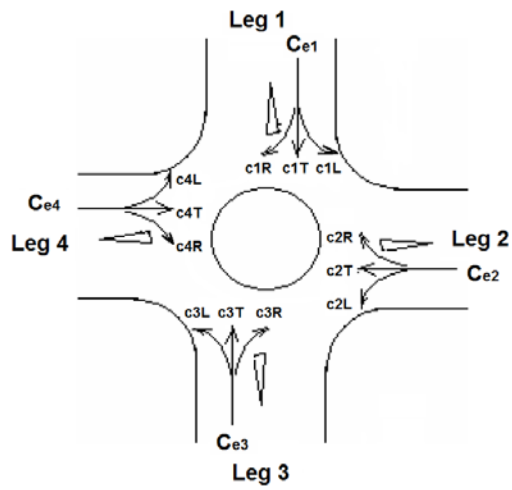
The model indicates that as traffic volumes or cyclist volumes increase, the number of crashes also increases in almost a linear manner. The number of crashes is influenced more by an increase in the motor vehicle volume than an increase in the cyclist volume. Increasing the cyclist volume has a 'safety in numbers' effect, where the per-cyclist crash risk drops as the number of cyclists increase. More evidence of this effect can be found in Turner et al (2006).

B2 'Implementation of the models

Both the A_{UCAR1} and A_{UCAR2} models need to be applied to estimate the expected average number of bicycle crashes at a roundabout.

Ideally these models should supplement analysis using the ARNDT software developed by TMR. The ARNDT software calculates 85th percentile motor vehicle entry speed which is also the required input parameter S_e in A_{UCAR1}.

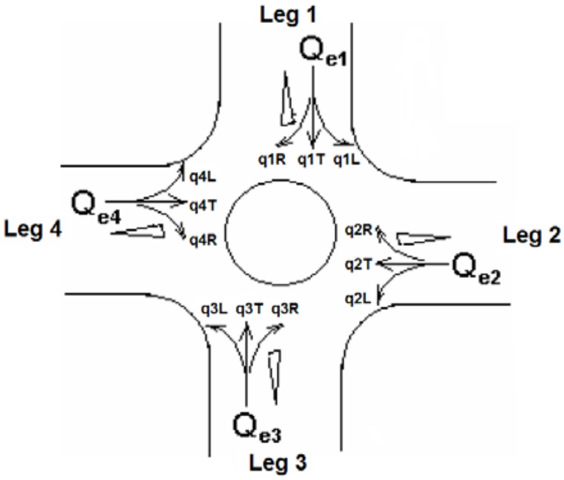
Figure B1: Bicycle volume notation (Adapted from Turner and Roozenberg 2006)



Note that the value C_e on each leg is derived from the bicycle flows occurring in front of that leg for example:

$$C_{e1} = c4T+c4R+c3R$$

Figure B2: Motor vehicle volume notation (Adapted from Turner and Roozenberg 2006)



The values Q_a and C_a are the two way volumes on each leg. This could be found either through mid-block traffic counts on each leg (if available) or derived from turning movement volumes for example:

$$Q_{a1} = Q_{e1}+q2r+q3T+q4L$$

$$C_{a1} = C_{e1}+c2r+c3T+c4L$$

A spreadsheet tool complements this Technical Note to assist analysis.

Appendix C – Comparison of Compact (Radial) and Tangential geometry using ARNDT crash prediction models

A1 – Purpose

As radial roundabouts do not currently exist in Australia the ARNDT program was used to compare potential differences in predicted crash types against typical tangential design.

The original ARNDT research did not include roundabouts with compact (radial) geometry in the data set so conclusions drawn in this comparison should be considered indicative at best.

A2 - Method

A series of similar roundabouts were generated using the ARNDT program, the principal variations were entry/exit geometry and approach speeds. The cases used for comparison were as shown on Table A1. Figure A1 and Figure A2 show a graphical comparison of the roundabout geometry. All roundabouts had 4 legs, single lane approaches and departures, a central island radius of 15 metres and circulating road width of 5 metres.

Table A1 – Roundabout comparison cases

Geometry	Approach Speed (km/h)	Entering Traffic on Each Leg (AADT)
Compact (Radial)	40	2000
Compact (Radial)	50	2000
Compact (Radial)	60	2000
Compact (Radial)	70	2000
Tangential	40	2000
Tangential	50	2000
Tangential	60	2000
Tangential	70	2000

Figure A1 – Compact (Radial) Geometry

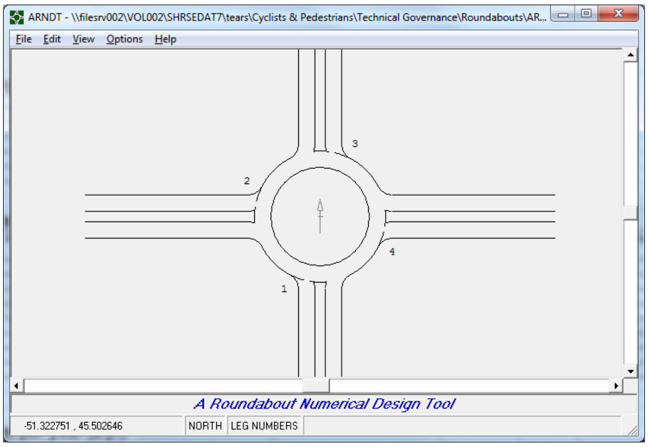
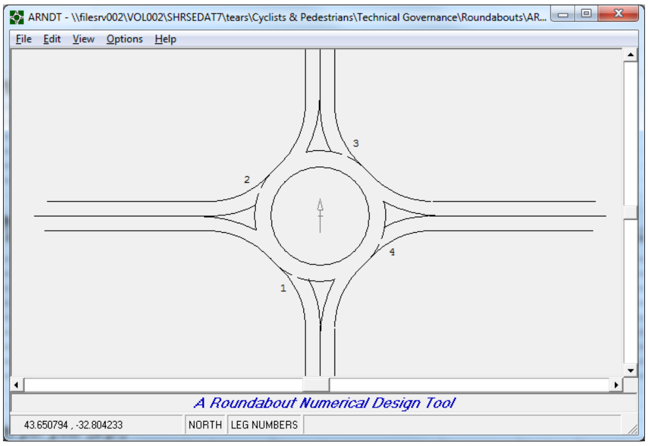


