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Towards a Safe System Approach

Selection of Intersection Control

Guidelines

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1 DEFINITIONS

Term	Definition
BCR	Benefit Cost Ratio
DOS	Degree of Saturation
EDD	Extended Design Domain
FSI	Fatal and Serious Injury
Intersection Capacity	The maximum traffic volume that an intersection can accommodate during a given time period, typically the morning and afternoon peak hours.
LGA	Local Government Authority
LOS	Level of Service
Main Roads	Main Roads Western Australia
Operational Efficiency	The ability of an intersection to adequately cater for the horizon year forecast demands. Operational efficiency is measured relative to target performance criteria, such as Degree of Saturation, Level of Service and Queue Lengths. Refer Section 5.6.5 for further details including typical target performance criteria.
OSOM	Over Size Over Mass (heavy vehicles)
PCU	Passenger Car Units
Project Case Horizon Year	The target year for which forecast traffic volumes are estimated, and capacity analysis is undertaken to assess the performance of the intersection under future traffic demands. Minimum requirements for Main Roads roads and intersections are outlined in Section 5.6.4 and 5.6.5. The Project Case layout is the proposed intersection layout at opening (i.e. the 'project' to be delivered).
ROSMA	The Main Roads Road Safety Management system
Roundabout Metering	Where one or more approach legs are metered (signalised) with two-phase signals (red and amber). These signals are set back from the roundabout entry, with the entry itself still operating under normal priority-control rules. Roundabout metering is typically applied to help with unbalanced flow situations, i.e. to provide gaps in the circulating traffic stream, with the dominant approach metered to provide gaps for the downstream approach legs, often only activated during the peak periods. Outside of peak periods, the signals are blank, and normal operation applies.
Roundabout Signalisation	Both external and internal approach legs are signalised with three-phase signals (red, amber, green), thus directly controlling traffic entering the 'intersection' area of the roundabout. Roundabouts can be fully controlled, i.e. all internal and external legs are signalised, or partially controlled, i.e. one or more of the approaches remain under priority control.
RRPMs	Raised Reflective Pavement Markers
Safe Systems Compliant	An intersection that meets the Safe System principles, by recognising that people can make mistakes that result in a crash, and that the road system needs

Term	Definition
	to be designed to limit the impact of these crashes via reduced vehicle speeds and dedicated facilities. Refer Section 2.2 for further details.
Ultimate Case Horizon Year	The target year for which forecast traffic volumes are estimated, and capacity analysis is undertaken to assess the performance of the intersection under long-term future traffic demands. Minimum requirements for Main Roads roads and intersections are outlined in Section 5.6.4 and 5.6.5. The Ultimate Case layout may include additional lanes or modifications above the Project Case layout, which may be delivered beyond the Project Case Horizon Year.
'Significant' Number of Vulnerable Road Users	The term 'significant' is defined in terms of the probability of exposure to conflict and the level of "Place" function within the "Movement and Place" framework. Methodologies to determine whether the number of vulnerable road users is "significant' can be found in Appendix E.
SISD	Safe Intersection Sight Distance
VPH	Vehicles Per Hour
VRU	Vulnerable Road Users

2 INTRODUCTION

Intersections of roads are often locations of congestion, high pedestrian activity, and motorised vehicle and active transport traffic and turning movements. They are crucial to the efficient movement of all modes of transport, and also a known location of a high proportion of crashes including those that cause injury.

These guidelines have been developed to provide assistance to traffic engineers and road designers to select an appropriate form of at-grade intersection control that maximises safety for all users, provides for required levels of traffic flow, and is appropriate for the movement and place objectives of the road and surrounding precinct.

2.1 Purpose of this Guideline Document

The purpose of this document is to inform practitioners of the Safe System approach to intersection design and to provide information to assist practitioners to make an objective comparison between roundabouts and traffic signals for the purpose of intersection control-type selection. The following aspects are considered:

- Safety performance.
- Operational performance.
- Reliability and accuracy of currently available analytical tools for intersection performance.
- The movement and place objectives of a street / precinct.
- Guidelines for the selection of an appropriate intersection form of control and traffic control in various situations.

The guideline relates to Primary Distributor roads (excluding freeways), Distributor A, B and Local Distributor roads in urban and rural environments, as well as intersections of these roads with local roads. Although some of the principles may also be relevant to local / local access road intersections, this is not the intended focus of the document.

The guideline provides additional information and guidance in relation to design involving roundabouts and traffic signals. Reference should also be made to current Main Roads and/or Austroads guidelines for design details and other supporting information.

The primary objective of this document is to provide an intersection type that "maximises safe mobility". If the proposed intersection design demonstrates that it (a) meets Safe System requirements, and (b) meets operational efficiency requirements, then the design would be acceptable to Main Roads. It provides a robust framework to seek a balance between these often competing objectives, and to assist determine whether these requirements are best delivered by a roundabout, traffic signals, or an alternate / hybrid arrangement.

General information on grade separated interchanges, use of traffic signals at roundabouts, and unconventional and innovative intersection treatments is also provided in Sections 7 and 8 of this guideline. Reference should be made to the Austroads Guide to Road Design and the Austroads Guide to Traffic Management, and Main Roads supplements to those guidelines, for further guidance on these alternative intersection and interchange types.

2.2 Safe System Approach

In 2008 there was a bipartisan agreement by the State Government and opposition to adopt a "Towards Zero" road safety strategy. This was part of a nation-wide initiative to improve road safety. The intent was that by the year 2020 there would be a significant reduction in the number of Fatal and Serious Injury crashes (FSIs) in the state, with a target of 40 percent reduction from 2008 levels by 2020. Zero FSIs was adopted as a notional long-term target. The national strategy was updated in 2021 with release of the National Road Safety Strategy 2021-30, and outlines Australia's 10-year plan for dramatically reducing road trauma on Australia's road. It sets out the national road safety objectives, key priorities for action, and targets to reduce the annual number of fatalities by at least 50 per cent and serious injuries by at least 30 per cent by 2030.

Western Australia's state strategy was renewed in 2020, in "Driving Change – Road Safety Strategy for Western Australia 2020 - 2030" (Road Safety Commission). This strategy maintains the target of zero fatalities or severe injuries on WA roads by 2050, however also sets a target of to reduce the number of FSI crashes by 50-70% by 2030. Main Roads is committed to substantially reducing road trauma through the implementation of the Safe System principles, in line with this strategy.

An integral part of the Driving Change – Road Safety Strategy is the adoption of a Safe System approach as the way forward in achieving the road safety benefits, with an understanding of shared responsibility. The priorities underpinning the Safe System approach are:

- Safe road users,
- Safe roads,
- Safer vehicles,
- Safe speeds, and
- Post crash response.

This is illustrated in Figure 2-1 below.

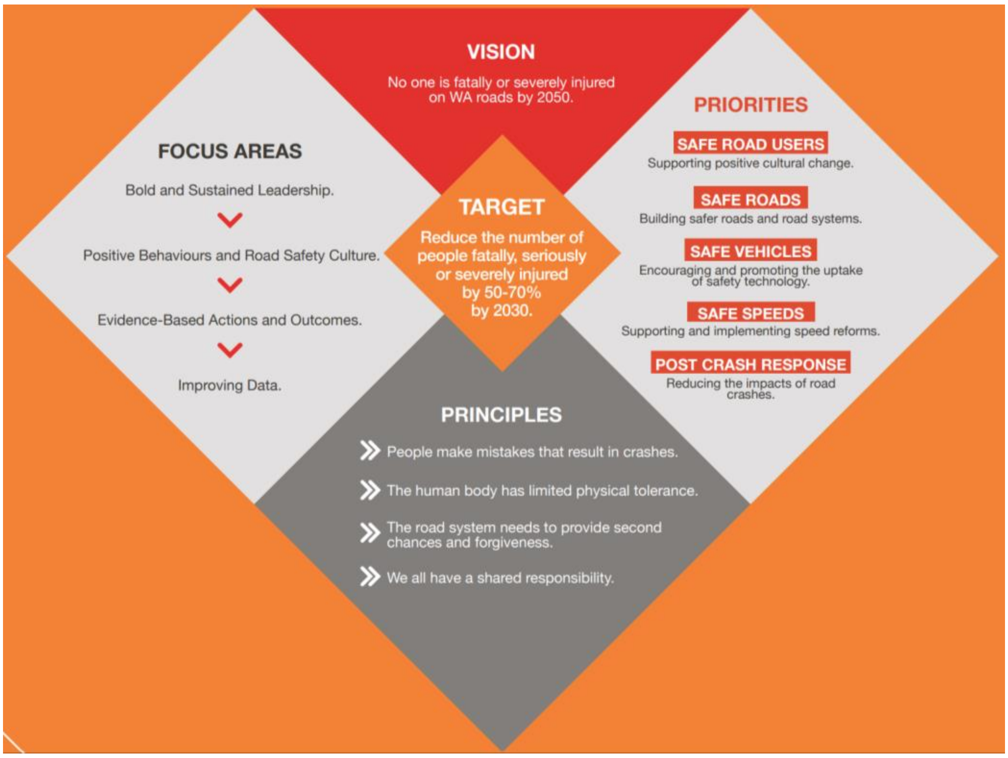

Figure 2-1: Safe System Principles (Road Safety Commission, 2020)

The Safe System Approach recognises that our bodies have a limited tolerance to forces exerted during an impact. A Safe System approach seeks to ensure that those forces are not exceeded, regardless of the cause of the crash. Even though people make mistakes, they shouldn't have to die or be seriously injured as a result of those mistakes.

Research has shown that there is approximately a 10% probability of a fatality in a crash between a pedestrian and a car travelling at 30 km/h. Similarly, the critical speed for a right angle crash between two vehicles is 50 km/h and 70 km/h for a head-on crash between two vehicles. This is illustrated in Figure 2-2.

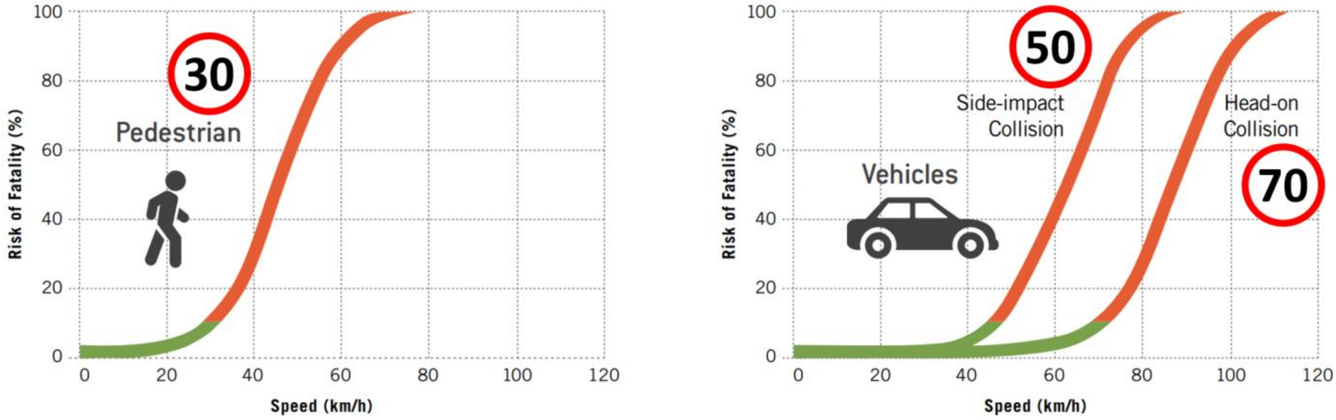

Figure 2-2: Probability of a Fatality for Various Speeds and Crash Types (Adapted from South Australia's Road Safety Strategy 2020, Government of South Australia)

Based on the above critical speeds, an intersection may be considered as "Safe System compliant" under the following circumstances:

- For intersections with significant[1] vulnerable road user activity, a safe crossing facility shall be provided. Where there is a possibility of a right-angle collision between passenger vehicles, the through-traffic speed should ideally be restricted to less than 50 km/h. Where the crossing facility relies on a driver giving way to a pedestrian (e.g. turning traffic at an intersection, zebra or wombat crossing), the speed of the traffic at the potential conflict point should ideally be restricted to less than 30 km/h.
- For intersections with little or no vulnerable road user activity, the through speed should ideally be restricted to less than 50 km/h, where there is a possibility of a right-angle collision between passenger vehicles.

These target values should be viewed as aspirational: there would be hundreds of intersections around the Perth metropolitan area and state that do not meet these criteria. However, that should not stop designers from aiming to meet these target values, and in those cases where the target values are not met, designers should implement mitigating measures that aim to reduce the number of FSIs and achieve a "towards Safe Systems" outcome. The Main Roads Road Safety Management (ROSMA) system provides a suite of road trauma treatment countermeasures in its on-line (iRoads) Treatment Resource Guide (Main Roads WA, 2021b), including speed control measures prior to an intersection.

This is the reason why over recent years there has been a growing interest in the selection of roundabouts for intersection control. It is recognised that roundabouts provide significant safety benefits for vehicular traffic by slowing down through traffic, reducing the number of conflict points and reducing the angle of potential conflict. The roundabout is considered as one of the few Safe System compliant intersection types[2] and as such is often viewed as the ideal at-grade intersection option. It is acknowledged that there are concerns from a pedestrian and cyclist point of view, however, as discussed in later sections, there are ways to address these concerns. Notwithstanding this, if the speed environment is low, e.g. in an urban activity centre, then there would be limited additional benefit from choosing a roundabout as the form of intersection control: a signalised intersection may well prove to be the most appropriate form of intersection control.

There has also been some concern about when roundabouts or traffic signal control may be appropriate and the relative performance of these forms of control from an operational point of view. This guideline document has been developed primarily to provide assistance to traffic engineers and road designers to determine whether traffic signals or a roundabout are the appropriate form of intersection control on major roads carrying higher traffic volumes, such as Primary Distributors, Distributors A & B and Local Distributors, as well as intersections of these roads with local roads. It is presumed that the traffic volumes would be too high for unsignalised intersections to be an appropriate form of intersection treatment; hence a comparison between roundabouts and unsignalised intersections is not discussed in this document.

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[1] *The term "significant" is defined in terms of the probability of exposure to conflict and the level of "Place" function within the "Movement and Place" framework and is described in the document "Position Paper – Quantifying Pedestrian and Cyclist Activity", April 2021 (D23#786115). Methodologies to determine whether the number of vulnerable road users is considered "significant' can be found in Appendix E.*

[2] *Roundabouts are considered a Safe System Option ("primary" or "transformational" intersection treatment) along with "close intersection", grade separation, low speed environment / speed limit and raised platform – Table 5.4 Austroads Research Report AP-R560-18 – Towards Safe System Infrastructure – A Compendium of Current Knowledge (Austroads, 2018)*

Main Roads acknowledges that this document is based on the VicRoads "Traffic Management Note No. 22 (VicRoads, November 2005)," but has been customised to suit Western Australian circumstances and needs. As such Main Roads takes full responsibility for the content of this document.

2.3 Overview

Intersections play a significant role in the operation of the road network. Where two or more roads meet or cross, the intersection controls the amount of traffic able to use the intersecting roads and together with the capacity of the road links themselves, provides a significant contributing factor in determining the capacity of the road network as a whole. Generally, in urban areas, the intersection capacity controls the capacity of the road network.

The crossing and turning movements at intersections need to be appropriately managed to ensure that safety and operational efficiency are optimised. Whereas previously the approach was to balance safety and mobility, the current Safe system approach is one of "maximising safe mobility". Generally, appropriate intersection control depends on traffic and site needs that may rely on giving way at a T-intersection, regulatory signs (Stop or Give Way), roundabouts, traffic signals or grade separations. These forms of control may also be provided with appropriate layout design and channelisation to control vehicle movements and points of conflict.

Table 2-1 over the page provides a broad guide to the suitability of the type of traffic control in relation to functional classification of roads (Austroads, 2020b). The functional classification for WA roads is available internally through the Integrated Mapping System by ticking the "Road Hierarchy" box under "Classification" in the Catalogue. It is also available online on Main Road's Road Information Mapping System, under the Road Hierarchy layer.

The table is based on the general appreciation of the need to provide a satisfactory level of mobility on arterial roads as well as maximising safety, i.e. "maximising safe mobility". "Mobility" is usually defined in terms of Level of Service (LOS) and Degree of Saturation. For intersections, LOS is measured by the average delay per vehicle. This is dealt with in more detail in Section 5.6.5 where performance criteria are defined.

From Table 2-1 it can be seen that at major arterial road intersections with medium and high volumes (Primary Distributor and Distributor A roads) and where grade separation cannot be justified, traffic would generally be controlled by either traffic signals or roundabouts. In some cases the suitability is obvious; in other cases traffic analyses and examination of other factors will be necessary to determine the most appropriate form of control at a site.

The needs of all road users should be taken into account when selecting an appropriate traffic control. For example, as noted in Section 3.4, while roundabouts are generally safer than other types of at-grade intersections for motor vehicle occupants, they do not offer the same extent of benefits for cyclists and motorcyclists. "A key factor is the speed that drivers can enter and pass through roundabouts, particularly larger roundabouts. Where cyclists or pedestrians are expected to use a roundabout, the design speed should be minimised, within the limitations necessary to provide adequate service to other road users. Where a significant number of cyclists or pedestrians use or are expected to use a site, and if a low-speed roundabout suitable for pedestrians and cyclists is not feasible, then the alternative of providing a signalised roundabout with full pedestrian and cycling crossing facilities should be assessed before the signalised intersection option is considered" (Austroads, 2020b).

	Primary Distributor (excluding Freeways)	Distributor A	Distributor B & Local Distributor	Access Road
Traffic Signals				
Primary Distributor (excluding Freeways)	O	O	O	X
Distributor A	O	O	O	X
Distributor B & Local Distributor	O	O	X	X
Access Road	X	X	X	X
City Centre / Activity Centre (any road type)	A	A	A	A
Roundabouts				
Primary Distributor (excluding Freeways)	A	A	X	X
Distributor A	A	A	A	X
Distributor B & Local Distributor	X	A	A	O
Access Road	X	X	O	O
City Centre / Activity Centre (any road type)	O	O	O	O
STOP signs or GIVE WAY signs				
Primary Distributor (excluding Freeways)	X / (O)	X / (O)	A	A
Distributor A	X / (O)	X / (O)	A	A
Distributor B & Local Distributor	A	A	A	A
Access Road	A	A	A	A
City Centre / Activity Centre (any road type)	O	O	O	O
Legend: A = Most likely to be an appropriate treatment O = May be an appropriate treatment X = Usually an inappropriate treatment	**Note:** The needs of all road users should be taken into account when selecting an appropriate traffic control. Where a significant number of cyclists or pedestrians use or are expected to use a site, and if a low-speed roundabout suitable for pedestrians and cyclists is not feasible, then the alternative of providing a signalised roundabout with full pedestrian and cycling crossing facilities should be assessed before the signalised intersection option is considered.			

Source: Adapted from (Austroads, 2020b)

Table 2-1: Suitability of Types of Traffic Control to Different Road Types

3 SAFETY PERFORMANCE OF ROUNDABOUTS AND TRAFFIC SIGNALS

3.1 Crash Frequencies

Typical crash rates for similar types of intersections can provide a basis for assessing safety performance in the following ways:

- A comparison of performance for intersections of differing types or traffic control.
- A benchmark against which a specific intersection can be compared.

Summary statistical data for the five-year period 2019 to 2023 for the Perth Metropolitan Area provides averaged safety performance data for road intersections controlled by roundabouts and traffic signals. These average rates may be used to compare a specific intersection with the network wide averages appropriate to the road environment. The safety performance rates for different road types in different environments for all crash types are summarised in Table 3-1. It should be noted that while these figures are based on limited data, similar trends have been observed in Victoria.

	Mean Crash Frequency for All Crash Types (Crashes / Intersection / Year)		
State Road / State Road Intersections	**Traffic Signals**	**Roundabouts**	**Ratio TS/R**
Inner Metropolitan Area[1]	9.4	1.7	5.4
Outer Metropolitan Area[2]	10.1	4.8	2.1
State Road / Local Road Intersections			
Inner Metropolitan Area	7.6	4.2	1.8
Outer Metropolitan Area	8.6	3.3	2.6
Local Road / Local Road Intersections			
Inner Metropolitan Area	4.9	2.4	2.1
Outer Metropolitan Area	5.2	1.3	3.9

Notes:

1. Inner Metropolitan Area: Bassendean, Belmont, Canning, Claremont, Cottesloe, Fremantle, Melville, Nedlands, Perth, Stirling, South Perth, Subiaco, Cambridge
2. Outer Metropolitan Area: Armadale, Kalamunda, Cockburn, Gosnells, Rockingham, Swan, Wanneroo, Joondalup, Mundaring, Kwinana, Serpentine-Jarrahdale

Table 3-1: Summary of All Crash Type Rates in Perth Metropolitan Area

From the above table it is quite clear that intersections controlled by roundabouts have a significantly lower crash rate than intersections controlled by traffic signals. Even where traffic volumes are higher, roundabouts have less than half the crash rate of intersections controlled by traffic signals.

3.2 Crash Rates – Exposure Relative to Traffic Volumes

When crash frequencies are related to traffic volumes using the intersections, they provide a measure related to exposure and traffic use.

The mean safety performance rates for different intersection types for casualty crashes only are summarised in Table 3-2. In this case the crash rates are per million entering vehicles, based on crash data from 2019 to 2023.

Mean Casualty Crash Rate (Casualty Crashes / Intersection / 10^6 entering vehicles)	
Traffic Signals	**Roundabouts**
0.68	0.38

Table 3-2: Summary of Casualty Crash Exposure Rates in Perth Metropolitan Area

The summary data generally indicates that the casualty crash exposure rate at roundabouts in the Perth Metropolitan Area is approximately 55% that of the casualty crash exposure rate of signalised intersections, when averaged across all road environment types. Similar trends have been observed in other jurisdictions across Australia. Nationally weighted mean road intersection casualty crash rates based on data from 2004 to 2009 (ARRB, 2010) shows the crash exposure rate for roundabouts was 13% less than for signalised intersections in urban environments, and 20% less than for signalised intersections in rural environments.

3.3 Pedestrian Safety at Roundabouts

Evidence suggests that roundabouts are at least as safe for pedestrians as other forms of intersection control possibly because pedestrians are able to cross one direction of traffic at a time by staging on the splitter islands. The report, Improving the Performance of Safe Systems Infrastructure: Stage 1 Interim Report (Austroads, 2013) compares the safety performance of traffic signals, priority-controlled intersections and roundabouts, based on crash data from intersections across Victoria for a five-year period between 2007 – 2011. This analysis focuses on fatal and serious injury crashes.
The report uses data from the Road Safety Engineering Risk Assessment Part 7: Crash Rates Database (Austroads, 2010) to compare the severe (FSI) crash rating between traffic signals and roundabouts, as shown in Figure 3-1 below. This is based on Australia-wide crash data from 2004 to 2008, and shows that urban roundabouts have the lowest risk of severe crashes. Urban roundabouts have a FSI crash rate approximately half that of the FSI crash rate of urban signalised intersections. The 2007 – 2011 Victorian crash data (Austroads, 2013) shows that pedestrians were involved in a significant proportion of FSI crashes at urban priority-controlled and signalised intersections, at 13% and 18% respectively. In contrast, pedestrians were involved in only 7% of all severe crashes at roundabouts, as demonstrated in Figure 3-2 below. It is noted that this data may be skewed due to pedestrians choosing to avoid crossing at roundabouts.

Intersection type	Severe crash rate	CMF	95% confidence interval	
			Lower-bound	Upper-bound
Rural traffic signals	0.57	1.06	0.79	1.40
Urban traffic signals	0.54	1.00	0.93	1.07
Rural roundabout	0.41	0.76	0.53	1.10
Urban roundabout	0.26	0.49	0.35	0.68

Source: Based on Austroads (2010a).

Figure 3-1: Severe (FSI) Crash Rates for Different Urban Intersection Types per 10 Million Vehicles Entering

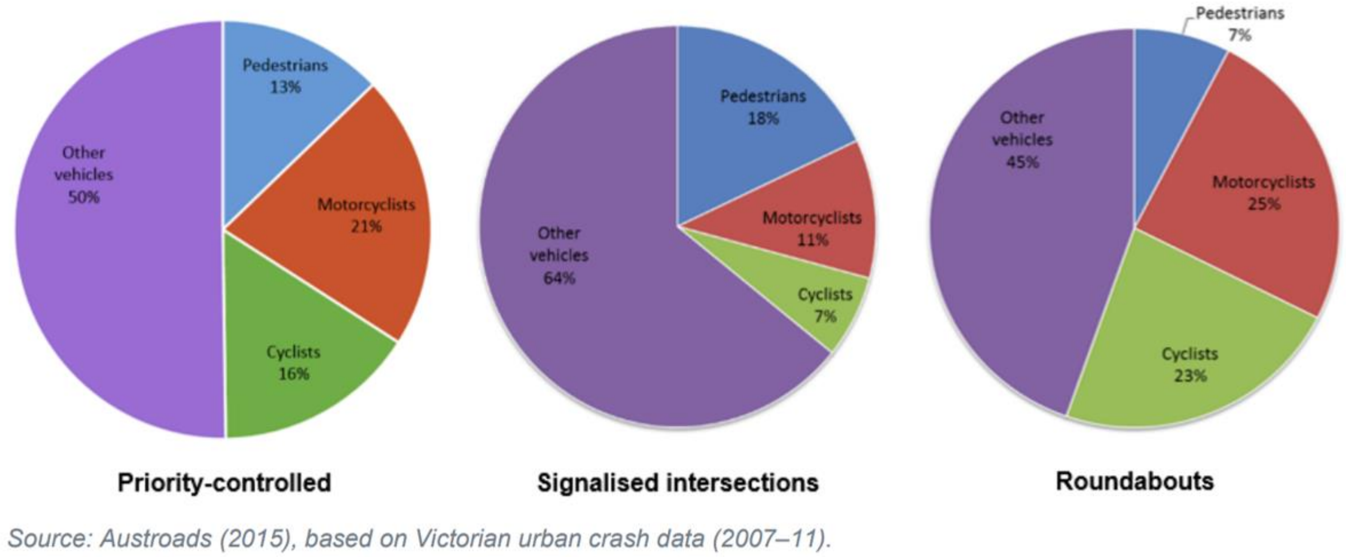


Figure 3-2: Severe (FSI) Crashes for Different Road User Types for Different Urban Intersection Types

Notwithstanding this, the use of roundabouts at freeway ramp junctions (on-ramps in particular) should carefully consider the need for grade separated facilities for pedestrians.

Although available information indicates that roundabouts are relatively safe for pedestrians, there is a perception that they are unsafe. It is acknowledged that roundabouts generally do not give priority to pedestrians over vehicular movements and this raises some safety issues that need to be managed in intersection design.. Exits are problematic, particularly for elderly pedestrians and children who may consider that traffic signals provide greater security for them to cross the road. In addition, pedestrians who are sight impaired have greater difficulty assessing traffic movements at roundabouts.
These pedestrian difficulties in using roundabouts can result in gaps in the in desired level of service and safety of an intersection." Section 5.5.2 discusses various design features that should be considered in relation to pedestrians and roundabout use.

Where pedestrian volumes are high, consideration should be given to the use of an alternative intersection treatment to a roundabout, particularly where there is a high percentage of school children, elderly pedestrians or pedestrians who have a vision, mobility or hearing impairment (Austroads, 2020b).

3.4 Cyclist Safety at Roundabouts

Evidence exists to show that roundabouts are not as safe for cyclists as for other road users, and that traffic signals are generally safer for cyclists.

The size and layout of roundabouts is a factor in safety for cyclists. In general, small roundabouts with relatively low traffic speeds, and with a circulating roadway narrow enough to prevent motor vehicles overtaking cyclists, present no special risks for cyclists (Balsiger, 1992) (Bruede U. & Larsson J., 1996) (Van Minnen, 1996). Studies have shown that a large proportion of cyclist crashes (about 50%) involve an entering motor vehicle colliding with a cyclist on the circulating roadway. This suggests that entering drivers have difficulty in detecting the presence of cyclists as they scan for larger vehicles that are approaching from their right.

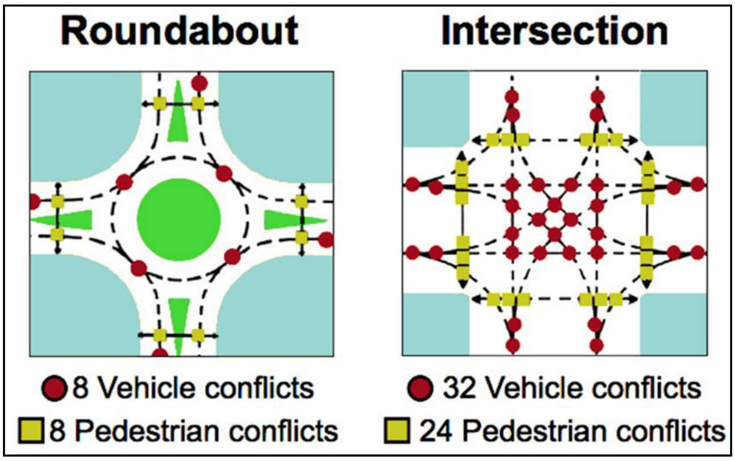
Specific provision for cyclists is not generally required at single lane roundabouts on local streets where vehicle speeds are low (i.e. ≤ 30 km/h) and traffic volumes are low (i.e. in the range of 3,000 to 5,000 vehicles per day, two-way flow) (Austroads, 2020b). From a safety point of view, particularly for larger roundabouts, a key factor is the speed at which vehicles can enter and pass through the roundabout. Cyclists and pedestrians are expected to use most intersections including roundabouts, and intersection design including design speed should give due consideration to providing adequate service to all users. Where a significant number of cyclists or pedestrians use or are expected to use a site, and if a low-speed roundabout suitable for pedestrians and cyclists is not feasible, then the alternative of providing a signalised roundabout with full pedestrian and cycling crossing facilities, and a signalised intersection, should be assessed for suitability.

Section 5.5.4 discusses various design features that should be considered in relation to cyclists and roundabout use.

3.5 Why are Roundabouts Safer for Vehicles?

When designed correctly, the roundabout is one of the safest types of intersections for motor vehicles. The following features generally contribute to the high standard of safety of roundabouts:

- Low operating speed. Slow moving traffic means low energy / low severity crashes and can also enable a driver to avoid a collision. Traffic at a roundabout is initially slowed down by the curved approach and the provision of the splitter island. The location of the central island then physically deflects the traffic through the intersection and controls the speed of traffic.
- Elimination of high angles of conflict thereby ensuring low relative speeds between conflicting vehicles. The roundabout layout limits the types of crashes and angle of impact. This results in low severity crashes in the event of a collision because traffic is moving in the same general direction at a low relative angle i.e. significantly reducing the incidence of head-on or right angle crashes.
- Fewer and further separated conflict points. A conflict point occurs where two travel paths merge, diverge or cross. Roundabout layouts satisfy safe intersection design principles in relation to conflict points as they minimize the number of conflict points and separate the areas of conflict as demonstrated in the following diagram.



Traffic signal phasing separates major conflicting movements in time, so this reduces some conflict situations. However, this is less effective in preventing crashes than physically restricting vehicle conflicts. At signals, crashes may also occur at controlled conflict situations when a vehicle travels through a red light.

A large area of conflict can occur where wide roads or offset crossroads intersect or where roads intersect at an acute angle. Roundabout layouts minimise conflict areas and have simple channelised approaches to separate points of conflict.

- The decision making for drivers is relatively simple. Drivers only look for traffic on the right, making it easier to judge an entry into the intersection.
- On undivided roads in high speed areas, long curvilinear splitter islands can provide good "advance warning" of the presence of the intersection and type of intersection.

These factors not only reduce the number of crashes but ensure that crashes are less severe than those that occur at other types of intersections. In this regard roundabouts fit well within the Safe System approach to road safety. The Safe System approach takes human errors and frailty into account, acknowledging that crashes will continue to occur but seeking to avoid death and serious injury as outcomes. Speed is a critical element in this approach. Speeds must be contained so that in the event of a crash the impact forces remain below human injury tolerance. Studies have consistently shown that the installation of roundabouts results in crash reductions of up to 75% in overall crashes and injury crashes (Austroads, 2020b).

3.6 Safe System Intersection Design Principles

Compared to a signalised intersection, a roundabout not only has significantly less conflict points, but because through speeds are significantly reduced, the impact severity is a lot less. Also, the impact angle is less than 90-degrees which further reduces the impact severity.

In recent years, the roundabout was considered the only existing commonly-used intersection type that meets Safe System requirements and for this reason it was Main Roads first choice of intersection type in the development of a new intersection or the upgrade of an existing intersection. However, it is now recognised that, rather than dictating a particular intersection type, from a design point of view what we should be trying to achieve is to emulate the advantages that roundabouts provide, at the same time applying due consideration to the needs of vulnerable road users.

From this point of view, the Safe System Intersection Design principles may be taken as:

- Minimise conflict points.
- Minimise entry and impact speeds:
    - For intersections with little or no vulnerable road user activity, the through speed is restricted to less than 50 km/h.
    - For intersections with significant[3]vulnerable road user activity, the through speed is restricted to less than 30 km/h.
- Minimise impact angles.
- Remove or simplify road user decisions.

[3] *Methodologies to determine whether the number of vulnerable road users is "significant' can be found in Appendix E.*

4 CAPACITY PERFORMANCE OF SIGNALS AND ROUNDABOUTS

The process of selecting an appropriate intersection control assumes that the preferred control is acceptable from a capacity point of view. ***If an acceptable operational efficiency cannot be practically achieved for a particular type of intersection control, this would likely constitute a "fatal flaw"***. It may be necessary to investigate alternative intersection forms, ban certain turn movements or make some movements free-flow / grade separated. Operational performance is typically measured in terms of "Level of Service" (LOS) and "Degree of Saturation" (DOS). Section 5.6.5 provides additional information on acceptable intersection operational performance based on these parameters.

Traffic model development, including choice of software, model inputs, calibration, validation, and appropriate model parameters to be adopted, should be in accordance with the Main Roads Operational Modelling Guidelines (Main Roads, 2021a).

4.1 Accuracy of Current Analytical Tools

The computer software SIDRA INTERSECTION has traditionally been used as the primary tool to analyse the capacity and operating performance of traffic signals, roundabouts and other non-signalised intersections in WA. LINSIG is also used for intersection analysis and optimisation, particularly for signalised intersections, arterial routes and networks. The strength of LINSIG is as an optimisation tool for signalised intersections, so it is not the preferred tool for roundabout analysis. Main Roads requires the use of LINSIG for the installation or modification of traffic signals, as outlined in the Main Roads Traffic Signals Approval Policy (refer also Section 5.6.3).

Although early manual analysis methods based on ARRB Research reports or Austroads guides are available, the SIDRA INTERSECTION software has refined these methods and theory over the years. While the roundabout analysis method used in SIDRA INTERSECTION was originally based on the Austroads Roundabout Guide, significant enhancements have been introduced in various versions of the program including the ability to analyse roundabout metering applications.

SIDRA INTERSECTION is capable of analysing individual intersections as well as multiple networked intersections, and this has enabled the analysis of linked intersections, such as a freeway diamond interchange, to be modelled more accurately.

Case studies relating to the validation of the SIDRA modelling are referred to in the SIDRA INTERSECTION User Guide. For signalised intersections, one case study indicates that performance measures for actuated signals were found to be highly accurate based on the results of real-life surveys. In a roundabout case study, the analyses showed that the roundabout operated in excess of expectations in spite of increased levels of demand.

Micro-simulation software such as VISSIM and AIMSUN are also used to analyse roundabouts and traffic signals. The strength of these tools lies in their ability model networks taking into consideration the interaction between intersections as well as using an input flow profile over a period of time, rather than just for a peak hour. The graphic output is also very useful for demonstrating to stakeholders the impact of various options, in particular the impact on congestion and queue lengths. Main Roads reserves the right to request micro-simulation modelling if it is considered necessary to assess the full impact of the proposals. Micro-simulation modelling may be requested for the following reasons:

1. Weaving / merging behaviours at critical locations;

2. Where exit blocking is observed or likely to occur;
3. Where critical links are forecasted to be operating above capacity;
4. Where modelling in LINSIG or SIDRA is too simplistic (e.g. uneven utilisation of lanes or roundabouts with three lanes); or
5. Where the study area includes a mix of different intersection control types.

Practitioners should also refer to the "Operational Modelling Guidelines" (Main Roads, 2021a) for further information on the selection of appropriate analysis and modelling tools.

4.2 Reliability of Capacity Analyses

The analysis of intersection capacity needs to consider a number of parameters including traffic volumes for the various movements, number of lanes and lane configuration, type of control, signal phasing, etc. The studies referred to in Section 4.1 and other anecdotal experience indicate that generally there can be confidence in the capacity analysis tools available. However, the results obtained from analyses may sometimes be questionable due to the following factors:

- Knowledge and expertise relating to the use of the software. Although the SIDRA INTERSECTION and LINSIG software packages are relatively user friendly, there are a number of variables to be entered and default values may need to be adjusted to accurately calibrate the program. All models of existing intersections should be calibrated based on field observations such as queue lengths, lane usage, saturation flow rates, gap acceptance and follow-up headways, and in accordance with the Main Roads Operational Modelling Guidelines (Main Roads, 2021a). Training and knowledge in the use of SIDRA INTERSECTION and LINSIG is essential.
- Knowledge and experience of the person undertaking the analysis relating to geometric intersection layout and parameters affecting capacity. The capacity analysis is closely related to the geometry of an intersection, the number of lanes, need for exclusive lanes and, if a signalised intersection, the type of signal phasing to be provided. Knowledge of these factors, as well as a sound knowledge of the SCATS operating system, is essential to the effective use of the capacity analysis computer software.
- Severely congested intersections may result in inconsistent performance outputs. In some situations the software programs may also indicate uncertainty due to the analysis having 'unsettled results.' It is important that the designs have sufficient residual capacity to avoid these effects (refer to Section 5.6.5). Micro-simulation modelling may be required in these situations.
- While analysis of an isolated intersection can be relatively straightforward, analysis of a number of intersections within a network can be quite complex, and requires understanding of the interaction between adjacent intersections, including origin-destination patterns, traffic signal coordination, lane utilisation and lane-changing behaviour between intersections, and the impact of queuing on the capacity of upstream intersections. A network of intersections with more than one choice of routes becomes further complicated.
- The traffic volumes used in a capacity analysis are often the 'weak link' in the overall process of determining performance. This may be due to:
    - Using existing traffic counts where demand is much higher than the volumes able to clear the intersection. In this case existing throughput is counted rather than the volumes actually needing to use the intersection.
    - Adopting existing traffic volumes rather than future volumes based on an assessment of traffic growth. The determination of realistic design volumes is one of the keys to accurate modelling of intersection performance. This is discussed further in Section 5.6.3.

The actual performance of an intersection some years after construction may also lead to certain conclusions relating to the adequacy of the initial analysis or the form of control choice. For example, with traffic signals, the signal timings are only effective as long as the traffic patterns that were used to generate the initial signal timings or lane configurations remain reasonably similar. Over time traffic patterns change, so initial signal timings, phasing, linking plans or lane allocations should be reviewed to ensure effective operation. Similarly, traffic patterns may change at a roundabout and a review of exclusive lane allocation or need for change (additional lanes or metering signals) may be required. Ideally, flexibility should be built into an initial design, particularly in a developing area, to accommodate future changes.

Section 5.6.5 provides further discussion relating to capacity analysis of intersections and alternative forms of control involving roundabouts and traffic signals.

5 FACTORS AFFECTING THE CHOICE OF INTERSECTION FORM OF CONTROL (ROUNDABOUT OR TRAFFIC SIGNAL INTERSECTIONS)

5.1 Balancing the Factors to be Considered

Traffic signals or roundabouts are generally considered for major arterial road intersections with significant traffic flows where Stop signs, Give Way signs or other forms of channelisation would be unsatisfactory.

The objective when choosing a form of control for an intersection should be a cost effective control that maximises the safe mobility and amenity needs of both motorised and non-motorised road users.

The choice of type of control of either a roundabout or traffic signal is influenced by consideration and 'balancing' of important drivers in the overall decision process. These may be either general factors relating to higher level objectives and viability or site specific requirements related to engineering and traffic operational details of the location involved. In the past there has been a focus primarily on the capacity analysis, or the operational performance of the intersection type. However, this should be viewed as only one factor, and ***provided that an acceptable operational performance is achievable*** (Section 3 refers), then the additional factors shown in Figure 5-1 need to be considered.

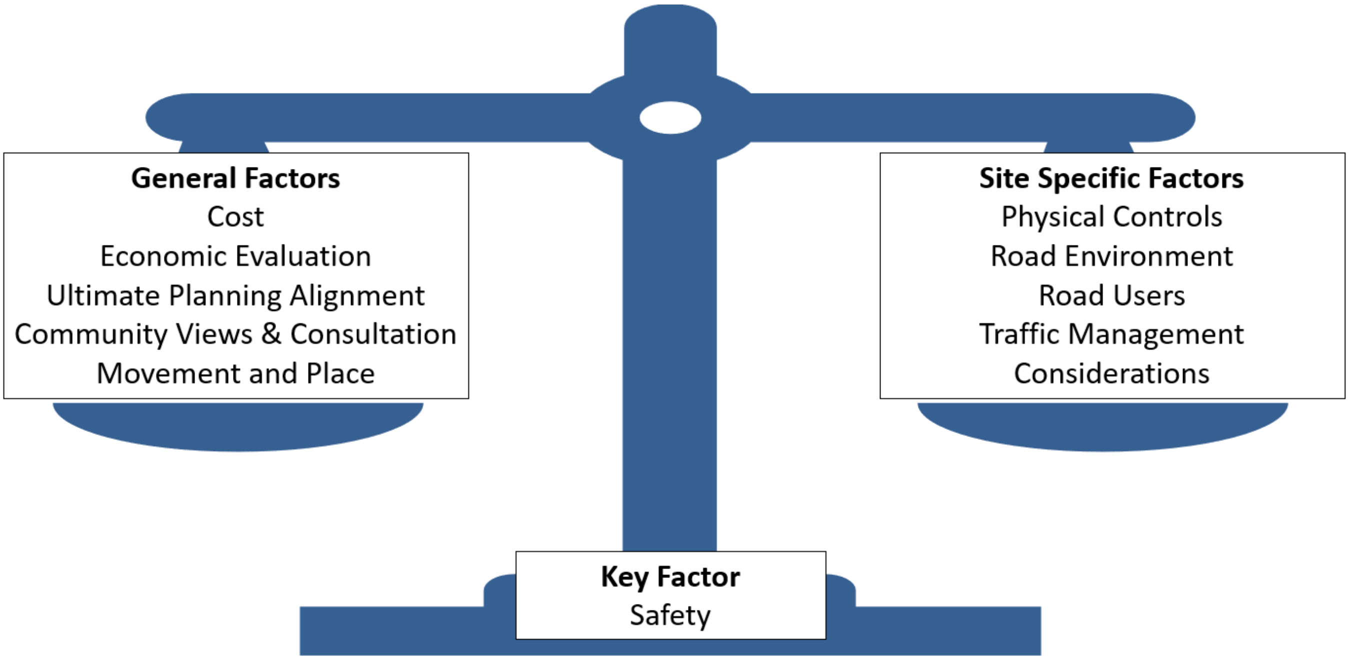


Figure 5-1: Balancing Factors in the Choice of Form of Intersection Control

The following Sections provide information relating to balancing these various factors. These are also summarised in Section 5.7.

5.1.1 Key Factor - Safety for All Road Users

The safety of an intersection needs to be a key input when selecting a treatment or type of intersection control. Main Roads is committed to substantially reducing road trauma through the implementation of Safe System principles, in line with the Driving Change – Road Safety Strategy for Western Australia. One of the cornerstone components of the Safe System approach is to reduce speeds at intersections without significant vulnerable road user usage so that any potential right-angle conflicts would be limited to a speed of less than 50 km/h. At that speed the likelihood of a motorist surviving a crash of this nature is 90%. At intersections with significant vulnerable road user usage, any potential right-angle conflicts should be limited to a speed of less than 30 km/h.

The research summary provided in Section 3 indicates that roundabouts are generally safer for vehicles when compared with signalised intersections. Therefore, where signals are chosen at a site, it is generally accepted that there needs to be a balance between safety and other important factors at the site. To maximise safety on the road network, a roundabout would generally be the preferred option unless entry speeds can be reduced to less than 50 km/h (or less than 30 km/h if vulnerable users are present), and unless other factors make a roundabout option inappropriate.

5.2 General Factors

5.2.1 Costs

The initial cost of a control proposal may include:

- Land acquisition.
- Relocation of utilities.
- Construction costs.

The cost may also be influenced by the degree to which a proposal is to be compatible with staging of longer term works.

Recurrent costs may also need to be considered, particularly in relation to an economic evaluation. A form of control involving traffic signals would generally have higher recurrent costs than a roundabout. The costs include maintenance, linking and operation of the signals. Up to date operational costs should be sought from Main Roads Network Operations Directorate for detailed Benefit Cost Analysis.

5.2.2 Economic Evaluation

The economic evaluation relating to a decision on control options under consideration needs to quantify and compare the anticipated benefits for each option (positive and negative) and costs discounted over the life of the control. The factors to be considered generally include:

- Safety performance - anticipated crashes that may occur (cost) or be saved relative to an alternative option (benefit).
- Capacity performance – delay costs or calculated delays relative to alternative options (cost / benefit).
- Vehicle operating costs and environmental costs associated with the performance of the intersection.
- Initial cost.
- Recurrent costs.

All factors should be assessed across a 24/7 period, and not just during peak hour periods, to ensure the full impacts and whole-of-life benefits and costs of each option are considered.

The project life in the economic evaluation needs to consider a realistic timeframe relating to the nature of the works before the control may need to be replaced or upgraded. Common practice for assessment of 'accident black-spot' projects is to adopt a standard project life of 10 years for both signal projects and roundabouts. While the objective of the program is to address current crash problems, invariably the longer term capacity needs are not evaluated.

The project life can be an important issue in relation to capacity, particularly in a developing area where there is the potential for high traffic growth. Where forms of control are designed as a staging of medium or longer term works, a 20 year project life may be more appropriate. However, if a control is not compatible with upgrading to accommodate traffic increases, a shorter project life is appropriate. Consideration needs to be given to the practicality of converting to another intersection form in the long term (construability), which may influence the short/medium term choice.

The travel time costs relating to operation would usually be based on calculated delays obtained from capacity analyses using design volumes for the peak periods. However, also considering the operation for control options during off peak operation provides a more precise assessment of 'whole of day' community benefits or disadvantages. The off-peak operational periods during the day are particularly relevant for business and freight.

In determining the costs of crashes in WA, the Willingness to Pay approach has been used to estimate various crash type costs and severity costs. These are the average crash costs derived on the basis of the number of crashes of various types which occurred in WA over the five-year period from 2018 to 2022 using the person costs the community is prepared to pay in order to eliminate a particular crash type. Table 5-1 gives the average severity crash costs by region.