Figure A2 – Tangential Geometry



A3 – Summary of ARNDT Output

Figure A3 shows tangential geometry and compact geometry have similar predicted overall crash costs up to an approach speed of about 60 km/h.

Figure A3 – Roundabout Approach Speed vs Total Annual Predicted Crash Costs ARNDT output

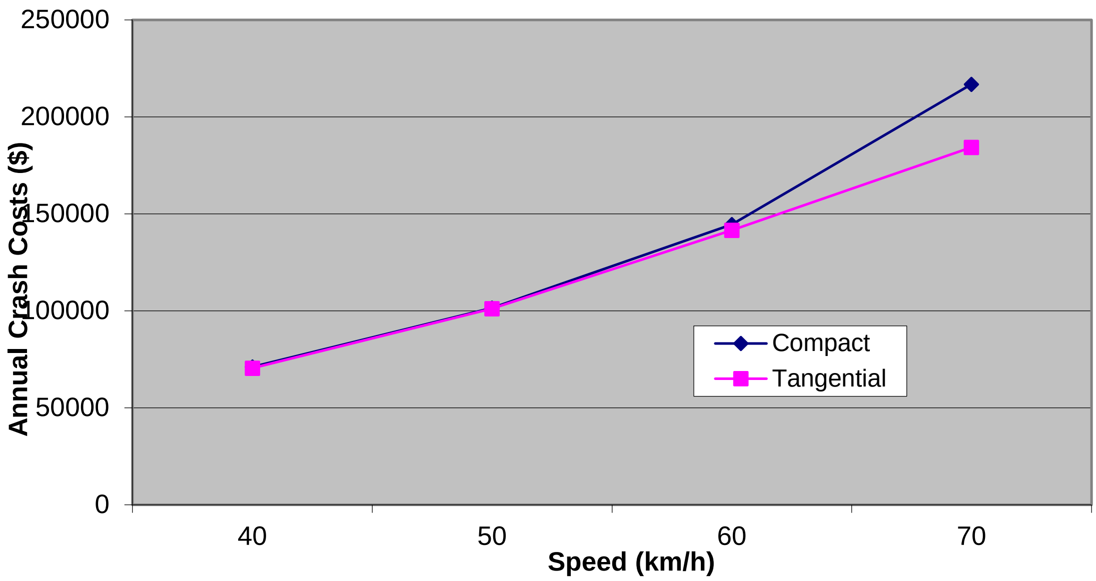


Figure A4 shows compact geometry results in higher predicted single vehicle crash costs compared to tangential geometry. This indicates speed control treatments on approach to a compact roundabout may be appropriate.

Figure A4 – Roundabout Approach Speed vs Single Vehicle Predicted Crash Costs

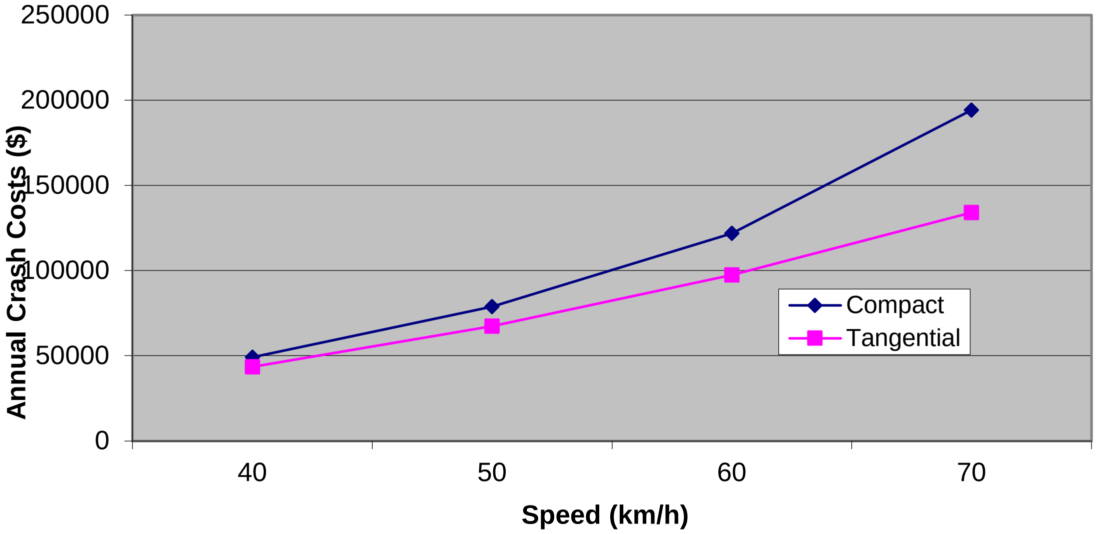


Figure A5 shows, compared to tangential geometry, compact geometry would be expected to significantly reduce entering/circulating crashes (DCA101) for all road users. As this is the critical crash type for motorcyclists and bicyclists. This indicates compact geometry may be a promising treatment vulnerable road user safety.

Figure A5 – Roundabout Approach Speed vs Entering/Circulating Predicted Crash Costs