	Fatal	Hospital	Medical Treatment	Property Damage Only
Rural Regions	$8,584,758	$353,298	$85,226	$14,367
Metro Regions	$10,011,670	$555,694	$114,552	$14,367
WA Average	$9,481,905	$417,533	$88,395	$14,367

SOURCE: (Main Roads WA, 2023b)

Table 5-1: Average Crash Costs by Severity and Region in WA (2023 Dollars)

The information in Table 5-1 has been combined with the information Table 3-2 to produce the average crash costs for signalised intersections and roundabouts in metro regions per million entering vehicles. These values, given in Table 5-2, may be used (suitably discounted, as applicable) in economic analyses. It should be noted that the significantly higher crash costs for signalised intersections is a reflection of the higher crash type severities.

Mean Annual Crash Costs / Intersection / Year / 10^6 entering vehicles	
Traffic Signals	**Roundabouts**
$25,500	$14,300

Table 5-2: Mean Annual Crash Costs in Perth Metropolitan Area by Intersection Type (2023 Dollars)

5.2.3 Ultimate Planning Alignment

Review of the ultimate planning for the area, route and intersection should be undertaken. There may be ultimate (long-term) plans for upgrade to the route, e.g. from single-carriageway to dual carriageway, or to Expressway standard, and there may be associated ultimate plans for the intersections along the route, e.g. to grade-separated interchanges. If so, the design of a medium-term intersection upgrade should aim to interface with the ultimate plans, to allow for future upgrade with minimal redundancy of infrastructure, and with consideration of staging and traffic management requirements for the ultimate upgrade. Ultimate planning considerations should include:

- Future land development, structure plans or zoning changes to the surrounding area that may change the land use or traffic characteristics.
- Ultimate plans by Main Roads, DPLH or the Local Government Authority for the routes and intersection.
- Potential changes to the RAV network, that may result in a change to the design vehicle for the intersection.

5.2.4 Community Views and Consultation

The views of the Local Government Authority relating to community needs and preferences are key inputs to the decision making process. Inputs in relation to freight and public transport needs are also important. In some situations the views of the community or stakeholder groups (e.g. a chamber of commerce, local bicycle interest and user groups or heavy vehicle operators) may also be desirable.

In some cases the community has a clear preference for roundabouts as they:

- Generally keep the traffic moving with minimal delay.
- Are more aesthetically pleasing than traffic signals.
- Are not traffic signals (Great Southern Region has resisted traffic signals for many years).

In other more developed or congested areas community groups (such as local cycling lobby groups) have indicated a preference for intersections controlled by traffic signals. A preference for traffic signals can be because they:

- Allow all traffic movements to get a turn in a signal cycle. This results in a form of control that is more predictable to use, often reducing stress on the user.
- Give pedestrians specific priority.
- Are safer for cyclists.
- Allow specific priority to public transport vehicles.
- Allow the use of longer delays for particular movements to discourage these specific movements.
- Traffic signalised intersections are generally smaller in area and have less impact on adjacent properties and services.

5.2.5 Movement and Place

Movement and Place recognises all roads and streets perform two key roles – movement and place, and that these have different objectives and priorities.

- For movement: To minimise time taken and/or improve travel time reliability to keep people and goods moving as safely and efficiently as possible.
- For place: To create places that that facilitate public interaction, meet people's needs and serve as a meeting place where people spend time to carry out a variety of activities.

The Movement and Place Framework provides a basis for considering a road against key characteristics associated with movement (known as transport, link or similar) and place (known as location, land use, or similar) and promotes a strategic, integrated approach to guide corridor planning across the planning and transport portfolios.

An example Movement and Place Framework is shown in Figure 5-2 (Austroads, 2016). Such a framework provides a basis for considering a road or street against key characteristics associated with movement (known as transport, link or similar) and place (known as location, land use, or similar) and promotes a strategic, integrated approach to guide corridor planning across the planning and transport portfolios.

Source: Guide to Traffic Management Part 4: Network Management (Austroads 2016a)

Figure 5-2: Example Movement and Place Framework

The Movement and Place Framework for Western Australia is currently under development by the Department of Transport (DoT) and the Department of Planning Lands and Heritage (DPLH). Assessment and decisions for new and upgraded intersections should consider the existing and desired classification of the connecting streets on the movement and place matrix, and the future desired modal priority for each road user, with the aim to allocate appropriate street space between road users based on the future modal priority. The modal priority and street classification should be developed in collaboration with key stakeholders, including the LGA, DoT, DPLH and the community.

This may influence the preferred form of intersection control, for example if there is a desire to allocate more space for the place-function of a street, and the preferred intersection form may place a higher value on accessibility and pedestrian priority. A more compact signalised intersection may best achieve these outcomes. Locations with a low place value and high movement value, such as at intersections along primary distributer roads, generally have higher speeds and a low number of pedestrians. An intersection form that prioritises vehicle safety and efficiency, such as a roundabout, may be more acceptable at these locations.

5.3 Physical Controls

5.3.1 Number of Intersection Legs and Angle between Legs

At intersections with more than four legs, if one or more legs cannot be closed or relocated, or some turns prohibited, roundabouts may provide a more convenient and effective treatment, since (a) with 'STOP' or 'GIVE WAY' signs, it is often not practical to define priorities adequately, and (b) signals may be less efficient due to the large number of phases required, resulting in a high proportion of lost time.

Single Lane Roundabouts

With single lane roundabouts, aligning roundabout legs at approximately 90° is preferable because it results in the least amount of driver confusion. This design limits the maximum number of roundabout legs to four. However, where economic and practical reasons have dictated, the provision of a greater number of legs on a single lane roundabout has proved workable in some cases. It is suggested however that more than six legs would lead to driver confusion as to which exit leg is required (Department of Main Roads, Queensland, 2006) as well as to confusion by entering drivers as to which exit circulating drivers are indicating to exit. Adequate signing may also be difficult to achieve.

It should also be noted that larger diameter roundabouts are generally better at catering for more than four legs than smaller diameter roundabouts, because the exits would be further apart. Moreover, if one or more of the exits are one-way only, this simplifies the layout and makes the driving task easier. However, very large diameter roundabouts can lead to higher circulatory speeds, which may create difficulties for entering vehicles, especially multi-combinational vehicles, to "pick the gap". It is important therefore that entering speeds are controlled by appropriate horizontal geometrics.

Figures A.1 and A.2 in Appendix A show examples of a five-legged and six-legged single lane roundabout in Queensland.

Multi-lane Roundabouts

Limiting the number of legs of a multi-lane roundabout to four and aligning them at approximately 90° is the most preferable treatment because drivers are easily able to comprehend the layout and determine the appropriate choice of lanes for their path through the roundabout. Multilane roundabouts with more than four legs have some or all legs aligned at angles other than 90°. On these roundabouts drivers can experience difficulty in determining which is the appropriate lane choice required for left, through and right turns on some of the approaches. In general, two-lane roundabouts with more than four legs may cause operational problems and should be avoided. However, the provision of a greater number of legs on a multilane roundabout has proved workable in a number of cases where some of the following conditions apply:

- One or more of the legs are one-way only.
- The roundabout has a large internal diameter and is an oval shape, allowing adjacent legs at each end of the oval to be at approximately 90° to each other.
- Some of the circulatory parts of the roundabout are single lane only.
- Lane allocations for downstream exits are clearly marked on the approaches to the roundabout through the use of pavement markings, overhead signage, or both.
- Effective use has been made of "spiral markings". Commentary 1 provides guidance on the use of spiral markings.

Figures A.3 and A.4 in Appendix A provide examples of multi-lane roundabouts along the Pacific Motorway in Queensland with more than four legs each.

5.3.2 Number of Lanes through the Intersection

In WA there are currently no priority controlled multi-lane roundabouts with more than two through lanes, noting that Eelup Rotary in Bunbury is a signal controlled roundabout (refer case study in Appendix C). However, there are a limited number of multi-lane roundabouts with three circulating lanes or three approach lanes on one or more legs of the roundabout, including:

- Tonkin Highway / Hepburn Avenue / Beechboro Road North interchange in Ballajura
- Joondalup Drive / Burns Beach Road in Joondalup
- Joondalup Drive / Wanneroo Road interchange in Wanneroo
- Hester Avenue / Connolly Drive in Clarkson
- Armadale Road / Tapper Road / Verde Drive interchange in Jandakot
- Armadale Road / Beeliar Drive / Solomon Road interchange in Jandakot

In these cases, the number of through lanes is limited to two lanes, with the third lane generally provided for exclusive right turn or left turn movements.

While the Road Traffic Code 2000 allows for more than two circulating lanes in a multi-lane roundabout there is a preference to limit the number of circulating lanes based on a perception of poor driver behaviour in two-lane roundabouts in WA. Roundabouts with three lanes can create further complexity for driver behaviour, and increased safety risk for pedestrians and cyclists to cross the three lane legs. While in some locations it may be appropriate to have up to three approach lanes on high-demand approaches (e.g. the locations listed above), for priority controlled roundabouts the number of through lanes should be limited to two, and three lanes only provided for heavy turn movements as an exception, and where adequate justification is provided.

However it should be noted that roundabouts with up to three circulating through lanes have been successfully implemented in Victoria. Figure B.1 in Appendix B shows an example of a three-lane roundabout in a semi-urban environment. Figure B.2 shows an example of a 3-lane roundabout in a light industrial / commercial area. In both these examples, roundabout metering is applied during the peak periods.

5.3.3 Space Available

The Road Reserve width, size of intersection splays as well as the availability and/or cost of land acquisition are key considerations when choosing which form of control to adopt. The space needs to accommodate:

- The required number of traffic lanes to ensure appropriate capacity, including the provision of future left turn slip lanes in the ultimate stage, if required.
- The median width to accommodate turn pockets, roadside furniture such as signals and direction signs and to store crossing pedestrians safely.
- The turning paths for design vehicles at an appropriate radius.
- The clearances to the Road Reserve boundary for footway or verge areas, with adequate space for direction signs, traffic signals and traffic signal cabinets, including associated clearances to the carriageway and footway.

For example, with reference to Figure 5-3, to accommodate a design semi-trailer turning right at the minimum inside radius of 10 m, the carriageway width of the roundabout would need to be approximately

8 m for a single lane roundabout, giving an inscribed circle radius of 19.75 m. Allowing for 5.5 m for Road Reserve clearance gives a total footprint roundabout diameter of 50.5 m.

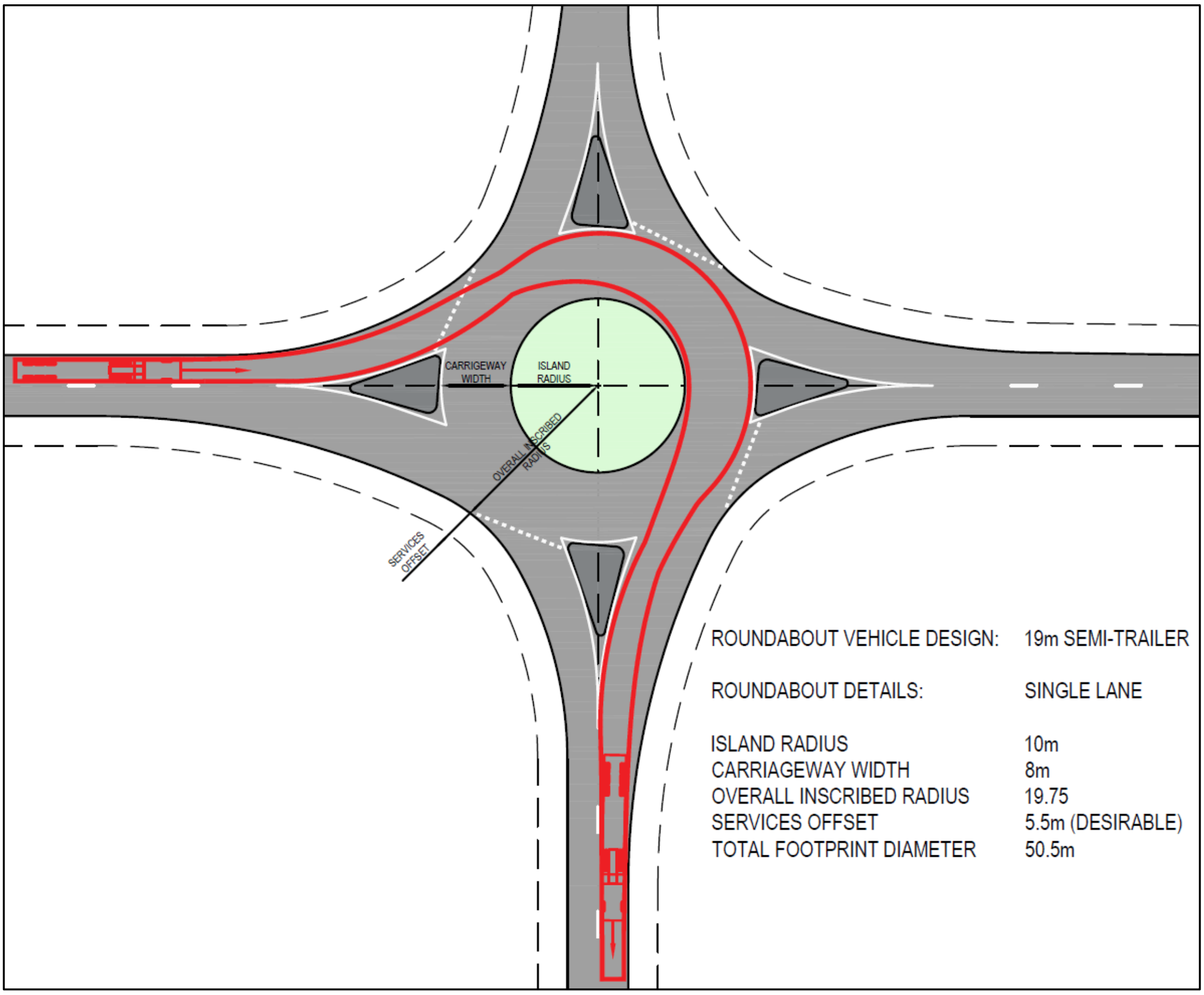


Figure 5-3: Space Requirements for a Single Lane Roundabout with 19 m Semi-trailer as Design Vehicle

Similarly, for a two lane roundabout with the same design vehicle, the carriageway width would need to be approximately 18 m, giving an inscribed circle radius of 30 m. Again, allowing for 5.5 m for Road Reserve clearance gives a total footprint roundabout diameter of 71 m. Table 5-3 gives the space requirements for single and two lane roundabouts for a range of standard design vehicles.

Vehicle Type	Minimum Island radius (m)		Carriageway Width (m)		Overall Inscribed Radius (m)		Total Footprint - Desirable Diameter[1] (m)	
	Single	Dual	Single	Dual	Single	Dual	Single	Dual
19 m Semi-trailer	10	18	8	9.7	19.75	30	50.5	71
36.5 m B-Triple	12	26	9.9	10.6	24	38.6	59	88.2
53.5 m Double B-Double	20	30	10.1	11.6	31	43.5	73	98

1. Assuming a 5.5 m verge width to Road Reserve boundary.

Table 5-3: Space Requirements for Roundabouts

The diameter of a roundabout should be large enough to achieve adequate entry-path radii and thereby minimise the potential impact angle of a crash. However this needs to be balanced against roundabout diameters that are too large, which could encourage higher entry or circulating speeds. Table 4.1 of (Austroads, 2023b) provides guidance on the selection of a minimum roundabout diameter to achieve adequate entry path radii, based on typical conditions, however this needs to be adjusted to suit actual site conditions to ensure maximum entry path radii are not exceeded. Commentary 4 provides a list of potential treatments to reduce vehicles speeds at the approaches to roundabouts.

Where roundabouts are located on an Over-Size Over-Mass (OSOM) corridor, design requirements should take into account the clearance requirements as outlined in the Guide to Design of Oversize and Over-Mass Vehicle Corridors (Main Roads, 2022b).

The desirable minimum clearance requirements for OSOM corridors is 10 m wide by 10 m high, which caters for OSOM vehicles up to 8.5 m wide and 8.5 m high. The following minimum clearances and recommended treatments apply to OSOM corridors and intersections along these corridors:

- 1.0 m - absolute maximum height of non-removable roadside furniture, relative to road surface, where load overhangs medians, islands and verges.
- 0.75 m - desirable minimum lateral clearance between laden vehicle and non-removable roadside furniture which exceeds 1.0 m height.
- 0.5 m - absolute minimum lateral clearance between laden vehicle and traffic signal post target boards and roadside furniture.
- Absolute maximum height for trafficable median/central island, with semi-mountable or mountable kerb and reinforced concrete infill shall be 150 mm.
- Where traffic signals or regulatory signs such as STOP and KEEP LEFT cannot be relocated to a permanent position clear of the laden vehicle, detachable posts may be located in sleeves cast into the traffic island to permit easy removal (this is not a preferred treatment given the ongoing operational costs, and should only be applied as an exception).

When planning new areas for future development, the Road Reserve widths and splays can enable flexibility for future control options.

5.3.4 Site Topography

The topography at a site can influence a designer's ability to achieve appropriate standards for sight distance, grades and crossfalls within the intersection. Crossfalls and grades need to be maintained within limits to provide stability for turning vehicles with a high centre of gravity. This requires relatively level ground unless significant earthworks are undertaken which will also have an impact on the cost of construction.

Ideally, roundabouts should be sited on relatively level ground or in sag vertical curves rather than near crests, so that road users have good visibility and can adjust their driving behaviour to respond to the layout. In addition, relatively flat grades on intersection approaches facilitate acceleration of heavy vehicles and acceptance of gaps by drivers.

Traffic signalised intersections must provide adequate sight distance to the traffic signal heads, and should not be located with horizontal curves continuing through a signalised intersection. Where possible, vehicles at the stop line intending to travel straight through should be directly facing the respective exit lane. Horizontal curves should be accommodated in the approaches and departures. This reduces potential sideswipe problems, and the need for guidelines and raised pavement markers, which may pose a risk to motorcyclists, and may suffer from high wear, requiring frequent maintenance.

5.3.5 Access to Adjacent Properties

In some locations the nature of access to adjacent properties may need to be considered where major points of access and turning movements to private property occur at or close to the intersection. Roundabouts facilitate opportunities for improvement to access management on arterial roads by enabling vehicles to access nearby properties through a left-in, left-out manoeuvre (see Figure 5-4). This can avoid the need to implement median breaks within a turn pocket.

However, it should be noted that access to adjacent properties needs to be carefully managed and controlled in accordance with the Main Roads' Driveways Policy (noting that this will soon be superseded by the Main Roads' Crossover Policy). On regional roads the practice should be to limit and control property access to provide both traffic safety and efficiency benefits.

Figure 5-4: Example of left-in, left-out access near a roundabout

5.4 Road Environment

5.4.1 Rural, Outer Urban and Inner Urban Areas, Activity Centres

In all areas both signalised intersections and roundabouts shall have lighting in accordance with the Lighting Design Guideline for Roadway and Public Spaces (Main Roads, 2024). For traffic signals, where the approach road is speed zoned at 80 km/h or above, the approach shall be a speed zone not greater than 70 km/h with a desirable length of 300 m and a minimum length of 200 metres upstream of the intersection. For roundabouts, where the approach road is speed zoned at 90 km/h or above, the approach shall be a speed zone not greater than 80 km/h with a desirable length of 300 metres and a minimum length of 222 metres upstream of the intersection. Very large roundabouts (rotary intersections) or roundabouts with metering signals shall be treated in the same manner as traffic signals. On divided carriageways, if offset speed zones are appropriate, the length of the speed zone should be reduced to 100 metres on the departure side of the road feature. Reference should made to the Speed Zoning Policy and Application Guidelines (Main Roads, 2022a).

In rural areas traffic signals would generally be inappropriate due to the nature of the road environment, relatively low traffic volumes and the approach speeds of traffic. Roundabouts should be considered where a T intersection, staggered T intersection, or wide median control would be unsatisfactory due to the relative traffic volumes involved. They are likely to be appropriate options at rural cross intersections (including those in high speed areas) where there is a crash problem involving crossing or right turn (vs. opposing) traffic. However if the traffic flow on the lower volume road is less than 200 vehicles per day, consideration should be given to using a staggered treatment. Other intersection options may also be appropriate for the rural areas outlined above, such as reduced-access intersections (e.g. left-in / left-out only), or removal of the intersection if feasible. Studies have indicated that the crash reduction achieved by roundabout installation in high speed areas has been similar to that for low speed areas, with an expected reduction of 70% in adjacent approach crashes but with an increase of 20% in lower severity rear-end crashes (Austroads, 2023b).

Roundabouts in rural, high speed environments must be highly visible and incorporate appropriate geometric characteristics (deflection of approaches, central island size, long splitter islands etc), signs and pavement markings to ensure safe operation. In rural WA, particular emphasis needs to be placed on designing an intersection solution that meets the needs of multi-combinational vehicles (refer to Section 5.5.5).

In rural towns and cities with short peak periods, roundabouts would generally be appropriate and operate with minimal delays. Roundabouts also facilitate U-turning movements where traffic circulation in a shopping or town centre is a consideration. At cross or T intersections where the major flow of traffic turns right or left (which often occurs on highways in country towns) and at other Y or T junctions where a high proportion of right turning traffic exists, a roundabout will generally provide a safe and efficient form of control to manage the turning traffic. Traffic signals (or separate nearby pedestrian crossings or pedestrian signals) need to be considered in areas with high pedestrian numbers.

Roundabouts are also appropriate at arterial and collector roads in outer urban areas and country towns where only short periods of congestion occur. In such situations, control by traffic signals would be relatively inefficient and costly from a maintenance and operation point of view.

In outer urban and fringe areas either traffic signals or roundabouts may be appropriate, subject to other considerations described in this guideline. However, roundabouts would generally provide safety advantages and lower delays in off peak periods.

For inner urban areas roundabouts may be appropriate at sites which are not influenced by adjacent intersections and where space and other factors are appropriate. However, traffic signals are often the preferred form of control due to pedestrian or signal linking needs.

Activity centres are places of higher pedestrian activity, and the roads and access ways available to vehicles will generally not be exclusively or even predominantly for through traffic. Traffic management in and around activity centres must therefore acknowledge that the needs of vehicles will generally be of secondary importance in planning, design and management of the centre (Austroads, 2015a). In this regard the needs of vulnerable road users, i.e. pedestrians and cyclists are paramount. Moreover, the speed environment is often lower. For these reasons traffic signals may often be a more appropriate form of control than roundabouts.

5.4.2 Speed of Approaching Traffic

In high speed traffic environments, such as in rural or urban fringe areas, roundabouts generally operate safely and provide physical control of speed when designed with appropriate alignment and channelisation. This may be difficult to achieve where there are restrictive vertical and horizontal geometric issues.

In those environments, where capacity and other constraints such as land are not an issue, it is generally preferable to keep the traffic moving with roundabout forms of control, rather than using traffic signals.

If traffic signals are used in high speed areas, in addition to the mandatory 70 km/h maximum speed zone, the use of advanced warning devices may also need to be considered. However, these measures generally have limited success in controlling speeds without regular enforcement or installation of a red light / speed camera. Installation of Advance Warning Flashing Signals shall be in accordance with the Advance Warning Flashing Signals Guidelines (Main Roads, 2016).

In environments where the speed of the approaching traffic meets the Safe System criteria spelled out in Section 2.2, intersections are likely to be considered as Safe System compliant regardless of the type of traffic control implemented.

Commentary 4 provides additional guidance on intersection design treatments to reduce entry speeds, such as pre-deflection at roundabouts.

5.4.3 Adjacent Land Use

Traffic signals or roundabouts may operate satisfactorily in a range of environments. However, the nature of the adjacent land use may influence a decision.

At strip shopping centres in urban areas and rural townships, roundabouts at each end of the shopping area can be advantageous in slowing traffic entering the area and in providing U-turn opportunities for motorists circulating to and from kerbside parking.

In an industrial area where a median may restrict vehicle movements into adjacent properties, a roundabout of appropriate size may also facilitate circulation and U-turning of trucks. The special needs of multi-combination vehicles may preclude this option. Moreover, if towed agricultural implements and /or over dimensional loads being transported on oversize trailers (with very wide wheel spreads) are required to operate out of the industrial area this should be taken into account.

5.5 Road Users

5.5.1 Needs related to Pedestrians

Pedestrians are unprotected road users and therefore are generally at greater risk than road users in motor vehicles. Pedestrian needs on the road relate to mobility and safety and this is of particular concern in relation to children, the elderly and people with disabilities.

In high traffic volume locations, pedestrians generally prefer to use traffic signals as these provide priority with a pedestrian signal phase and separation from through traffic flows (VicRoads, 2005). Pedestrian crashes at signalised intersections generally involve turning traffic failing to give way, pedestrians crossing against the red light or vehicles driving through the red light.

While crash data at roundabouts generally indicates that there is not a particular safety problem for pedestrians (refer Section 3.3), there is a general dislike for roundabouts by pedestrians and a perceived safety risk as they may be difficult to cross. Pedestrian concerns at roundabouts (VicRoads, 2005) generally relate to:

- No specific priority for pedestrians compared to signals where 'Walk' phases are provided.
- Drivers looking right towards circulating or entering traffic, rather than watching for pedestrians. Pedestrians crossing from the left may be more vulnerable in this situation.
- Lack of gaps in the traffic flow, particularly at congested roundabouts and moving queues of traffic, rather than the queue of vehicles coming to a complete stop.
- Roundabouts with two or three lane approaches presenting greater crossing difficulties for pedestrians compared with single lane roundabouts, even with the provision of splitter islands which can act as staging points.
- The long walking distances involved in negotiating a large roundabout may be a concern to some pedestrians.

5.5.2 Provision for Pedestrians at Roundabouts

Where a roundabout is being considered in an environment with pedestrians, consideration should be given to incorporating the following design features, as appropriate, and in accordance with design guidelines:

- Provision for active transport infrastructure should meet the Active Transport Infrastructure Policy (WA Transport Portfolio, 2021), and the Supplement to the Active Transport Infrastructure Policy (WA Transport Portfolio, 2022). This sets out minimum requirements for active infrastructure along State controlled roads and rail corridors, required as part of any new roads and network expansion, and existing road upgrades. Reference should also be made to the Pedestrian Crossing Guidelines (Main Roads, currently under development, expected to be published in 2025).
- Pedestrian signals across the approaches. Reference should be made to the Guidelines for Pedestrian Crossing Facilities at Traffic Control Signals (Main Roads, 2023a).
- Pedestrian (zebra) crossings or pedestrian signals across approaches – where a significant number of pedestrians are expected (e.g. near a shopping centre or school) and where speeds at the proposed crossing points are ≤ 30 km/h. Where the operational speed is > 30km/h, a wombat crossing may be required to reduce speeds at the crossing point to ≤ 30 km/h.
- An entry geometry (including horizontal and / or vertical deflection devices as necessary) to slow vehicles entering and travelling through the roundabout, resulting in an operating speed of less than

or equal to 30 km/h. This will improve the ability of pedestrians to cross and also assist in reducing the severity of injury in the event of a pedestrian crash.

- This lower design speed may be achieved with physical horizontal deflection of vehicle paths prior to the pedestrian crossing points using an appropriate left hand curve radius and a splitter island or shaping of the median. The size of the central island and the adverse crossfall of the circulating roadway also assist in controlling vehicle speeds. Tighter geometry to achieve low exit speeds, rather than the usual practice of facilitating the exiting of vehicles, will also improve safety for pedestrians crossing the roundabout departures.
- Reverse curves should be considered for all roundabouts where the approach speeds are 60 km/h or greater. They can also be used to reduce vehicle approach speeds for small roundabouts that cannot be designed with adequate deflection within the roundabout.
- Alternatively, use may be made of Raised Safety Platforms or Wombat Crossings to reduce speeds. The use of Pedestrian Signals, Raised Safety Platforms or Wombat Crossings should only be applied where there is adequate Approach Sight Distance and Crossing Sight Distance, lighting, and only on appropriate routes. Generally they are not appropriate on high-speed routes and in rural areas where drivers would not expect them.
- Ensuring good visibility so that pedestrians can see traffic and be seen by drivers and motorcyclists, with all sight distance requirements being met (e.g. Crossing Sight Distance).
- Ensuring the roundabout has satisfactory operational performance. With minimal congestion, the resultant gaps in traffic flow can facilitate pedestrians crossing the vehicle flows on approaches and departures. (Note: pedestrian needs are usually considered in traffic signal capacity analysis but rarely considered in relation to roundabouts).
- Pedestrian crossing points set back approximately 6 metres or 12 metres (one or two car lengths) from the holding line to separate the points where pedestrians and circulating vehicles cross a driver's path. At this location a pedestrian is not crossing in front of vehicles about to enter or leave the circulating roadway and is more likely to be seen by a motorist in the queue. For major multi-lane roundabouts, an allowance for three to four car lengths (approximately 18 to 24 m needs to be considered to provide additional reaction time for pedestrians to make a decision to cross at the exit. (A balance must be made here as vehicles exiting the roundabout will be accelerating as they pass this point and drivers coming out of the roundabout may not see pedestrians using the crossing).
- Splitter islands on each leg of the roundabout being of sufficient size to provide staging points for pedestrians (including wheelchairs, bicycles, prams etc.). This enables pedestrians to cross one direction of traffic flow at a time and also minimises the width of roadway to be crossed. The pedestrian refuge should be at least 2.5 m x 2.0 m wide.
- On multi-lane approaches and departure legs, splitter islands between lanes to allow a staged crossing of the carriageway. Appropriate horizontal geometry is required on each lane to achieve adequate refuge area at the splitter island. On three lane approaches, the splitter island should ideally be provided between the two through lanes and the exclusive turn lane (i.e. not separating two traffic lanes that cater for the same turning movement). An example of a splitter island located on the southbound departure leg of the Wanneroo Road / Joondalup Drive roundabout, in Wanneroo, is shown in Figure 5-5 below.
- Where a signalised pedestrian crossing is provided across an approach, the crossing points across each section of roadway should be staggered at the median or splitter island to minimise 'walk' times and delays to traffic. The stagger also increases the distance for queuing on the departure before traffic interferes with the circulating flow in the roundabout. Section 7.1.2 provides more information on the use of signalised pedestrian crossings at roundabouts.
- Consideration of fencing or landscaping to discourage inappropriate pedestrian movements and to direct pedestrians to the formal crossing points.

- Provision of grade separated pedestrian facilities, particularly at freeway ramp junctions.
- It is preferable that any pedestrian / cyclist paths should not be immediately adjacent to the roundabout and should be separated from the roundabout by a road safety barrier.
- It is preferable that multi-lane roundabouts are not installed adjacent to areas with a high Place value on the Movement and Place framework, and where there is significant pedestrian demand, and installation of a roundabout would require the pedestrian crossing facility to be located a significant distance from the key pedestrian desire lines (i.e. requiring the majority of pedestrians to re-route more than 100 m to use the pedestrian crossing facility).

Figure 5-5: Example of Splitter Island on a Roundabout Departure Leg, Wanneroo Road, Tapping (source: Google Street View)

5.5.3 Needs related to Cyclists

While roundabouts are generally safer than other types of at-grade intersection for motor vehicle occupants, studies suggest that roundabouts do not offer the same extent of benefits for cyclists as for motor vehicle occupants (Austroads, 2015b). Cyclists are unprotected road users at greater risk than motorised road users. Therefore, where there is a high speed differential between bicycles and other vehicles, designs need to minimise risks to cyclists either by regulating the speeds on the approach and circulatory roadway through appropriate geometrics or by providing a separate off-road space.

At traffic signals, assuming that most cyclists are on the road, the cyclist's mobility needs relate primarily to sharing road space.

At roundabouts, cyclists' concerns relate more to safety and operation (VicRoads, 2005) such as:

- Motor vehicles travelling too fast.
- Motor vehicle drivers failing to see circulating cyclists and consequently entering the roundabout and in the process not giving way to cyclists in the circulating roadway. This may be because cyclists tend

to “hug” the left-hand side, especially on multi-lane and wider circulatory roadways where there is sufficient space for cars to pass. It may also be because cyclists, due to their smaller presence, are not as visible as cars.
- Motor vehicles cutting across lane lines.
- Cyclists needing to cross the path of exiting vehicles, particularly at multilane roundabouts.

Conventional right turning manoeuvres at multi-lane roundabouts are a problem for cyclists because of the nature of their interaction with motorised traffic. In terms of the Road Traffic Code 2000, cyclists may undertake a hooked right turn. This means that cyclists must give way to traffic exiting the roundabout and therefore provision of a storage area (i.e. a refuge) may be considered on the left side of exits where cyclists can wait for a gap in the traffic.

Cyclists differ from drivers in that they have to be able to balance the vehicle whilst negotiating the road and traffic situations. The type of cyclist to be catered for is an important design consideration. The main types of cyclist using the road system are recreational cyclists and commuter cyclists, although regular recreational cyclists may have similar characteristics and needs as commuter cyclists (Austroads, 2020b).

Recreational cyclists:
- Generally ride for the enjoyment of the ride and companionship
- Other than sports cyclists, are more likely to be inexperienced
- Are not intent on getting to a destination as quickly as possible
- Often prefer not to ride on the road

On the other hand, commuter cyclists:
- Ride for transport to work or other destinations
- Are usually very experienced
- Often travel relatively long distances
- Choose to ride on the major roads because the trip length and travel time is less than on alternative routes, including paths

Many commuter cyclists are not attracted to off-road paths because:
- Paths are often indirect and not located to satisfactorily serve the commuter trip
- The path surface may not be as smooth as arterial roads, especially if the paths are constructed from concrete
- They have to give way and are exposed to risk at every intersecting road
- They perceive that there is a high level of conflict with other path users (e.g. pedestrians, pedestrians walking dogs, vehicles using driveways.)

Many commuter cyclists would consider that the use of an off-road path around a roundabout is unacceptable in terms of delay and risk (i.e. crossing the approaches and re-joining the traffic stream). It is in this context that commuter cyclists prefer to use the road network and it is therefore necessary to cater for cyclists at all intersections, including roundabouts. In these circumstances it is essential that the speed differential between motor vehicles and bicycles is minimised through appropriate speed reduction geometrics.

At roundabouts, although commuter or experienced cyclists would generally prefer to use the roadway and ride through a roundabout with the traffic, an option to leave the road and use an off-road shared path is preferable, particularly for inexperienced cyclists and children. Even with uncontrolled pedestrian / cyclist movement across each approach leg, there is some evidence to suggest that this is the safest design, at least when traffic flows are high (Austroads, 2020b).

In an area with significant bicycle usage (particularly children or recreational cyclists), preference may need to be given to traffic signal forms of control with specific provisions such as bicycle lanes[4], advanced stop lines and storage areas.

5.5.4 Provision for Cyclists at Roundabouts

Where bicycles are expected to use a site where a roundabout is the preferred form of control, specific provisions may need to be considered such as:

- Provision for active transport infrastructure should meet the Active Transport Infrastructure Policy (WA Transport Portfolio, 2021), and the Supplement to the Active Transport Infrastructure Policy (WA Transport Portfolio, 2022). This sets out minimum requirements for active infrastructure along State controlled roads and rail corridors, required as part of any new roads and network expansion, and existing road upgrades.
- Low entry speed (preferably less than 30 km/h) using horizontal curves (pre-deflection), or other means, to slow vehicles entering and travelling through the roundabout (adapted from Austroads 2020b). This will enable cyclists to mix with other traffic and take control of the lane. This is particularly important when there are no alternate options such as shared paths for cyclists to exit onto. This may also need to include a low exit speed incorporating tighter geometry than the usual practice of enabling vehicles to exit easily. In the UK considerable success has been achieved through screening the sight distance to the right on the approach to a roundabout (effectively reducing design criterion 3 in Figure 5-9) to slow down entering speeds and force entering drivers to focus on the closer roadway.
- Avoiding squeeze points for cyclists on the approach and through the roundabout. If a bicycle lane is provided on the approach it should be terminated before the holding line. At multi-lane roundabouts the bicycle lane should be terminated in advance of the intersection by the provision of an off-ramp to a shared path or similar. The provision of a separate channelised entry into the roundabout on the left of the general traffic lane is not recommended, as the separation of entering bicycles may not be obvious to motorists.
- Provision for cyclists to move off the carriageway to use shared paths around the outside of the roundabout, particularly at locations used by children or recreational cyclists. The crossings of the splitter islands should be wide enough to shelter a bicycle, be flush with the road pavement and be set back 6 metres, or preferably 12 metres (one or two car lengths), from the holding line. For major multi-lane roundabouts, an allowance for three to four car lengths (approximately 18 to 24 m needs to be considered as per Section 5.5.2.
- Pedestrian signals or a pedestrian crossing could also be considered (refer Section 5.5.2).
- At roundabouts used by cyclists or where a safety problem has developed, consideration should be given to the provision of signs and / or markings to warn motorists to look out for and give way to cyclists moving around the roundabout.
- Where lane sharing at roundabouts is to be used on lower speed routes (60km/h or less), this can be done through the use of sharrows. Sharrows are pavement markings consisting of a bicycle symbol and two chevron markings and may be used on the approach to a roundabout where a bicycle lane or

[4] *It should be noted that DoT is moving away from the use of unprotected on road cycle lanes.*

similar facility terminates prior to the roundabout, and cyclists are required to merge into the main traffic lane. The intention of sharrows is to position cyclists into the centre of the traffic lane and to encourage them to mix with through traffic (VicRoads, 2016). An example of a Sharrow pavement marking is shown in Figure 5-6.

- Provision of a by-pass on three legged roundabouts for cyclists travelling along the top of the T-intersection.
- On approaches where the skew of an intersection necessitates provision of a left turn slip lane on the corner of a roundabout, a marked bicycle lane may be required.
- Provision of a marked bicycle lane where a major vehicle movement is able to by-pass a roundabout at speed.
- Where a bicycle path or shared path is provided around a roundabout, the intersection between the path and road should be designed to ensure that cyclists are able to safely cross the road and enter the bicycle lanes that may exist on the roundabout approaches and departures.
- It should be noted that it is not Main Roads' practice to install on-road cycle lanes within the circulating carriageway. (Since 2015, Austroads GRD Part 4B: Roundabouts recommends that separated off-road cycle paths be provided. The provision of on-road cyclists in road lanes is no longer supported.)
- It is preferable that any pedestrian / cyclist paths should not be immediately adjacent to the roundabout and should be separated from the roundabout by a road safety barrier.
- Further design guidance is provided in 'The All Ages and Abilities Contextual Guidance: Selecting and Designing High-Comfort Bicycle Facilities', (DoT, 2023), which aim to help practitioners make informed decisions relating to the selection, design and delivery of bicycle facilities that appeal to the broadest spectrum of bike riders.

Figure 5-6: Example of Sharrow Pavement Marking, Coppin Street, Richmond (source: Google Street View)

5.5.5 Needs of Large Vehicles

Signalised intersections are considered to provide a more convenient treatment for the drivers of large trucks than roundabouts, depending on the characteristics of the particular intersection. While trucks at times will encounter the inconvenience of coming to a complete stop at a red signal, they are often able to continue through a green signal. This is generally preferred to the inconvenience associated with negotiating a roundabout (Austroads, 2020b) where multi-combinational vehicles struggle to "pick a gap" when the circulatory traffic is high due to poor acceleration characteristics. However, it should be noted that at signalised intersections the traffic signal timing needs to accommodate the heavy vehicle acceleration characteristics. Moreover, traffic lights on downgrades are a problem for heavy vehicles and Advance Warning Flashing Signs are essential when traffic lights are on a downgrade.

In rural and semi-rural environments, the drivers of large vehicles dislike slowing down for a roundabout. In Victoria, in instances where the freight industry has indicated concerns after roundabouts have been installed at an intersection, the context of comments has generally been related to the previous intersection layout where traffic on the major road had right-of way and there was no need to slow down. However, the roundabouts at these locations had generally been installed for safety reasons or to enable vehicles to enter the major road from the intersecting arterial. Traffic signals in these locations would require traffic to slow and/or stop and this may have greater impact on freight movements. Generally, in these rural or semi-rural environments, it is preferable to keep the traffic moving with roundabout, Give Way or Stop controls, rather than using traffic signals. Give Way and Stop controls are applied to the minor intersection legs only resulting in negligible delay to the major through movements.

When considering heavy vehicles, particularly multi-combinational vehicles, the success of implementing a roundabout will be highly dependent on the truck driver's ability to pick a gap in the circulating traffic. This is greatly influenced by the circulating traffic volumes as well as the roundabout geometry; good sight distance is essential for truck drivers to be able to adjust their approach speeds to suit the gaps in the circulating traffic. This also highlights the importance that any capacity analysis makes suitable adjustments to the percentage heavy vehicles as well as gap acceptance parameters and follow-up headways for heavy vehicles.

A functional intersection layout based on the characteristics of a design vehicle should represent an economical level of design that caters safely, efficiently and comfortably for at least 85% of vehicles operating in accordance with normal traffic regulations, provided that on road train routes, the applicable multi-combinational vehicle (e.g. 53.5 m double B-double road trains and 36.5 m B-triple road trains) should be selected as the design vehicle, in which case they should enter and depart from the intersection in the correct lane/s. Any horizontal pre-deflection treatments should also be designed to accommodate the selected design vehicle travelling lane correct. However, where these vehicles and other vehicles operating under restricted access only use the intersection occasionally, it may be acceptable for the design to be based on them encroaching into the other traffic lanes. This may cause some inconvenience to other road users, but may be acceptable where there is a low frequency of occurrence together with the effect of special conditions associated with the permit.

For confined locations where a smaller roundabout needs to accommodate heavy vehicles, a heavy vehicle apron may be constructed around the central island to increase the circulating road width and facilitate right-turn movements. The heavy vehicle apron should be raised using mountable kerbing so as not to compromise the deflection path of standard vehicles proceeding straight through the roundabout (refer to Main Roads Roundabout Guidelines for heavy vehicle apron details). Main Roads supports the use of raised encroachment areas around the central island for permit vehicles only. It should be noted that raised aprons are not desirable on roundabouts where it is used by trucks carrying animals or fuel trucks.

Figure 5-7: Example of a Heavy Vehicle Apron Around the Central Island of a Roundabout

It is also important that practitioners are aware, through traffic data or other local knowledge, whether the location is subjected to seasonal cartage where the number of large vehicles may be very high for a relatively short period of time (e.g. harvesting of crops). In such cases the typical seasonal cartage vehicle should be considered as the design vehicle.

Where the route is designated for the use of special vehicles that fall outside of the three general classes (other freight efficient vehicles, over-length buses, Type 1 or Type 2 road trains), or where regular use of the route by these vehicles could reasonably be expected (access to industrial areas, bus routes), the design should satisfy the needs of such vehicles. The operation of these vehicles should not be compromised by having to encroach into other traffic lanes. In some cases roundabouts have been constructed to enable over-dimensional vehicles to drive straight through the central island (e.g. the Dunreath Drive dog-bone interchange on Tonkin Hwy).

In inner and outer urban areas, for the geometric design of intersections, the 19 m Semi-trailer is typically used as the design vehicle for cross section elements and turning paths and the Car is used as the design vehicle for horizontal and vertical geometry. The geometric design should also be checked for other design vehicles (such as B-Doubles, Road Trains or Tri-Drives) where they are likely to be permitted or encountered.

In rural areas intersections on major roads and highways should be designed to cater for a 36.5 m B-triple road train as a minimum. The design should also cater for 53.5 m double B-double road trains if Main Road's Heavy Vehicle Services permits use of these vehicles. Designers should refer to the RAV Network for further information and should confirm whether there are any planned expansions of the network in the near to medium future (10 years).

5.5.6 Provision for Large Vehicles at Roundabouts

Where large or special vehicles are expected to use a site where a roundabout is the preferred form of control, such as along roads that form part of the RAV network, it is important to:

- Provide appropriate space for the swept path of large vehicles such as semi-trailers and buses (refer to Section 5.3.3).
- Provide truck stopping sight distance
  - understanding that lateral sight distance restrictions are often critical, particularly at T-junctions in hilly terrain and near bridge piers.
  - understanding that at roundabouts it is difficult for drivers of multi-combinational vehicles to "pick a gap". It is preferable that if the design vehicle is an A-double, or larger, all three sight distance criteria given in the Austroads Roundabout Guidelines (Austroads, 2023b) should be satisfied, provided that the available sight distance does not greatly exceed requirements since this may lead to excessive entry speeds. If the design vehicle is a 19.0 m semi-trailer, then only criteria 1 & 2 must be satisfied. The sight distance criteria are shown in Figure 5-9.
  - Where practical, consideration may also be given to actually reducing criterion 3 sight distance (as shown in Figure 5-9) to discourage high entering speeds and to force drivers to focus on the closer roadway. In the UK considerable success has been achieved through screening the sight distance to the right on the approach to a roundabout (effectively reducing design criterion 3) to slow down entering speeds and force entering drivers to focus on the closer roadway.
  - for intersections on or near crest vertical curves.
  - to allow large / special vehicles to turn safely into each road.
  - to railway crossings, speed change areas and merge areas such as lane drops.
- Consider the provision of painted encroachment areas around the splitter islands, to provide adequate width between kerbs for the swept path of multi-combination vehicles, with the width to the painted gore marking to accommodate a standard design vehicle (typically a semi-trailer), as shown in Figure 5-8.
- Roundabouts on OSOM routes will need to consider the clearance requirements of these vehicles, as summarised in Section 5.3.3.
- Consider vehicle stability for turning movements by providing radii appropriate for the turning speeds and providing a satisfactory crossfall and a uniform rate of change of crossfall. This is particularly important for multi-combinational vehicles where the prime mover and trailer(s) may be on different crossfalls at the same time. Where possible, this needs to be minimised and should be checked using software such as HVE (Human, Vehicle, Environment) developed by Engineering Dynamics Corporation, USA, and used by Queensland Main Roads. The assessment should be undertaken using simulation software in accordance with the Guidelines for Vehicle Stability Analysis – Main Roads Internal Process (Main Roads, 2019a).

A case study example (Eelup Rotary in Bunbury) of designing a roundabout to accommodate multi-combinational vehicles is given in Appendix C. It should be noted that due to the high volumes at this roundabout, it was necessary to fully signalise the roundabout.

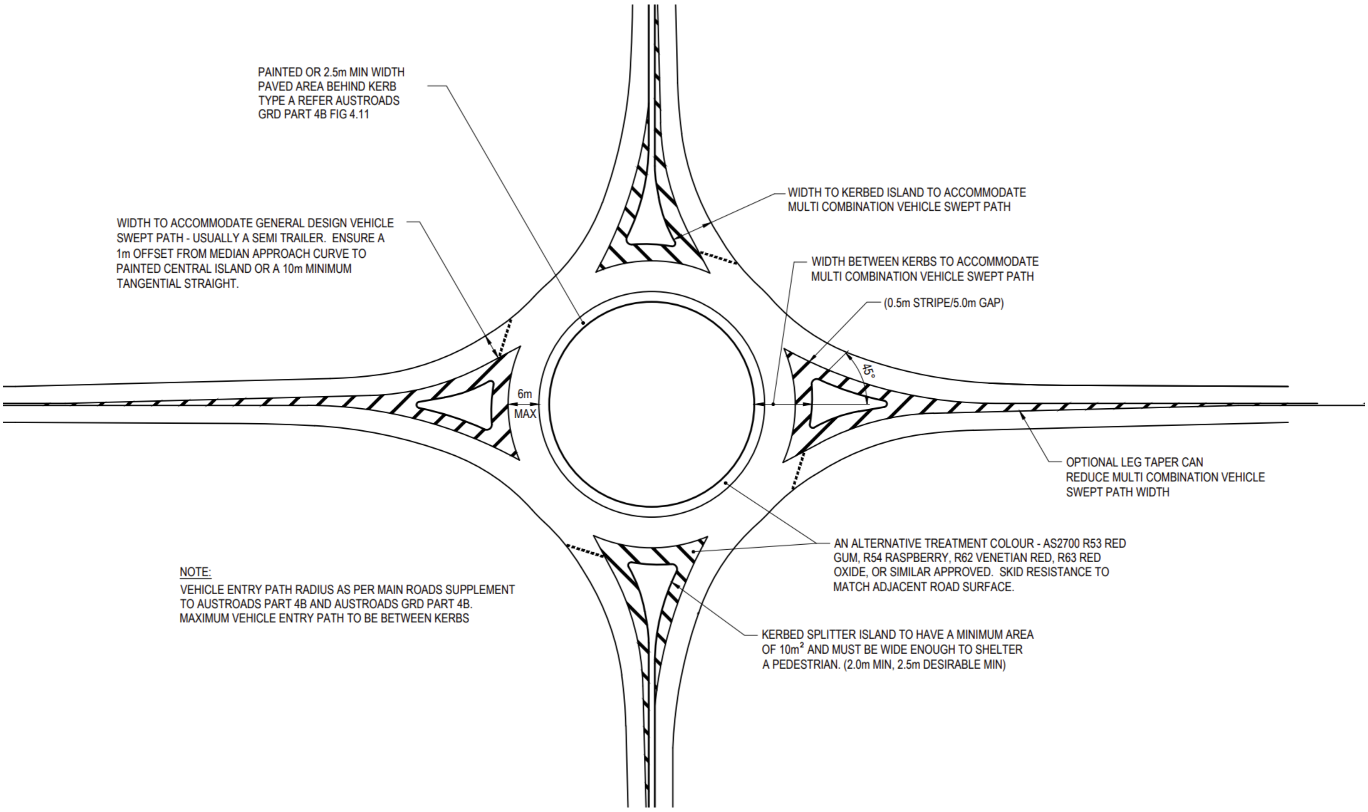
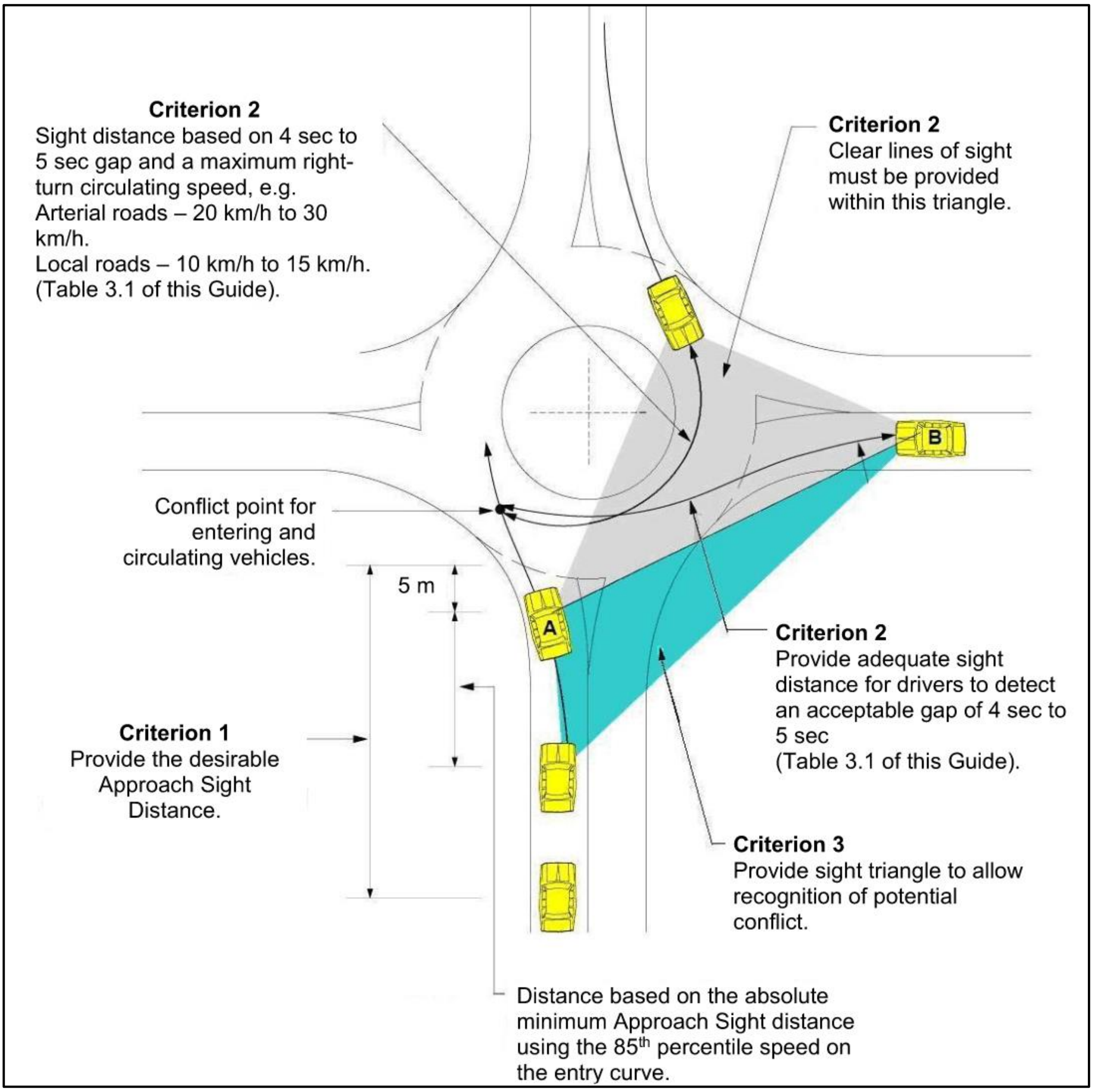


Figure 5-8: Example of Painted Encroachment Areas for Multi-Combination Vehicles



SOURCE: (Austroads, 2023b)

Figure 5-9: Sight Distance Criteria to be Satisfied for Multi-combinational Vehicles at Roundabouts

5.6 Traffic Management

5.6.1 Route or Area Strategies

The consideration of route strategies when selecting a form of intersection control includes consideration of the form of control at adjacent intersections. For example:

- Traffic signals would be appropriate where adjacent intersections are controlled by traffic signals and the spacing of intersections would enable effective signal linking. Roundabouts in this traffic environment would interfere with the platoons created by adjacent traffic signals and a conventional signalised (or unsignalised) at-grade intersection would generally provide a better level of service than a roundabout.
- Roundabouts would also be inappropriate where traffic flows leaving the roundabout would be interrupted by a downstream traffic control which could result in queuing back into the roundabout. An example of this is a nearby signalised pedestrian crossing. The use of roundabouts at these sites

should not be completely discounted, but they are generally found to be less effective than adopting a signalised intersection treatment.

- Traffic signals may be appropriate at arterial road intersections that are adjacent to signalised freeway interchanges, as they can provide greater operational control of traffic flows close to a freeway interchange and/or aid the implementation of a particular route strategy. An example of this is where heavy traffic exiting a freeway off-ramp onto an arterial road needs to be efficiently dispersed by downstream traffic signals to avoid ramp queues backing into the freeway mainline. The use of roundabouts should not be completely discounted, however allowance for partial or full signalisation of the roundabout may be necessary (refer Section 7).
- Roundabouts are more appropriate than traffic signals at relatively isolated locations or where the adjacent sites have roundabout control.

5.6.2 Road Hierarchy, Local Access and Amenity

Area strategies relating to the use of Local Government roads may also need to be considered. The functional road classification of the intersecting roads needs to be considered when determining the appropriateness of a form of control (refer to Section 2.2). This could be an issue where control of traffic into a local area is important for amenity reasons. This may occur where a Local Government road intersects with an arterial road intersection and 'rat running' could occur. In these situations traffic signals would give greater control of traffic movements, in the same way traffic signals enable priority to be given to particular routes / turns which warrant priority movements.

5.6.3 Traffic Volumes and Traffic Signal Warrants

In choosing a form of control for an intersection, operational analyses require an understanding of traffic volumes and the mix of traffic (e.g. percentage and types of heavy vehicles) that are to use the intersection during anticipated periods of peak flow.

The first step is to determine design traffic volumes that would be applicable for the morning peak, evening peak or high flow periods such as events, recreational periods, crop harvesting periods, holidays etc. The determination of design volumes may be based on:

- An existing turning movement traffic count. This may then be factored up using a growth rate appropriate to the site.
- Traffic studies considering a range of issues, including traffic growth that may result from development in the area or along a growth corridor.
- Network modelling that estimates future traffic flows. These may be based on various scenarios relating to land use development or road network improvements. In the Perth Metropolitan Area the ROM24 model may be used to estimate future peak hour traffic volumes and obtain projected turning movements at major intersections. It should be noted that any projected modelled volumes need to be adjusted based on a comparison between Base Year modelled volumes and actual count data for the same year.

At locations where traffic growth is expected to be high and where future traffic patterns are uncertain or changeable, roundabouts may be appropriate. However roundabouts do not operate well with unbalanced flows, hence care should be taken in assessing the future traffic volumes and their patterns. It is possible that a site considered appropriate for a roundabout now may become inappropriate in the future, requiring extensive modification to the intersection. Designers should consider the potential to build flexibility into the design to accommodate possible future changes, particularly when land use changes are likely to alter traffic patterns and volumes considerably. Allowance for future roundabout metering or signalisation may need to be built into the design where future traffic volumes and patterns are uncertain, and there is potential for unbalanced flows to eventuate. If this flexibility is not possible, roundabouts may not be the most appropriate form of intersection control.

It is important that traffic control signals are installed in situations where they are justified in order to be respected by the travelling public. Main Roads has developed a "Traffic Signals Approval Policy" (Main Roads, 2021c), which sets out the circumstances under which Main Roads' Network Operations Directorate will consider approving the modification of existing traffic signals and the provision of new traffic signals on all roads in Western Australia. This policy also applied to fully signalised roundabouts and roundabout metering.

5.6.4 Horizon Years

For future planning and major projects, the horizon years that should be applied for the purpose of traffic forecasts, capacity analysis and performance targets are:

- Project Case – 15 year horizon from project opening
- Ultimate Case – Horizon year to be determined by Main Roads Road Planning Branch

These horizon years are applicable to both roundabouts and traffic signals.

For roads and intersections controlled by Main Roads, any deviation from these horizon years will require Main Roads approval.

For operational assessment, including modification to existing traffic signals and new traffic signals that fall under the Traffic Signals Approval Policy (Main Roads, 2021c), the Short Term Horizon and Medium Term Horizon requirements shall apply.

5.6.5 Capacity Analysis

The capacity of a form of control to operate satisfactorily is dependent on the traffic volumes during periods of peak flow, including the volumes of turning traffic and the distribution of traffic on the various approach legs at the intersection. Therefore, it is important to determine appropriate design volumes as outlined above.

Analyses are best undertaken using software which provide the key output measures relating to operational performance for a proposed intersection layout of Level of Service (LOS), Degree of Saturation (DOS) and (in some situations) Length of Queues for evaluating or comparing performance of individual lanes, approaches or the intersection as a whole.

Main Roads has developed the "Operational Modelling Guidelines" (Main Roads, 2021a) and the "Guidelines - Auditing Process for Operational Modelling," (Main Roads, 2020) including checklists for LINSIG and SIDRA. These guidelines should be used for all operational analysis.

Level of Service (LOS)

The Level of Service (LOS) measure for intersections is "control delay" (measured in seconds) and is a measure of the driver discomfort, frustration, fuel consumption and increased travel time. As control delay increases, LOS worsens. LOS for intersections, based on Austroads Guide to Traffic Management Part 3: Transport Study and Analysis Methods (Austroads, 2020a) is given in Table 5-4.

Level of Service	Control delay per vehicle in seconds (d) (including geometric delay)		
	Signalised Intersections	Priority Controlled Intersections	Roundabouts
A	d ≤ 10	d ≤ 10	d ≤ 10
B	10 < d < 20	10 < d < 15	10 < d < 20
C	20 < d < 35	15 < d < 25	20 < d < 35
D	35 < d < 55	25 < d < 35	35 < d < 50
E	55 < d ≤ 80	35 < d ≤ 50	50 < d ≤ 70
F	d > 80	d > 50	d > 70

Source: (Austroads, 2020a)

Table 5-4: Level of Service Definitions based on delay

It should be noted that the delay for a particular level of service at signalised intersections is higher than the delay for the corresponding level of service at a priority controlled intersection or roundabout. This is because drivers tend to expect (and tolerate) higher delays at signalised intersections compared with non-signalised intersections. Analysts need to be aware of this when comparing results using packages that only report the intersection delay, and not the level of service as defined in Table 5-4.

Degree of Saturation (DOS)

The Degree of Saturation (DOS) is defined as the ratio of *demand flow to capacity* (also known as the volume to capacity ratio – *v/c ratio)* for any particular lane. The movement DOS is the largest DOS for any lane of the movement. The approach DOS is the largest v/c value for any movement (or lane) in the approach and the intersection DOS is the largest v/c value for any approach.

Length of Queues

This is of particular importance in assessing requirements for the length of auxiliary through lanes or storage in turn lanes. The 95% queue length is generally adopted as the minimum storage for turn lanes, however longer lane lengths may be required for deceleration of vehicles.

Performance Criteria

For future planning and major projects, the performance criteria outlined in Table 5-5 shall apply to the analysis based on traffic volumes in the Project Case and Ultimate Case horizon years (refer to Section 5.6.4).

Intersection Control	Criteria	Project Case Horizon Year	Ultimate Case Horizon Year
All Intersections	Intersection average LOS	D or better	E or better
All Intersections	Individual turn movement LOS	E or better	E or better for major road movements F or better for minor road movements
Signalised Intersections	Degree of saturation	≤ 0.9	≤ 1.0
Roundabouts	Degree of saturation	≤ 0.85	≤ 0.95

Table 5-5: Intersection Traffic Performance Criteria for Project Case and Ultimate Case

A sensitivity analysis to consider the implications of higher volumes may need to be considered where there is uncertainty regarding design volumes or future traffic growth.

In locations with a high Place value on the Movement and Place framework, there may be a preference to prioritise active transport modes over vehicular modes. In these locations, lower performance targets may be adopted for vehicles, in order to prioritise and improve the accessibility and level of service for pedestrians and cyclists. For example, this might be achieved with reduced cycle times at signalised intersections, to minimise delays for pedestrians. On roads and intersections controlled by Main Roads, a reduction in the performance targets outlined above will require Main Roads approval.

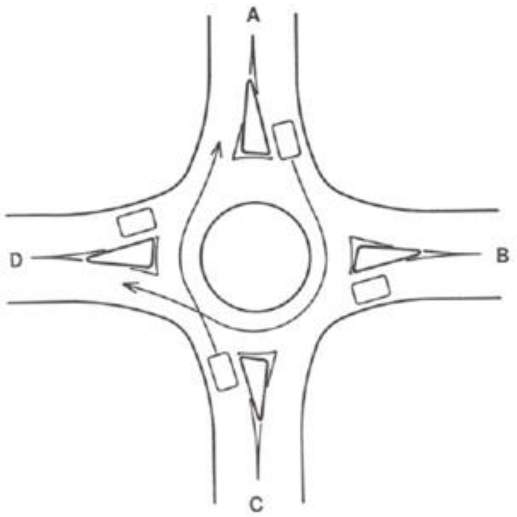
<u>Software Calibration</u>
The calibration of the software for the capacity analysis is desirable when modelling congested intersections or comparing improvement options with an existing situation. The most critical 'default' values and parameters that can be modified when calibrating the software are:

- Lane saturation flows.
- Gap acceptance and follow-up headway parameters for each vehicle category (these are particularly critical when assessing roundabouts with high percentages of multi-combinational vehicles: it is important that the analysis realistically reflects their reduced ability to "pick a gap").
- Phase and cycle times if signals are in a linked system (consultation with the Network Operations Directorate is important to establish appropriate phasing and cycle times).
- Lane utilisation factor, where applicable.

Gap acceptance parameters are particularly important for modelling roundabout operation. When modelling in SIDRA, default gap acceptance parameters are typically adopted, which allows the model to adjust for geometry and flow conditions. However consideration should be given to reviewing these defaults, particularly where there is a high proportion of multi-combinational vehicles. This can be done through calibration of the existing roundabout operation, or based on recorded heavy vehicle kinematics, and adjustment of the Gap Acceptance Factor and Opposing Vehicle Factor for specific movement classes.

A roundabout operating within design volumes will manage peak traffic flows in a self-regulating manner and provide acceptable delays under usual roundabout priority control. Even with relatively high traffic flows on each approach, traffic is generally broken up to create gaps in the circulating flow for entering traffic.
For multilane roundabouts, the provision of exclusive lanes for turning traffic is generally unnecessary unless a turning movement requires more than one lane. The shared lanes then provide more flexibility for off peak periods or times when flows vary from the design volumes used.

At intersections where there are high proportions of right turning traffic, roundabouts may be an appropriate form of intersection control. Unlike most other intersection treatments, roundabouts can operate efficiently with high volumes of right turning vehicles. However, satisfactory operation is dependent on the entering flows being balanced so that a heavy right turn does not cause excessive delays on subsequent entries. Right turning vehicles contribute to good roundabout operation because they create opportunities for vehicles on other approaches to enter the roundabout (refer to Figure 5-10).



In this example:

1 The right-turner from A to D would stop the through movement from C to A thus allowing traffic from D to enter.
2 Traffic from D would then stop the through movement from A thus allowing traffic from B to enter.
3 Right-turners from A in this example would initiate traffic flow on adjacent entries and D which would otherwise experience longer delay.

Source: (Austroads, 2020b)

Figure 5-10: Effect of Turning Vehicles on Roundabout Operation

Generally, a vehicle can enter a roundabout when another vehicle exits the roundabout on the same leg. The exiting vehicle may be turning right or left from the other legs and it creates a gap for the entering vehicle. Therefore, a quick check for whether a roundabout will still function under high traffic volume on the major leg is to check if the traffic flowing in and out on the minor legs is balanced at peak hours.

Where the entering traffic from a dominant leg prevents traffic from another approach from entering the roundabout (generally the adjacent approach to the left of the dominant flow), this deficiency can usually be addressed by the provision of part time metering signals that regulate the dominant flow and provide gaps in the circulating traffic. Metering signals are activated by queue loops in the approach that is being delayed. Further information relating to signals at roundabouts is provided in Section 7.

Capacity analysis of roundabouts should also consider any proposed pedestrian facilities. For example, the impacts of zebra crossings and signalised pedestrian crossings should be assessed to understand their impact on roundabout operation, particularly if pedestrian volumes are likely to be significant.

Roundabouts generally provide advantages over traffic signals in minimising delays during off peak periods. An economic evaluation may be based on calculated delays for the peak periods, but may also consider the operation during off peak operation. A 'whole of day' analysis provides a more precise assessment of benefits / disadvantages. Lower off peak delay during the day is particularly beneficial for business travel and freight.

At traffic signals, the number and layout of lanes and phasing are determined to suit peak demands. The phase times and operation for the varying periods through the day are then managed by the vehicle actuated controller and signal linking settings.

5.6.6 Project Life

Consideration of the project life can influence a decision on the form of control, particularly where significant future traffic growth may be expected. Consideration of the form of control compatibility with other future works is also an important input in the decision process. For example a single lane roundabout constructed as an initial form of control may be a staging of a multi-lane roundabout in the longer term. Alternatively, a roundabout may be chosen as an appropriate form of control to address current problems, even though traffic signals (or a signalised roundabout) may be envisaged in the long term. It is important that from a planning perspective that the ultimate configuration be superimposed to assess the potential land implications.

The project life needs to be consistent with adopted design traffic volumes and capacity analyses, as well as the value used for the economic evaluation.

5.6.7 Public Transport – Light Rail (Trams) or Buses

Traffic signals enable specific priority to be given to trams or buses through an intersection. Signals may also facilitate the clearing of queues at an intersection that may be obstructing the movement of a tram or bus. Traffic signals would generally be preferred where a tram service passes through a new intersection. However, tram routes have been successfully accommodated within roundabouts with satisfactory operation being supported by appropriate signs or signals.

In relation to buses, roundabouts generally provide lower delays during off peak periods and may also provide lower delays during the peak periods, subject to available capacity. Traffic signals provide greater control where bus priority or exclusive bus lanes are to be provided. Traffic signals can also be designed to incorporate Selective Vehicle Priority, i.e. signal phasing can be dynamically changed to prioritise approaching buses. This could similarly be applied to freight vehicles, emergency vehicles or other selected vehicle types. Hence traffic signals may be more appropriate on high frequency bus routes, adjacent to hospitals, at the access points to inter-modal terminals, or along high frequency freight corridors.

Roundabouts should be designed to meet passenger comfort requirements, especially considering any vertical displacements or horizontal pre-defection.

5.6.8 Public Transport – near Railway Level Crossings

The control of traffic movements adjacent to a railway level crossing can be a significant matter that affects the choice of the form of control to be adopted. Traffic queues extending across a railway level crossing are able to be controlled more effectively with traffic signals. These controls would generally include a ‘track clearance’ signal phase and ‘train’ phase within the cycle. A roundabout could be considered near a railway level crossing where traffic volumes are low or where capacity analyses confirm that queues will not extend across the tracks.

5.7 Summary of Site Specific Factors and Form of Control Choice

A summary of the various factors outlined in Sections 5.3 to 5.6 is provided in Table 5-6. This table is designed as a “quick reference” guide and should not be treated as definitive. For example any proposed signalised intersection in a rural area will be labelled as “unlikely” to be an appropriate type of treatment. This does not automatically preclude it as a possible treatment since most issues can be “engineered out”, albeit at a cost. This table is intended to help identify which form of intersection control is likely to be appropriate given a range of factors. Further investigation is required to understand the interrelationship of these factors, which in some cases may point to different forms of intersection control, which may require trade-offs or prioritisation of factors to determine the most appropriate outcome.

Site Specific Factors	Signals	Roundabouts	
		Single lane	Multi-lane	Notes
Physical Controls				
Number of intersection legs ≤ 4	A	A	A	
Number of intersection legs = 5 to 6	X	O	O	Suitable for larger diameter roundabouts
Number of through lanes ≤ 2	A	O	A	For single lane must be ≤ 1
Number of through lanes ≥ 3	A	X	O	Subject to design. More than 3 through lanes should only be considered at signals in some circumstances (e.g. with bus priority lanes)
Space available	O	O	X	Subject to design (large roundabouts may be difficult in Brownfield sites).
Site topography	O	O	X	Subject to design (large roundabouts may be difficult in hilly terrains).
Access to adjacent properties	O	O	O	Subject to design.
Road Environment				
Rural area	X	A	A	
Outer urban or fringe areas	O	A	A	
Inner urban area	A	O	X	
Activity centres	A	O	X	
High speed approaching traffic	A	O	O	Signals - requires speed limit ≤70 km/h. Roundabouts – May be appropriate with design features to control approach speed.
Road Users				
Pedestrian needs - children, the elderly and the mobility impaired and / or significant[1] number of other pedestrians	A	O	X	Multi-lane roundabouts - unlikely to be appropriate unless pedestrian signals provided or pedestrian refuges between all lanes, and 85th percentile speeds ≤ 30km/h. Single lane roundabouts - consider pedestrian facilities, low design speed and spare capacity.
Pedestrian needs - insignificant[1] number of pedestrians	A	A	A	
Bicyclists needs - significant[1] number of children / recreational cyclists	A	O	X	Multi-lane roundabouts - unlikely to be appropriate unless off-road facility and pedestrian signals provided or pedestrian refuges between all lanes, and 85th percentile speeds ≤ 30km/h. Single lane roundabouts - consider pedestrian facilities, low design speed (≤ 30km/h) and spare capacity.
Bicyclists needs - significant[1] number of other cyclists	A	O	O	Roundabouts - may be appropriate with low-speed design (≤ 30 km/h). Multi-lane roundabouts appropriate only with the provision of adequate off-road facilities.
Bicyclists needs - insignificant[1] number of cyclists	A	A	A	
Needs of large vehicles	A	O	O	Roundabouts - may be difficult with high volumes, high % heavies or restricted geometry.
Table continued on next page...				

Site Specific Factors	Signals	Roundabouts		Notes
		Single lane	Multi-lane	
...Table continued from previous page				
Traffic Management				
Route or Area Strategies				
• Adjacent to linked signals	A	X	X	
• Isolated locations	O	A	A	
• Adjacent sites with roundabout control	O	A	A	
• Control of traffic through a local area	A	X	X	
Traffic Volumes and Capacity				
• Balanced flows	O	O	O	
• Unbalanced flows	O	O	O	Roundabouts - may be appropriate with metering signals.
• Significant turning volumes	O	A	A	Signals - may be appropriate with adequate turn lane capacity.
• Minimising off-peak delays	X	A	A	
Public Transport				
• Light Rail / Trams	A	X	X	
• Buses	A	A	A	
• Adjacent to railway level crossing	A	X	X	

Legend:
A - Likely to be an appropriate form of control O - May be an appropriate form of control X – Unlikely to be an appropriate form of control
[1] Note: Methodologies to determine whether the number of vulnerable road users is "significant' can be found in Appendix E.

Table 5-6: Summary of Specific Factors and Form of Intersection Control Choice

6 USE OF TRAFFIC SIGNALS AND ROUNDABOUTS AT INTERCHANGES

In WA there has been increased use of roundabouts (including "dog bone" roundabouts) as junctions at service interchanges. This is in response to the "Safe System" approach to intersection design, whereby it is recognised that roundabouts can offer significant safety advantages over signalised intersections. It should be noted that grade separated interchanges are typically applied the intersections of major roads, highways and freeways, which are also often major corridors for active transport, and may form part of the DoT Long Term Cycle Network. In general, riding and walking infrastructure should be grade separated in cases where the other modes are grade separated (i.e. road over/under road, road over/under rail or vice versa), as outlined in the Supplement to Active Transport Infrastructure Policy (WA Transport Portfolio, 2022).

Commentary 2 (adopted from (Austroads, 2020b)) summarises the advantages and disadvantages of various types of service interchanges using either traffic signals or roundabouts as the form of intersection control.

7 TRAFFIC SIGNALS AT ROUNDABOUTS

Although the combination of traffic signals with roundabouts is not the main focus of this document, the following comments are provided in relation to the operation of traffic signals in conjunction with roundabouts. Main Roads has developed Guidelines for the Full Signalisation of Roundabouts (Main Roads, 2024) in order to provide parameters and warrants for the installation of traffic signal control at roundabouts. Detail is provided on the alternative control options, and design considerations required for their implementation.

Fully signalised roundabouts and roundabout metering are also subject to the approval requirements of the "Traffic Signals Approval Policy" (Main Roads, 2021c).

A recently updated Austroads guideline (Austroads, 2020b) has noted that signalised roundabouts provide the greatest alignment with Safe System objectives:

"The opportunity for a crash to occur should be also diminished, as roundabouts have less conflict points than a comparably-sized traditional signalised intersection (opposing-turning and adjacent direction are combined). Signalised roundabouts have an additional advantage over typical roundabouts: the priority decision is simplified from gap acceptance to obeying the red signal. This should further reduce the likelihood of a crash occurring, especially at larger multilane sites. The severe (FSI) injury probability for pedestrians and other vulnerable road users would be greatly reduced as well, although not minimised. The likelihood of pedestrian and cyclist crashes could be further reduced by use of signalised crossings, cycle lanes/storage boxes, staged or offset crossings or bypasses."

If an existing roundabout is performing poorly in terms of safety, or delay on several approaches the benefits that might be derived from signalisation should be investigated. Roundabout metering (i.e. metering of one or more entries), partial signalisation (signalisation of only some of the roundabout legs) or full signalisation may be considered.

Moreover if the capacity analysis indicates that the residual capacity in the target horizon year is small (i.e. Degree of Saturation is close to 0.85) and there is a strong possibility of full signalisation being required, then the initial design should take into account the need to provide for internal queueing in the future (refer to Section 7.1.3) and the size of the roundabout should be designed accordingly. Also, any proposed change in intersection operational types should also check the suitability of the change for all expected vehicle operating characteristics.

The full signalisation of roundabouts can have a positive effect on some crash types (Dept. for Transport, April 2009):

- Crashes caused by poor judgement of gaps by drivers entering a high-speed flow of circulating traffic.
- Rear end crashes resulting from drivers having to simultaneously assess gaps in the circulating flow while watching the vehicle in front.
- Crashes with cyclists by regulating the speed of circulating traffic.
- Pedestrian crashes by providing protected crossings.

The partial signalisation of roundabouts (metering signals) can also have a positive effect due to increased capacity, although there may be a potential for increased rear-end crashes due to drivers becoming confused about two holding lines, (i.e. stop line at signals followed closely by holding line at roundabout entry). This may be mitigated by ensuring there is sufficient distance between the traffic signal stop line and the roundabout Give Way line. In addition, the use of two-aspect signals (red and amber) assists in preventing drivers from mistakenly driving through a green signal and failing to give way at the downstream give way line. Partial signalisation of roundabout has two types of operation; part time operation (metering signals with only two aspects, yellow and red) and full time operation (three aspects, green, yellow and red).

7.1 Partial Signalisation (Metering Signals) at Roundabouts

Practitioners should refer to the Guidelines for the Analysis of Roundabout Metering Signals (Main Roads, 2015) for detailed guidance on the application of roundabout metering in WA, with a general overview provided below.

7.1.1 General Provisions

Roundabout performance is sensitive to unbalanced traffic flows. This may occur where the entering traffic from a dominant leg prevents traffic from the adjacent or another affected approach to the left of the dominant flow from entering the roundabout. This situation results in excessive queues and delays on the affected approach.

The dominant traffic flow at a roundabout may be either:

- A high uninterrupted traffic flow.
- A low but consistent flow from a minor approach that takes priority over a major flow.

This deficiency can usually be addressed by the provision of part time metering signals that regulate the dominant flow and provide gaps in the circulating traffic. This enables the traffic from the affected approach to enter the roundabout. The metering signals are usually activated by queue loops in the affected approach that is being delayed, but may also be activated by downstream loops if a situation results in downstream traffic backing up into the roundabout. Metering can also be applied to more than one entry at a roundabout. Metering signals provide the following benefits:

- Management of the peak flows to provide appropriate priority for a major movement.
- Provide better balance of queues and delays between approaches.
- They can extend the life of a roundabout rather than require its replacement.

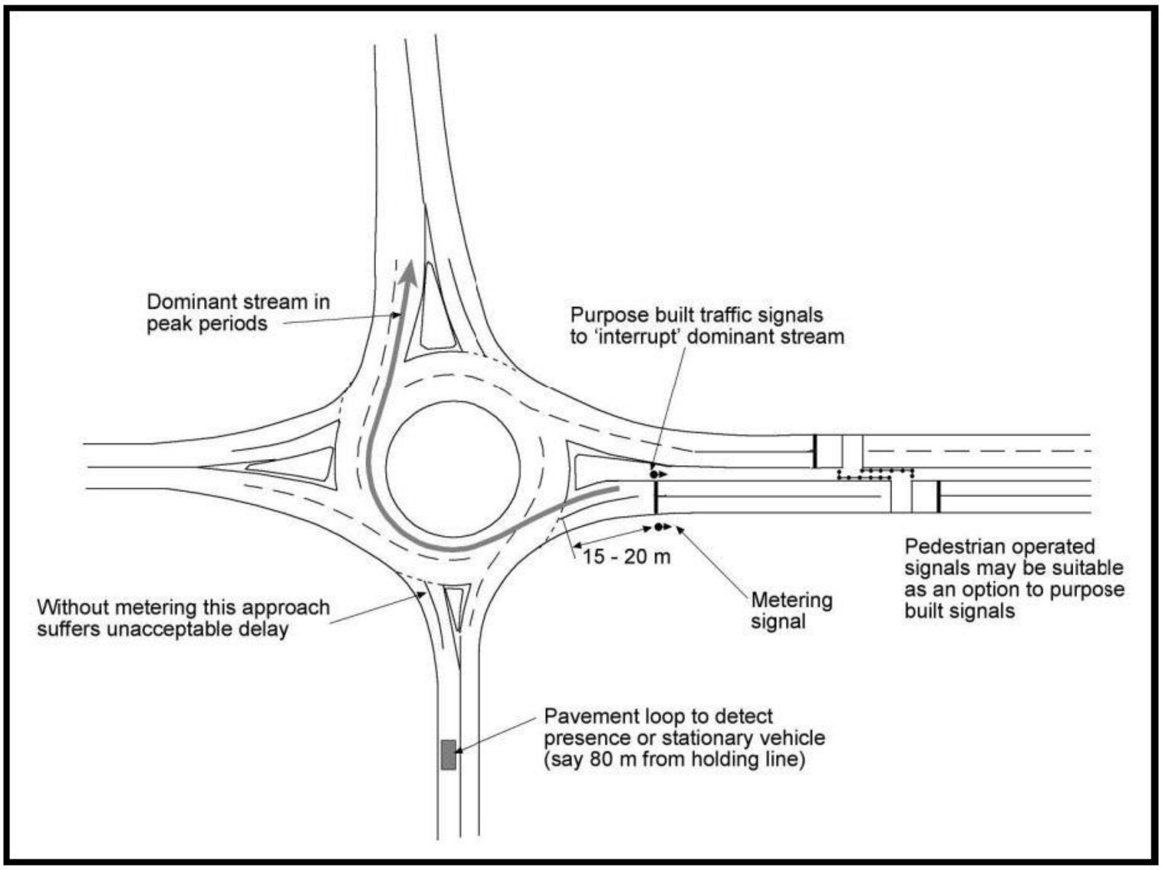
Metering signals are generally considered as a 'short term fix' stage when problems develop due to changing traffic flows over time. However, at some locations they could be considered as part of a new roundabout control to proactively manage the traffic. This form of control may avoid the need for installation of full traffic signals and retain safety and operational benefits at times of lower flow at the roundabout.

Metering signals typically use two aspect (yellow/red) lanterns set back on the approach to control the traffic. When traffic is released it enters the roundabout under usual 'give way' priority conditions in a self-regulating manner. This form of metering operates part-time, usually during peak periods or when flow is unbalanced. At "dog bone" interchanges, such as Tonkin Highway / Dunreath Drive, if the internal leg is metered, three aspect (green/yellow/red) lanterns are used, as the internal leg usually has no other form of control (i.e. give way line marking) and hence a green light is used to provide clear indication that the internal approach has priority at all other times (when metering is not activated).

7.1.2 Provisions for Pedestrians at Roundabouts with Metering Signals

The provision of metering signals can also be beneficial for pedestrians, as the metering system can be combined with pedestrian signals to provide a pedestrian facility across a leg (or legs) of a roundabout. In these installations the signals would also stop traffic leaving the roundabout, so queuing of traffic may extend back into the circulating roadway. As the crossing distances and times are usually relatively short, this queuing is generally not a significant operational problem, depending on the frequency of operation. Subject to the pedestrian 'desire line,' at some sites it may be possible to locate the crossing further back from the circulating roadway so that storage on the roundabout exit is maximised.

Figure 7-1 illustrates metered roundabouts using purpose-built signals or pedestrian operated signals as an option. These facilities must be located with reference to the estimated traffic operation at the roundabout and potential pedestrian safety issues. It should be noted that in this case the pedestrian crossing is staggered so that any pedestrian negotiating the stagger faces the oncoming traffic. If the pedestrian crossing were to be located closer to the stop line, the stagger is reversed to give more storage to the exiting vehicles (refer to 2nd last dot point in Section 5.5.1 and Figure 7-2 for an example).



Source: (Austroads, 2020b)

Figure 7-1: Metering of Roundabout Approaches

Where purpose built signals are used it is important that:

- They are located at least 15 to 20 m in advance of the roundabout holding line to provide adequate separation between the roundabout regulatory signs and the traffic signals so that possible driver confusion is avoided.
- Signs (MR-GT-26) are provided at the signals to advise drivers that the signals are activated by traffic on other legs (the road name is usually specified).

- "STOP HERE ON RED SIGNAL" signs (R6-6) are provided.

Where pedestrian operated signals are used for metering:

- The crossing must be located a sufficient distance from the exit, and on divided roads pedestrian movements may have to be staged to ensure that traffic queues will not unduly affect the operation of the roundabout. Pedestrian desire lines and the provision of pedestrian fencing should be considered to encourage pedestrians to use the crossing.
- The crossing should be located a sufficient distance from the holding line and roundabout regulatory signs to avoid driver confusion (usually greater than that required for purpose built signals).
- Appropriate signage should be erected to inform drivers that the pedestrian signals may change for metering purposes (i.e. signals are not faulty).

Figure 7-2 shows an example of a metered approach using a signalised pedestrian crossing to control the traffic. It should be noted that the traffic signals facing the traffic approaching the roundabout may also be activated by traffic queuing on the controlling approach. However, the traffic signals facing the traffic departing the roundabout will only be activated by a pedestrian waiting to cross the departing leg. It should also be noted that the example in Figure 7-2 does not include a stagger (as shown in Figure 7-1), which can be provided to increase the stacking distance for vehicles departing the roundabout.

Figure 7-2: Example of a Metered Roundabout using Pedestrian Crossing Signals

As an alternative to providing pedestrian operated signals across both the approach and departure legs of a roundabout, consideration could also be given to providing pedestrian operated signals on the approach side and a zebra crossing on the departure side. An example of this in Melbourne is shown in Figure 7-3.

Figure 7-3: Roundabout Metering Using Pedestrian Operated Signals on Approach Leg only and Zebra Crossing on Exiting Leg

The main advantage of this approach is that the minimum red time is reduced because it is calculated on the width of one approach only and can reduce the delay to vehicles on the approaching leg. It should be noted that loops are also provided on the controlling approach to activate the signals during peak periods when no pedestrians are present. Consideration should be given to the potential user types using this crossing, and supplementary measures to optimise legibility and safety for all road users.

7.1.3 Warrants for Roundabout Metering Signals

Currently, there are only a handful of roundabouts with metering signals in Western Australia, including:

- Point Lewis Rotary (Mounts Bay Road / Birdaya Drive, Perth) – refer Appendix D for a case study.
- Farrington Road / Murdoch Drive / Allendale Entrance, Murdoch
- Bibra Drive / Murdoch Drive northbound entry road, North Lake
- Airport Drive / Sugarbird Lady Drive / Horrie Miller Drive, Perth Airport
- Bunbury Outer Ring Road / South Western Highway, Bunbury

There was an initial concern that the part-time operation of the signals (generally only required during peak periods) may lead to driver confusion and error. Video surveys have highlighted some driver confusion and non-compliance but with few negative consequences. However, when the ongoing increased maintenance costs for the traffic signals are added in, the installation of roundabout metering signals should not be considered as the first option. There are a number of means of improving the performance of the roundabout that should be considered first, before considering installing roundabout metering signals (Austroads, 1993), including:

- Addition of continuous (left-turn slip) lanes
- Flaring (tapering) of the entries
- Adjustments to signal timings on adjacent intersections
- Signalised pedestrian crossing(s)

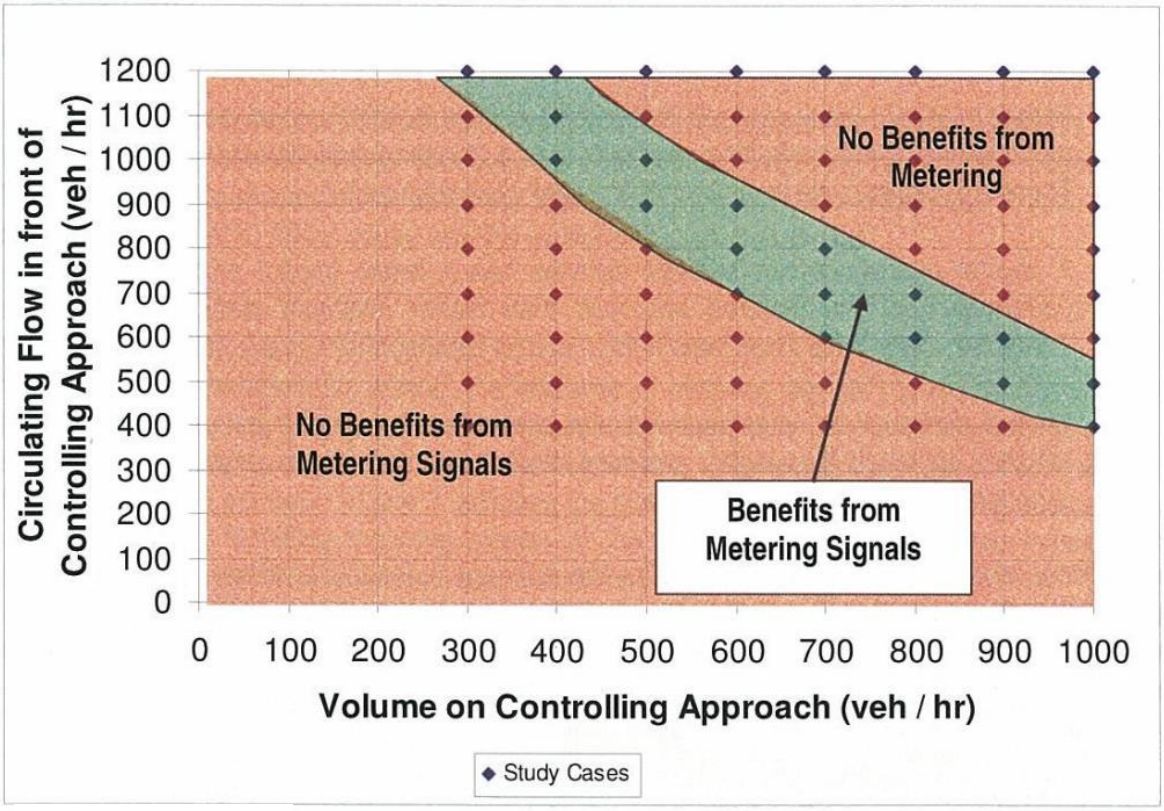
- Lighting
- Implementation of ITS measures such as VMS and ESLS.

Main Roads has developed the Guidelines for the Analysis of Roundabout Metering Signals (Main Roads, 2015) in order to provide a consistent methodology to justify the installation of roundabout metering signals. More detail is provided on the implementation of the above treatments.

In addition, the guidelines cite a methodology for single lane roundabouts that compares the volume on the controlling approach with the circulating flow in front of the controlling approach to check whether there would be any benefit from installing metering signals (Natalizio, 2005). This is illustrated in Figure 7-4 and described below from the same source:

The results indicate that metering signals are required at a single lane roundabout when the combined volumes of traffic flow on the delayed (controlling) approach together with the circulating flow in front of the delayed (controlling) approach is between 1300 and 1400 vehicles per hour. The benefits of metering signals begin to decline once the combined volumes of traffic flow on the delayed (controlling) approach together with the circulating flow in front of the delayed (controlling) approach is between 1550 and 1650 vehicles per hour.

Based on the above, it is recommended that for single lane roundabouts the relevant point on Figure 7-4 be found. If this point falls outside of the green area then it is suggested that alternative means to increase roundabout capacity be explored, rather than installing roundabout metering signals.



Source: (Natalizio 2005)

Figure 7-4: Single Lane Roundabouts - Flow Conditions on the Controlling Approach that would benefit by installing Metering Signals

A case study example of the partial signalisation of an existing roundabout by installing metering signals is given in Appendix D.

7.2 Full Signalisation of Roundabouts

Practitioners should refer to the Main Roads "Guidelines for the Full Signalisation of Roundabouts" (currently under development, expected to be published in 2025) for detailed guidance on the application of fully signalised roundabouts in WA, with a general overview provided below.

In the full signalisation of a roundabout, the signals control both entering traffic and circulating traffic at each entry but are not used to control traffic that is exiting from the circulating roadway. One of the major advantages of signalising a roundabout from a capacity point of view is that, in its simplest form, each signalised junction can be operated on a two-phase system, as illustrated in Figure 7-5. However, for full signalisation to be successful, the roundabout must be sufficiently large to accommodate any necessary queuing in the circulating roadway, or be of such a size that it can be operated without excessive lost time. Furthermore the cycle length should be comparatively short to limit the internal queue lengths arising from the right turning traffic.

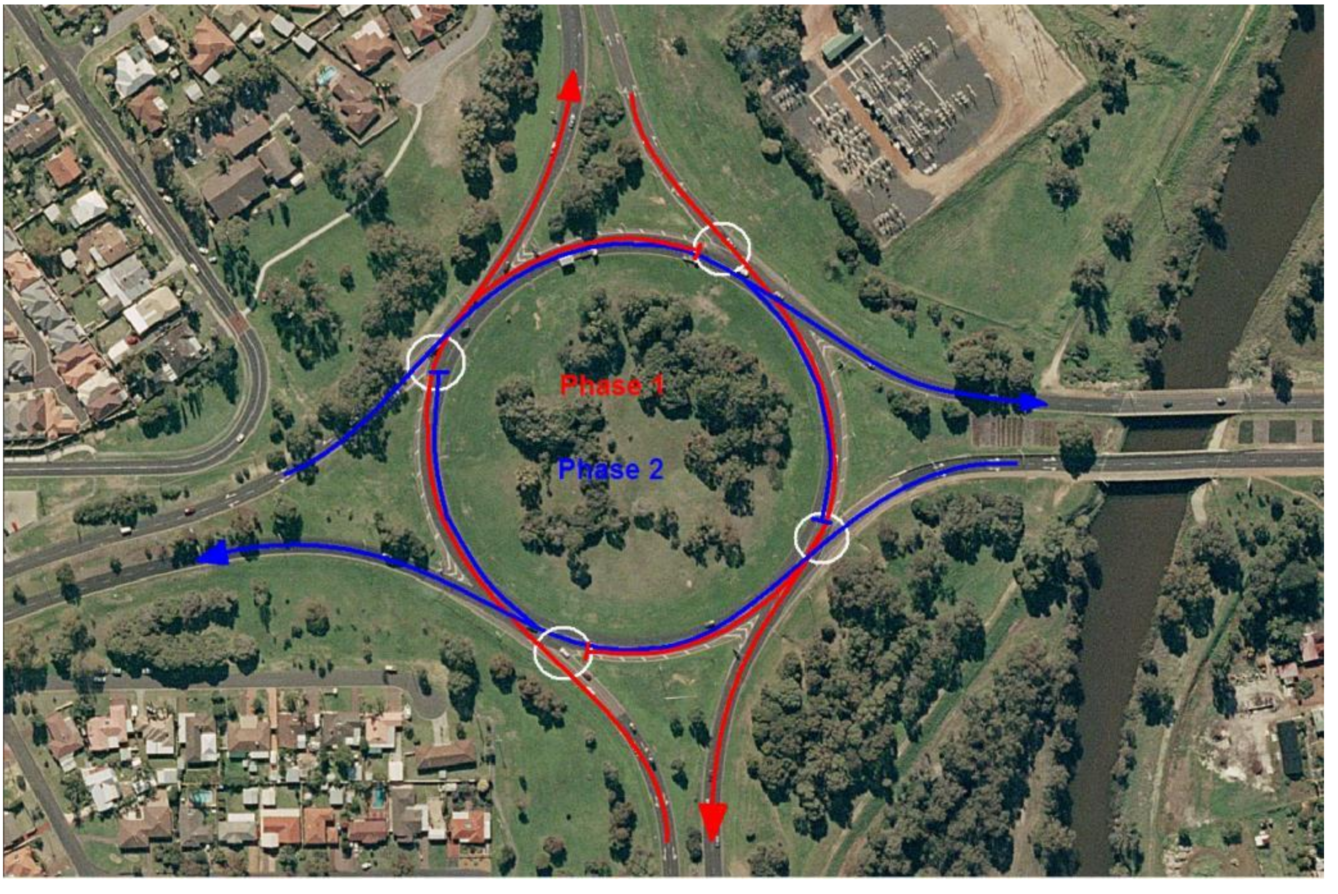


Figure 7-5: Two-phase Operation of Fully Signalised Roundabout

A decision to fully signalise a roundabout should be based on traffic analyses to establish the performance of the signalised roundabout compared to other options, e.g. replacement with a conventional signalised layout. An initial appraisal of the suitability of the roundabout for full signalisation may be based on the following capacity check methodology (Dept. for Transport, April 2009):

Individual signalised nodes on a roundabout will usually operate as simple two-stage signals. Once a draft lane flow diagram has been drawn up, a simple check will show if a node will have sufficient capacity. If the highest individual lane flow from each of the two stop lines (i.e. critical lanes) are added together, then a total less than about 1500 pcu/h would indicate that there is likely to be sufficient capacity. This is based on an assumed cycle time of 60 seconds, 5 second inter-greens, a lane saturation flow of 1900 pcu/h and a degree of saturation of 90 percent.

If the above methodology indicates that full signalisation of the roundabout may be promising, a further detailed analysis may be carried out using SIDRA INTERSECTION, making use of the network analysis methodologies, LINSIG or microsimulation modelling.

Currently in WA there is one fully signalised roundabout: Eelup Rotary in Bunbury. The background and success of this signalised roundabout has been detailed in Appendix C.

Signalisation of roundabouts is used extensively in the United Kingdom to improve capacity, reduce delays, reduce crashes and address pedestrian and cyclist difficulties. Roundabouts may be operated under:

- Full or Partial Signalisation
- Full-time or Part-time Signalling
- Indirect or Direct Signal Control

7.3 Unconventional and Innovative Intersection Designs

Is has been noted previously that the main advantages of a roundabout in meeting the requirements for a Safe System approach are the ability of a roundabout to (a) slow down through traffic, (b) reduce the number of conflict points, and (c) reduce the angle of potential conflict between entering vehicles. This approach was used in WA at the Roe Highway / Berkshire Road interchange shown in Figure 7-6.

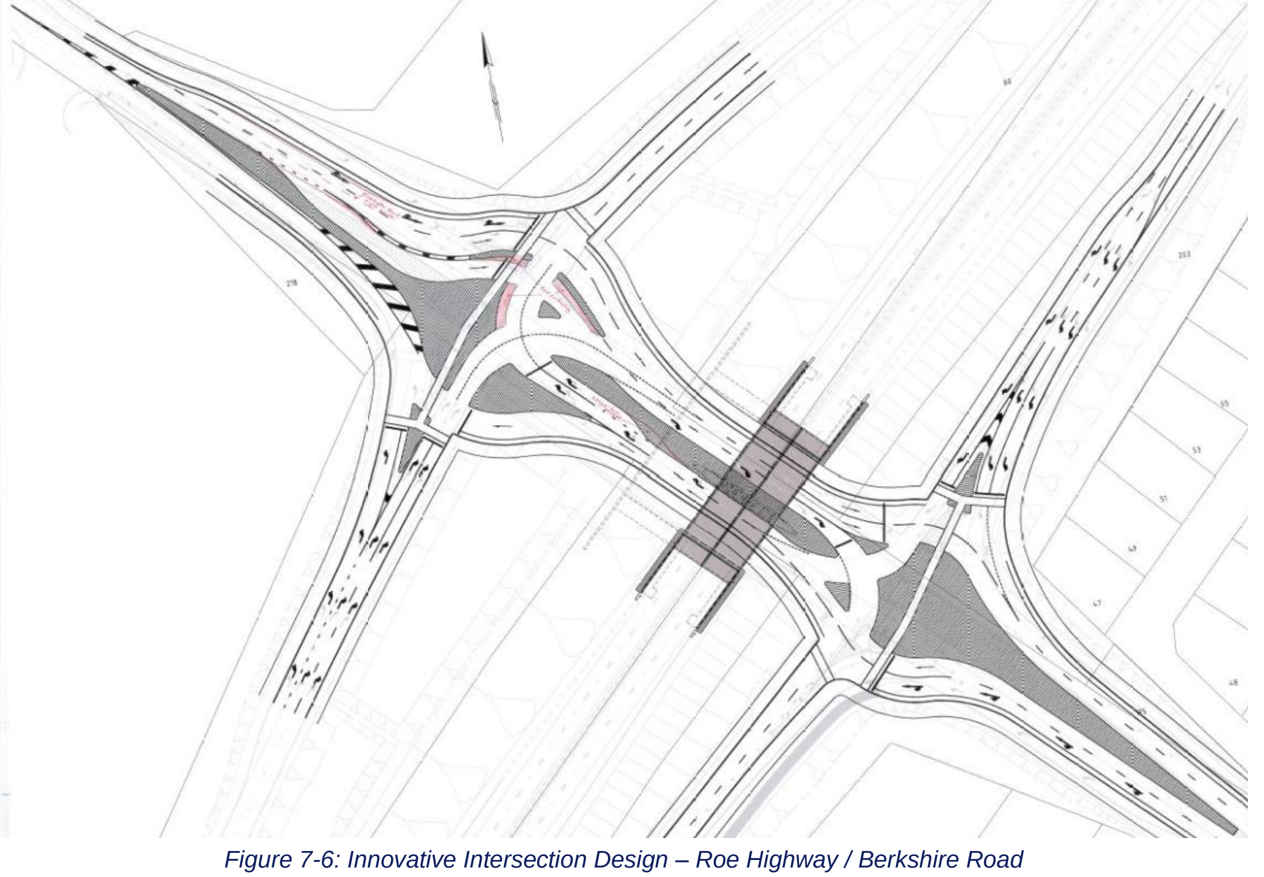


Figure 7-6: Innovative Intersection Design – Roe Highway / Berkshire Road

This design started out as a conventional diamond interchange but it was decided that a "more Safe System compliant solution" should be explored. A dog-bone roundabout wouldn't work from a capacity point of view. It should be noted that the interchange was required to cater for road trains, pedestrians and cyclists. The interchange was built within the existing MRS boundary.

The hybrid layout combines the road safety advantages of a roundabout, i.e. slow through-speeds caused by the deflections along with the operational efficiency of traffic signals. The similarity between the turn paths across the circular central areas and a tennis ball give rise to the interchange name, i.e. "tennis ball' interchange.

Commentary 3, adapted from (Austroads, 2020b) provides further examples of unconventional and / or innovative intersection designs based on Safe System principles, most of which have not yet been implemented in Australia or New Zealand. Main Roads is currently studying the impact that turbo roundabouts are likely to have on driver behaviour, especially entry speeds, through the use of the UWA driving simulator. The research project is expected to be completed in September 2025.

8 PROCESS FOR CHOOSING INTERSECTION CONTROL TYPE

The consideration and balancing of the site specific items shown in Table 5-6, as well as appropriate capacity analyses and economic evaluation, are essential parts of determining an appropriate form of control for an intersection.

The philosophy adopted in these guidelines for choosing between traffic signal control and roundabout control has been to balance all the relevant factors to arrive at the most cost effective solution that meets all (or the most) relevant criteria, with the prime objective being to **maximise safe mobility**.

From **an operational point of view, the proposed intersection must satisfy capacity requirements** (in the target year). Otherwise an alternative intersection form should be investigated, or investigate banning certain turn movements or making some movements free-flow / grade separated.

Ideally the design should satisfy the following Safe System Intersection Design principles:

- Minimise conflict points
- Minimise entry and impact speeds
- Minimise impact angles
- Remove or simplify road user decisions
- Accommodates for human error

An intersection may be considered as "Safe System compliant" under the following circumstances:

- For intersections with significant[5] vulnerable road user activity, a safe crossing facility shall be provided. Where there is a possibility of a right-angle collision between passenger vehicles, the through-traffic speed should ideally be restricted to less than 50 km/h. Where the crossing facility relies on a driver giving way to a pedestrian (e.g. turning traffic at an intersection, zebra or wombat crossing), the speed of the traffic at the potential conflict point should ideally be restricted to –less than 30 km/h.
- For intersections with little or no vulnerable road user activity, the through speed should ideally be restricted to less than 50 km/h, where there is a possibility of a right-angle collision between passenger vehicles.

In the absence of satisfying either of the above two criteria, the design should at least incorporate mitigating countermeasures which have been demonstrated to result in a reduction of FSI crashes to the extent that the design may be considered as a "towards Safe System" solution. For existing intersections, this solution should meet the FSI reduction targets specified by the Main Roads ROSMA process.

The type of intersection control can have a significant impact on the amount of land required as well as access to and from adjacent properties. For these reasons it is important that the intersection control type be determined early on in the planning or design process in order to define or redefine appropriate cadastral boundaries. Under certain constrained conditions, an initial analysis of options may be sufficient to eliminate any intersection control types as "fatal flaws", although as a minimum it will generally be necessary to take the option(s) to a concept design stage. In some cases it will be necessary to take the concept design to a preliminary design standard. Where an intersection design has already been

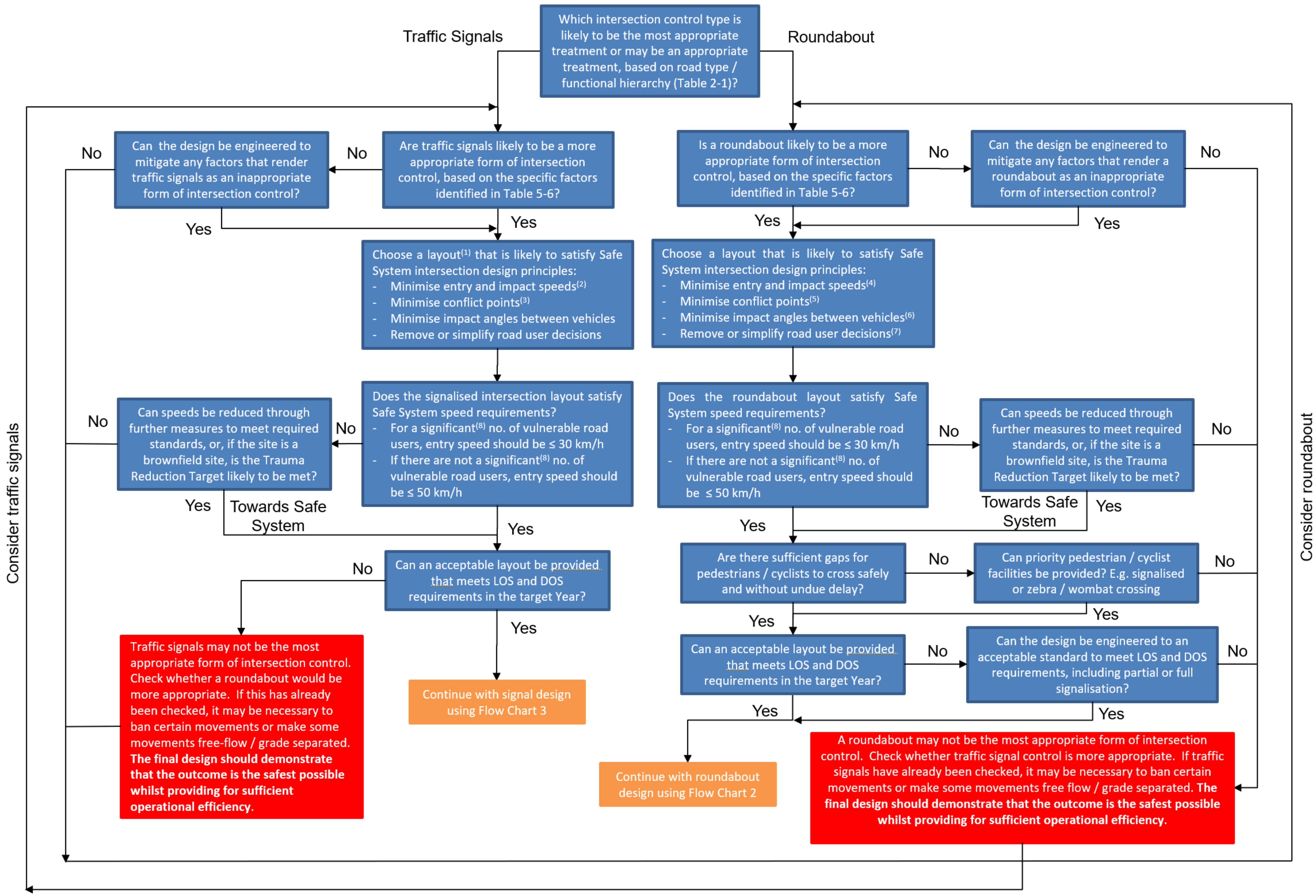
[5] *The term "significant" is defined in terms of the probability of exposure to conflict and the level of "Place" function within the "Movement and Place" framework and is described in the document "Position Paper – Quantifying Pedestrian and Cyclist Activity", April 2021 (D23#786115). Methodologies to determine whether the number of vulnerable road users is "significant' can be found in Appendix E.*

determined by the land use planning process, any proposed intersection design changes should take into consideration the impact upon neighbouring land uses and lot boundaries as well as any road safety implications.

If the proposed intersection configuration meets both operational and Safe System requirements then all that remains is for variations and / or alternatives to be explored in order to maximise safe mobility. The following design process is recommended.

The design commences by considering the suitability of the traffic control type in relation to different road types (Table 2-1). The traffic control type (roundabout or traffic signal) that is "most likely to be an appropriate treatment" should be chosen first. The process then considers whether the chosen intersection control type is appropriate in the context of the site specific factors summarised in Table 5-6 followed by testing to see whether the proposed intersection design meets Safe System and capacity requirements. At all stages the designer is given the option to make changes if the proposed design does not satisfy the criteria under consideration. The design process commences with Flow Chart 1 and depending on the outcome continues with either of Flow Chart 2 (roundabout control option) and / or Flow Chart 3 (traffic signal control option). Once this process is completed, the designer should document the results summarising the appropriate information for the project approval decision.

In using Flow Chart 1, there may be some instances where neither a roundabout nor traffic signals are considered appropriate treatments, despite restricting certain movements and grade separation is not feasible. In these circumstances, the design should demonstrate that the outcome is the safest possible whilst providing for sufficient operational capacity. If the project is a Main Roads project, the ROSMA process should demonstrate that the proposed design maximise the expected FSI reduction, if the FSI target reduction will not be met.



Notes:-

1. For at-grade intersections layout may be a simple signalised intersection or a continuous flow intersection. For an interchange, layout may be a conventional diamond, diverging diamond, SPUI or tennis ball.
2. If posted speed limit is ≤ 50km/h, entry speeds are likely to be low. If posted speed limit is > 50km/h, consider horizontal pre-deflection or vertical deflection (safety platforms) where suitable for vehicle types and loads.
3. A SPUI and diverging diamond have fewer conflict points than a conventional diamond interchange. If conflicts cannot be separated in space, consider phase sequences that separate conflicting movements in time, e.g. use of exclusive right turns rather than filter right turns.
4. Common practice is to use pre-deflection to limit entry speeds. This should be used with caution where the roundabout caters for multi-combinational vehicles because of stability issues. Large diameter roundabouts have higher circulating speeds.
5. Left-turn slip lanes may be used to increase capacity and reduce conflicts with other movements.
6. Use of larger diameter roundabouts can reduce impact angles. This is a trade-off with higher circulating speeds.
7. Fully signalised roundabouts remove the "gap acceptance" decision for drivers.
8. Refer to Appendix E of the Guidelines for a definition of "significant".

Figure 8-1: Flow Chart 1 – Process for Choosing between Roundabout and Traffic Signal Control

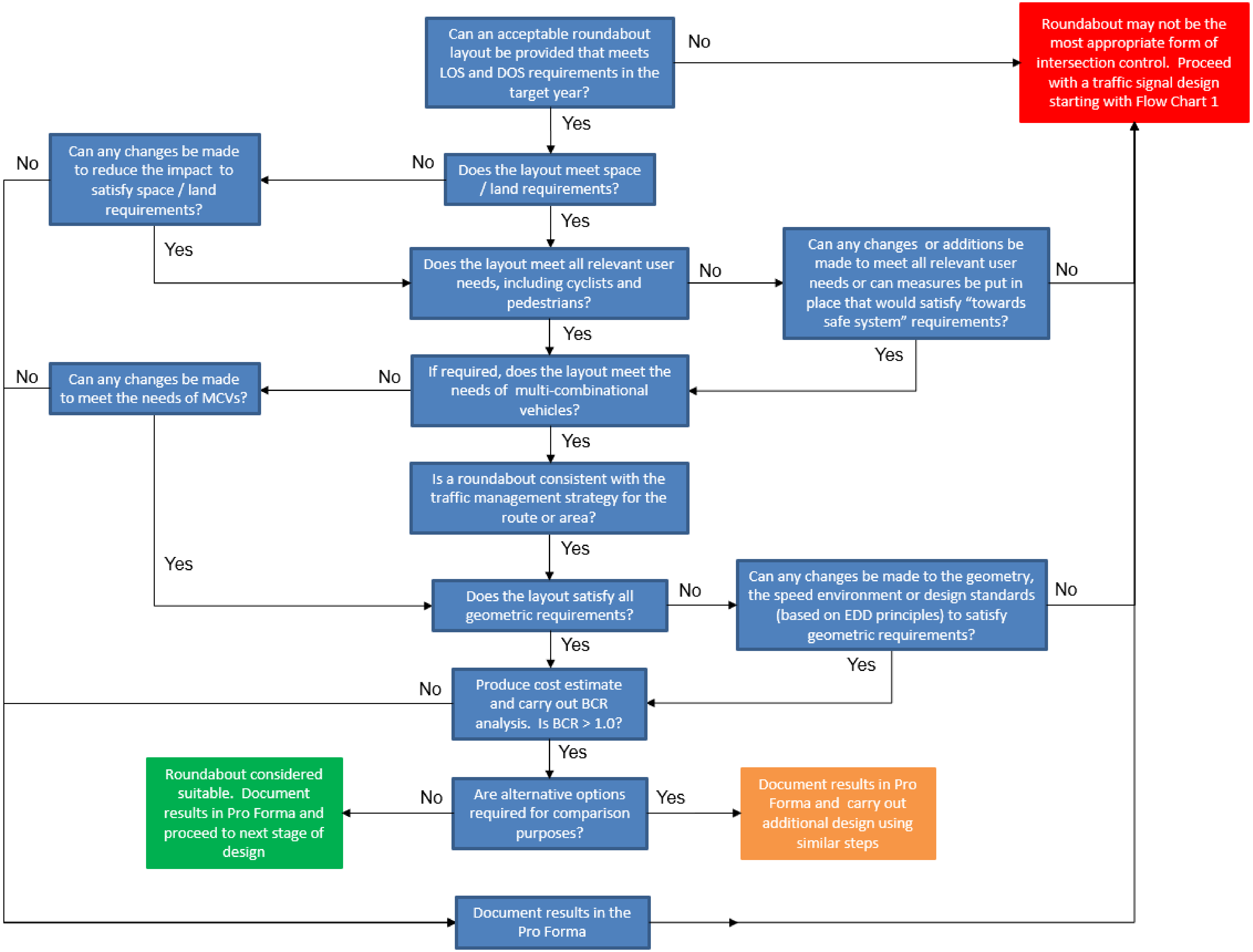


Figure 8-2: Flow Chart 2 – Roundabout Control Design Process

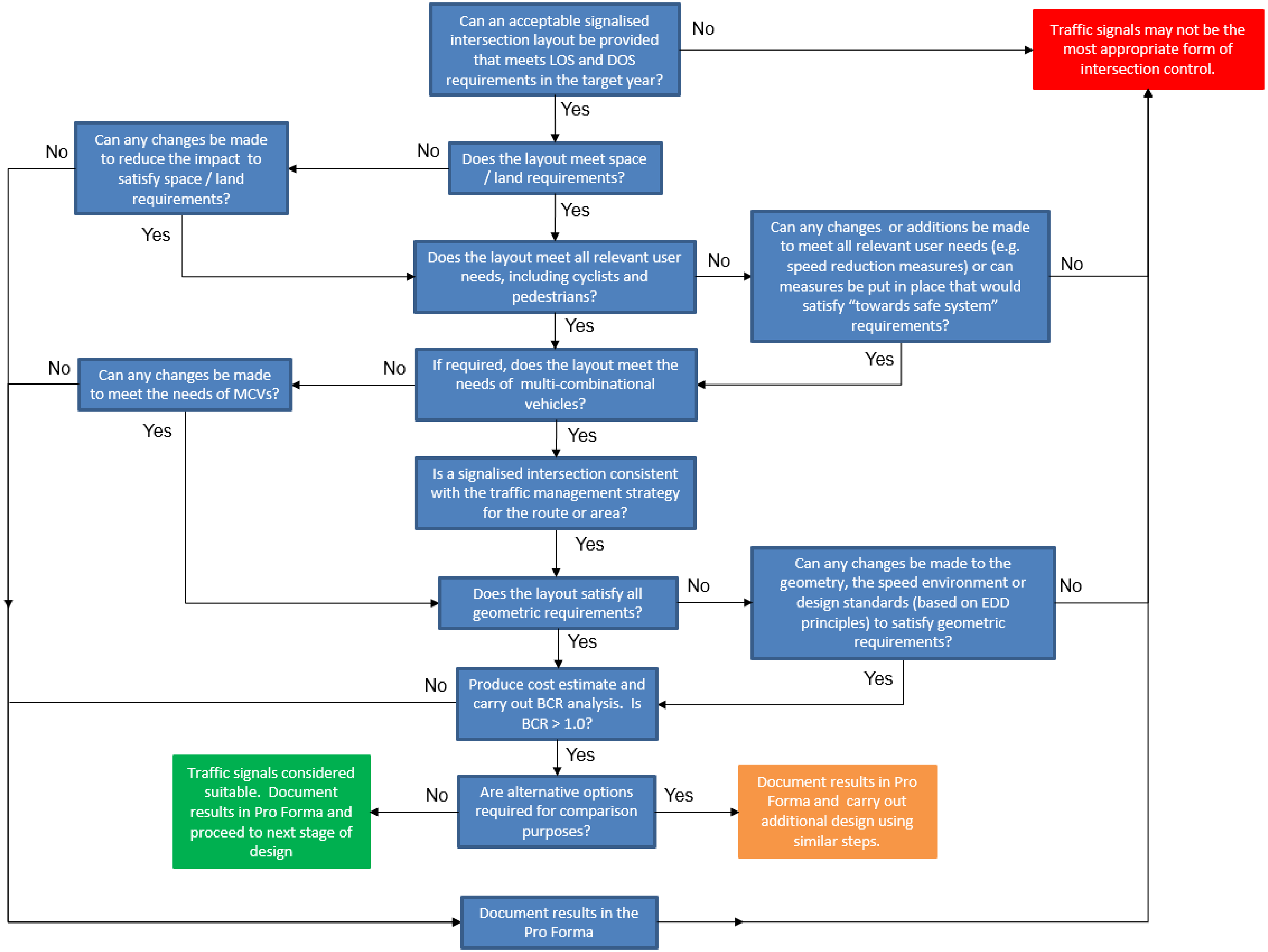


Figure 8-3: Flow Chart 3 –Traffic Signal Control Design Process

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10 COMMENTARIES

Commentary	Title
Commentary 1	Spiral Line Marking
Commentary 2	Conventional Interchange Types – Advantages and Disadvantages
Commentary 3	Unconventional and Innovative Intersection Designs
Commentary 4	Speed Reduction Treatments at Intersections

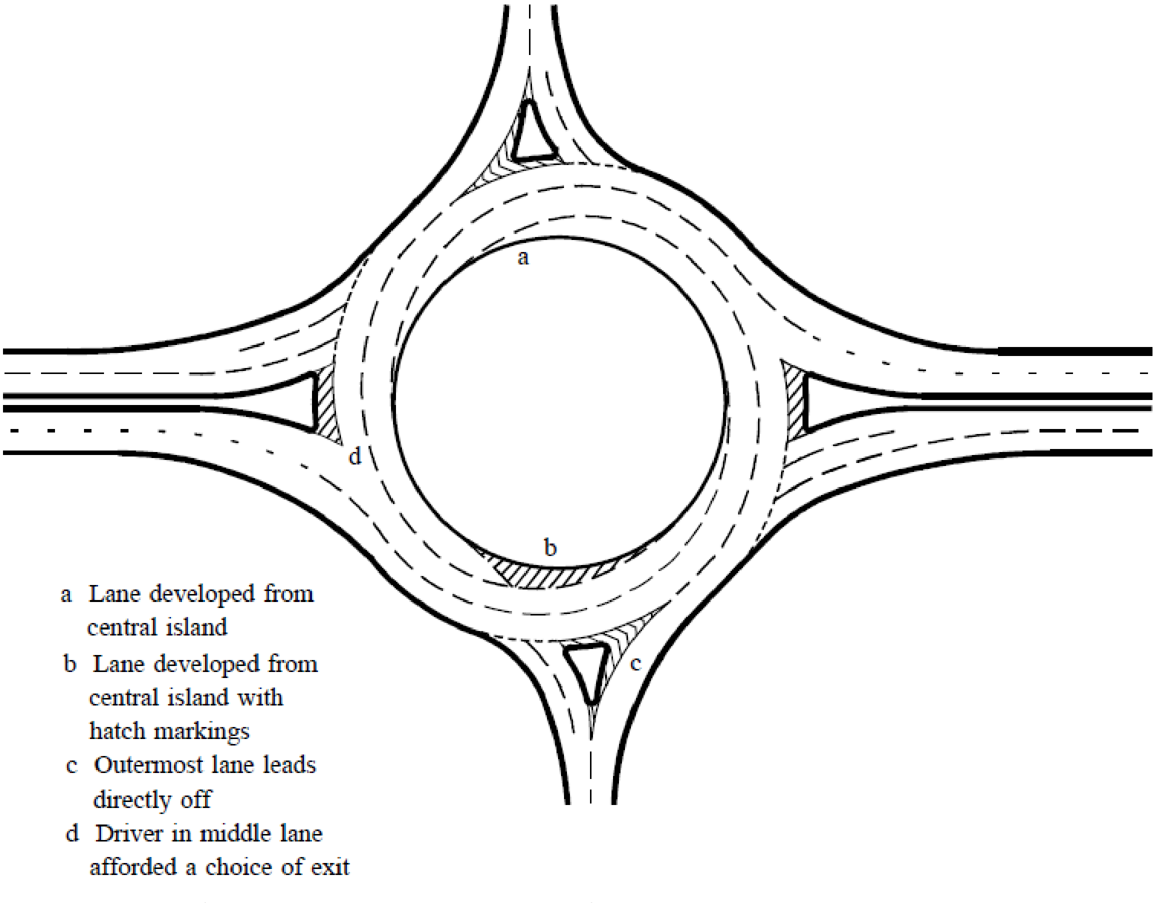
Commentary 1: Spiral Line Marking

A spiral marking system involves one or more of a series of lane gains and lane drops around the circulatory carriageway so that drivers enter in the lane appropriate for their desired exit, and follow the lane around the roundabout to be led off at that exit (Fig C1.1). The width of a particular exit will determine how many circulating lanes lead off the roundabout.

Spiral line making should only be considered as a solution to minimising operational problems on existing roundabouts where no other solution is feasible. Careful consideration needs to be given to the use/provision of spiral markings and, in all cases, advice should be sought from the Traffic Engineering Standards Manager or Traffic Manager Design in the Road & Traffic Engineering Branch prior to their installation.

The spiral markings may be developed from the central island by means of line markings, or by hatch markings until a full lane width is available. Line markings are appropriate on normal roundabouts, but where the inscribed circle and central island are small and/or the number of arms is high, the first two or three markings leading to the full lane width may be omitted. Hatch markings are appropriate on larger diameter normal roundabouts or grade separated roundabouts where the number of circulating lanes is to be varied to aid general operation.

Spiral markings may be appropriate on large roundabouts where they can be used to guide drivers around the roundabout to their desired exit, whilst maximising the use of the circulating space and reducing potential conflict between adjacent vehicles. The markings can also cater for heavily biased turning proportions, since the circulatory width may be divided according to traffic demand.



Source: Design Manual for Roads and Bridges TA78/97, Design of Road Markings at Roundabouts, Highways Agency, November 1997

Figure C1.1 Spiral Markings

Single lane exits adjacent to two circulating lanes

For multi-lane roundabouts, the standard exit line marking treatment alone does not appropriately allow for single lane exits adjacent to two circulating lanes in all cases. This typically occurs in the following instances:

- two-lane capacity is required from an entry leg to exits beyond the second exit leg;
- two-lane capacity is required for a right-turn; and
- two lane capacity is required for a through movement from an entry leg and a left-turn leg is present at a substantial distance from the entry leg

As a consequence of providing two-lane capacity from Leg 1 to Leg 4 of Example A in Figure C1.2, there is a requirement to drop a lane at the exit preceding Leg 4 (i.e. Leg 3 must be a single lane exit as shown). This helps mitigate exiting/circulating accidents at Leg 3 for traffic coming solely from Leg 1. However a problem still exists, as motorists entering from Leg 4 or Leg 5 and exiting at Leg 3 are required to cross the exit line marking as illustrated by Example B in Figure C1.2. A similar problem will occur for Examples C and D in Figure C1.2.

As a consequence of providing two lane capacity from Leg 1 to Leg 4 (of Example A in Figure C1.2), there is a requirement to provide motorists entering from Leg 4 or Leg 5 and destined for Leg 3 with an opportunity to get to the outer lane (and avoid a lane change at the exit). This can be achieved by using spiral continuity line marking as shown in Examples A and B of Figure C1.3. Examples C and D of Figure C1.3 illustrate this same concept for a four legged and a three legged, multi-lane roundabout respectively.

For Examples C and D of Figure C1.3, there are also spirals adjacent Legs 4 and 3 respectively. For these examples, the spiral line marking also provides the driver already circulating on the roundabout with an opportunity to exit in either the left or right hand lane of Leg 1. This is especially important were there are downstream accesses on Leg 1. The ability to exit in either lane will minimise lane changes for drivers turning into downstream accesses.

Spiral line-marking, however does not completely resolve driver confusion with regard to negotiating these roundabouts. For some paths through the roundabout, drivers will need to cross the continuity line, for other paths they will need to follow it. Examples of this are described below:

- Examples A and B of Figure C1.3
    - When travelling from Leg 1 to Leg 4 in the inner lane, a motorist is to cross the continuity line;
    - When travelling from Leg 5 to Leg 3 or from Leg 4 to Leg 3, a motorist must follow the continuity line;
    - When travelling from Leg 5 to Leg 5 (i.e. a U-turn from Leg 5), a motorist is to cross the continuity line; and
    - When travelling from Leg 5 to Leg 4 or from Leg 4 to Leg 4 (i.e. a U-turn from Leg 4), a motorist can either cross or follow the continuity line.

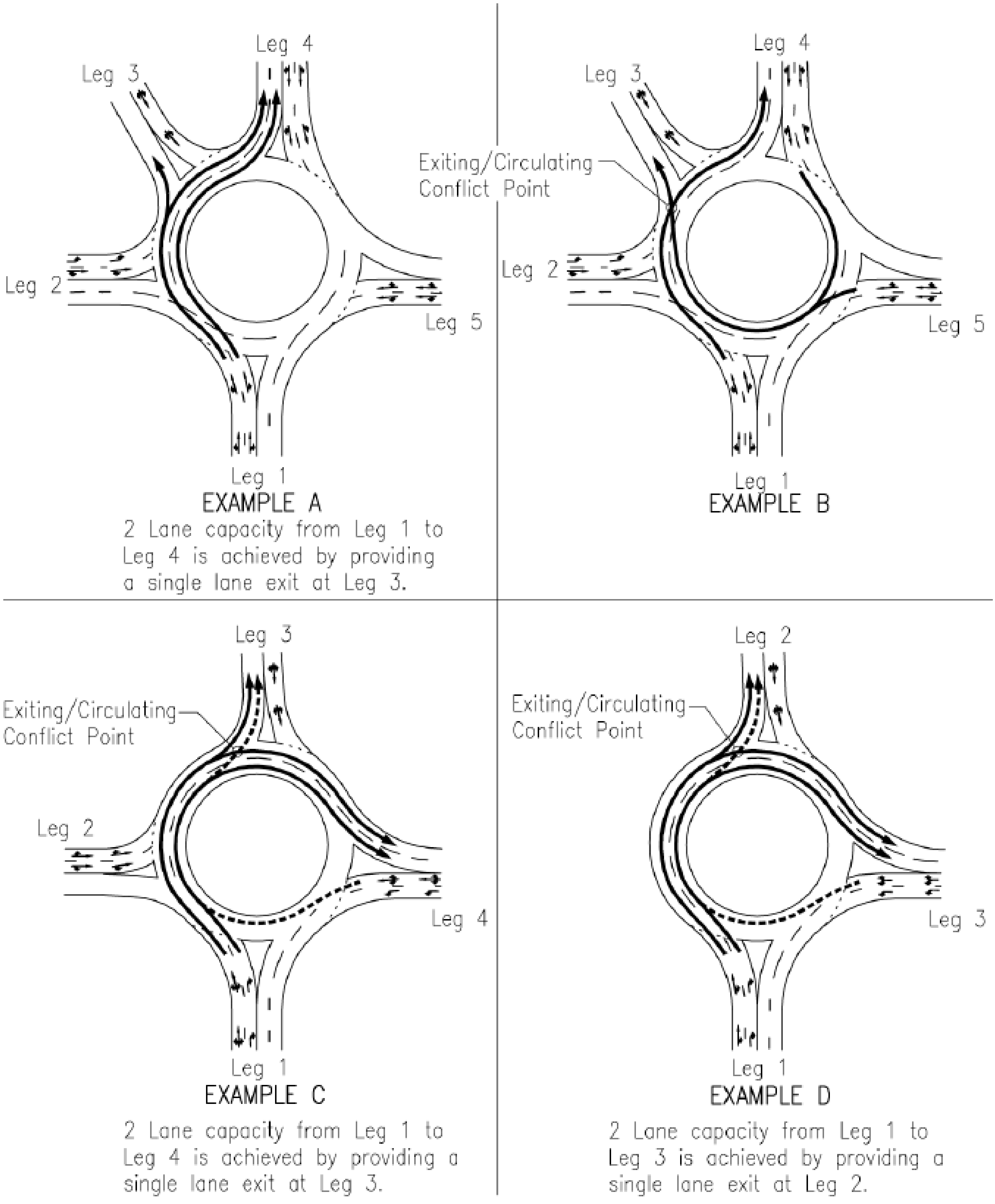
- Example C of Figure C1.3
    - When travelling from Leg 1 to Leg 4 on the inner lane, a motorist is to cross the continuity line;
    - When travelling from Leg 4 to Leg 3, a motorist is to follow the continuity line;
    - When travelling from Leg 3 to Leg 3 (i.e. a U-turn from Leg 3), a motorist is to cross the first continuity line, then follow the second continuity line; and

    - When travelling from Leg 4 to Leg 4 (i.e. a U-turn form Leg 4), a motorist can either follow or cross the continuity line.

- Example D of Figure C1.3
    - When travelling from Leg 1 to Leg 3 on the inner lane, a motorist is to cross the continuity line;
    - When travelling from Leg 2 to Leg 2 (i.e. a U-turn from Leg 2), a motorist is to cross the first continuity line, then follow the second continuity line;
    - When travelling from Leg 3 to Leg 2, a motorist is to follow the continuity, and
    - When travelling from Leg 3 to Leg 3 (i.e. a U-turn from Leg 3), a motorist can either follow or cross the continuity line.

It is very difficult to advise drivers of the above requirements for all movements through these roundabouts, particularly with regard to when/how a driver is required to follow the spiral line markings (i.e. change from the inner circulating lane to the outer circulating lane for the movements above). Advance intersection direction signs do not show the required action in this case. For this reason, drivers faced with the spiral line marking may be confused as to whether to cross the spiral line marking or not.

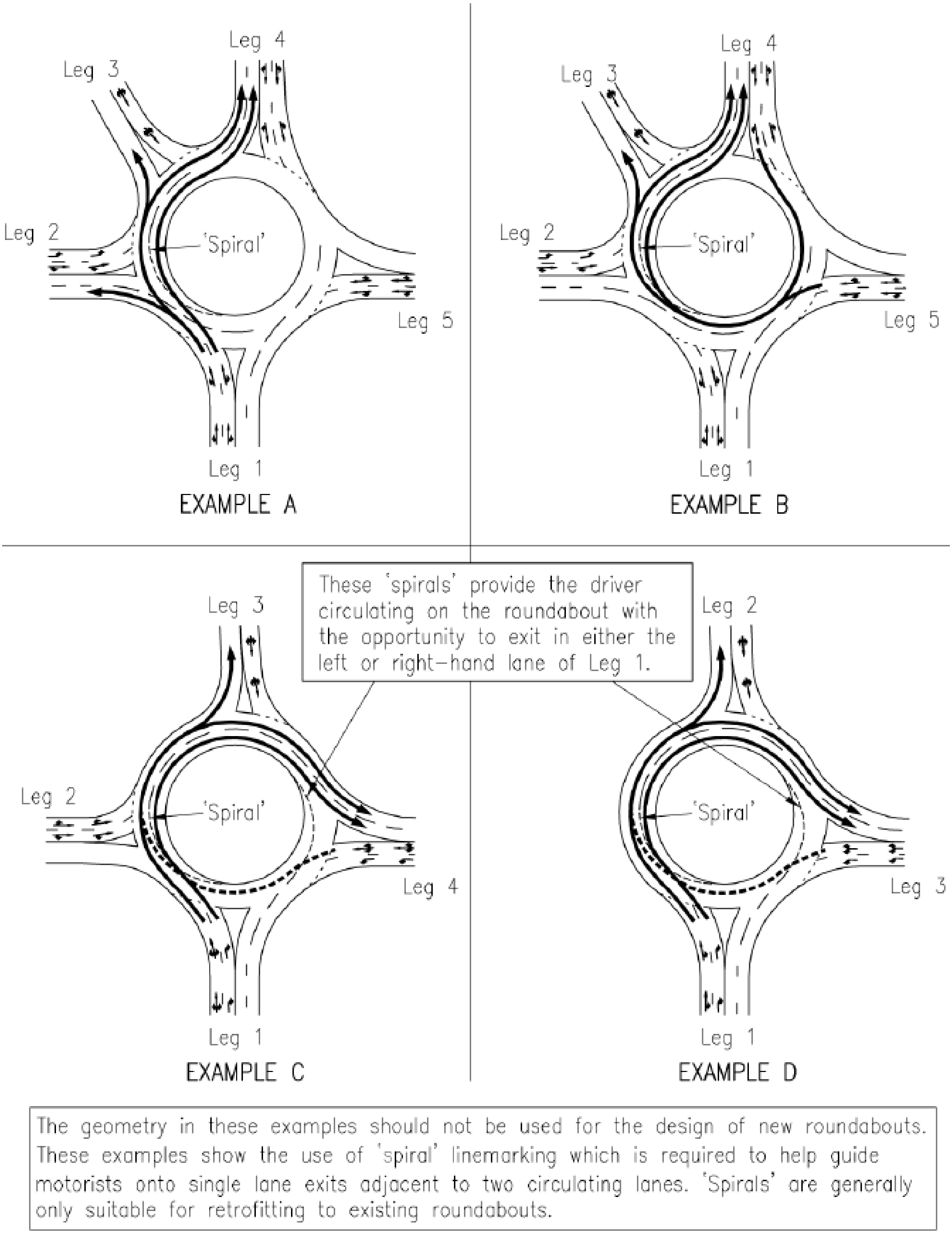
For the above reasons, two-lane capacity from an entry leg to an exit beyond the second exit leg is undesirable and should only be considered for existing roundabouts where there is a capacity problem.



The geometry in these examples should not be used for the design of new roundabouts. If the examples shown in this figure were existing roundabouts, they would require 'spiral' line marking. Without the use of 'spiral' line marking, exiting/circulating conflicts are compounded at single lane exits adjacent to two circulating lanes.

Source: Road Planning and Design Manual , Queensland Department of Main Roads, January 2006

Figure C1.2 Examples showing potential conflicts arising without the spiral line marking system



Source: Road Planning and Design Manual , Queensland Department of Main Roads, January 2006

Figure C1.3 Examples showing the use of the spiral line marking system for the examples shown in Figure C1.2

Figure C1.4 Example of Spiral Markings on a Signalised Roundabout in Bunbury

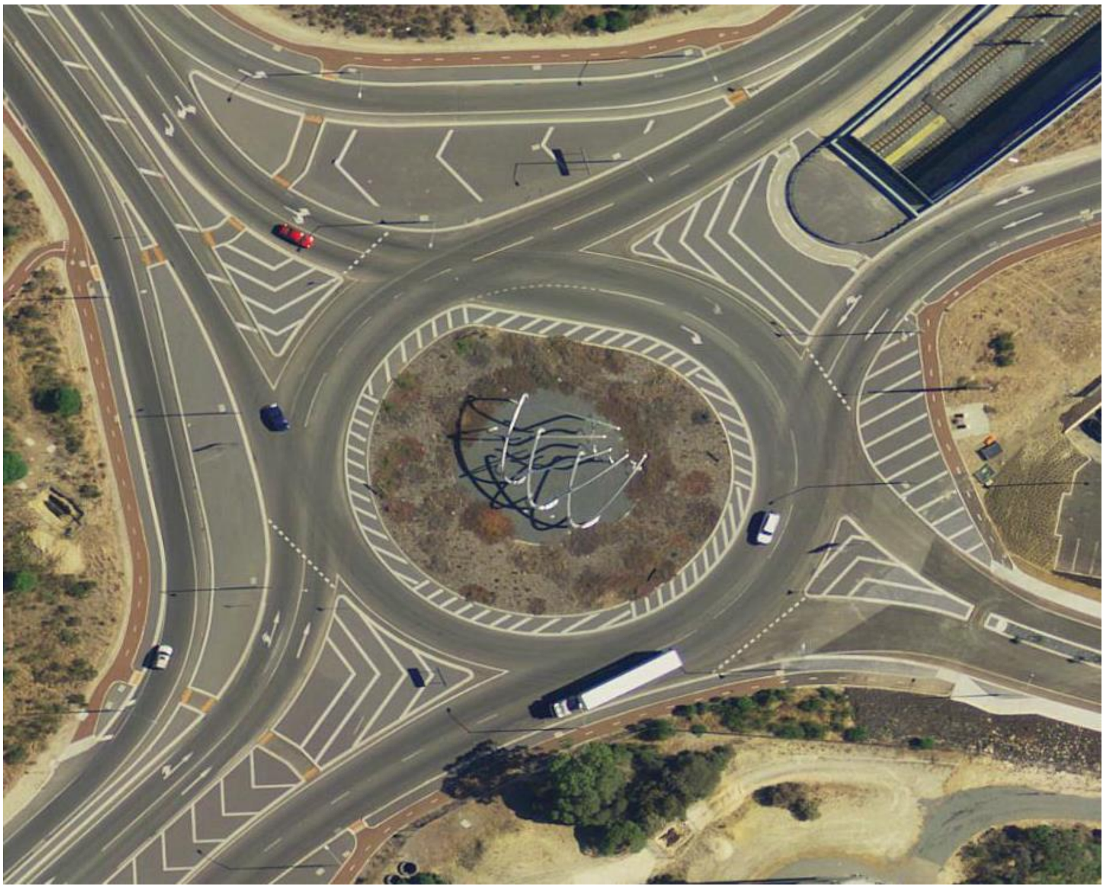
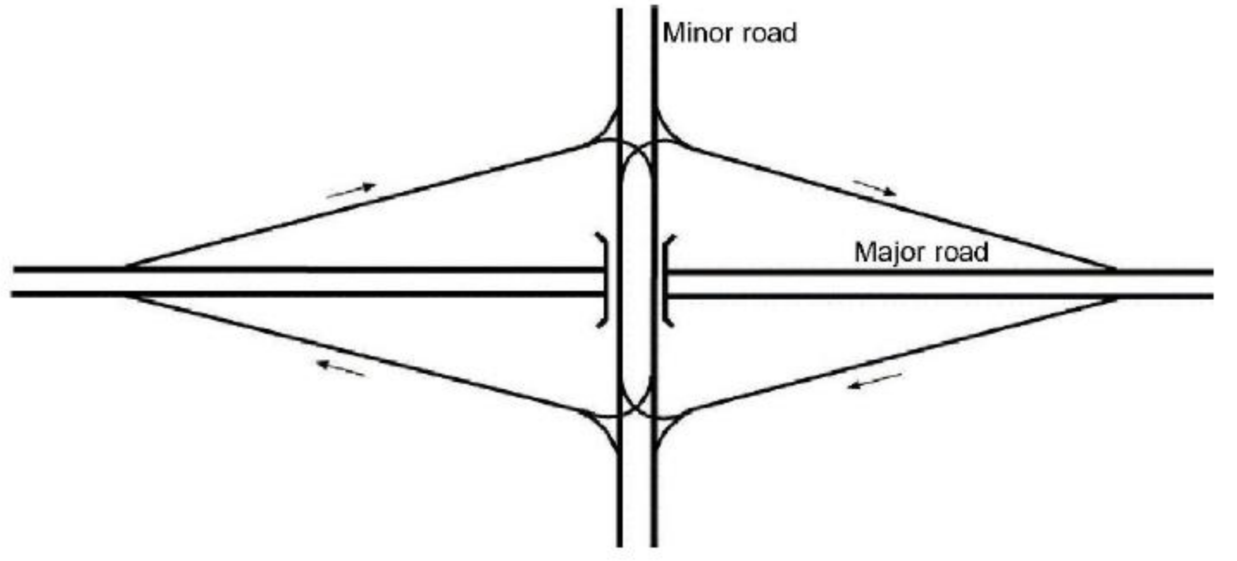


Figure C1.5 Example of Spiral Markings on a Roundabout in Mandurah to Facilitate Double Right Turns

Commentary 2: Conventional Interchange Types – Advantages and Disadvantages

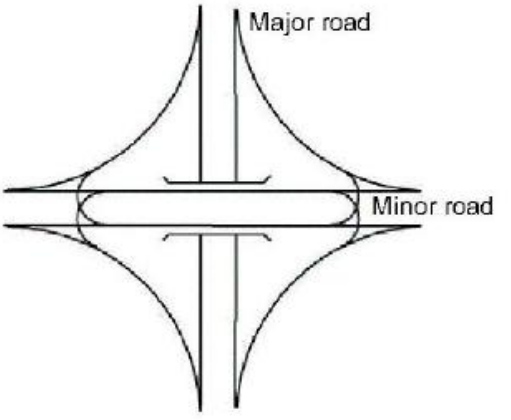
Figure C2.1 illustrates the conventional diamond interchange that is the most common form of service interchange. The advantages and disadvantages of the conventional diamond also apply to the variations of the diamond interchange shown in Figures C2.2 to C2.6. The advantages and disadvantages associated with Figures C2.2 to C2.6 are peculiar to that form of diamond interchange.



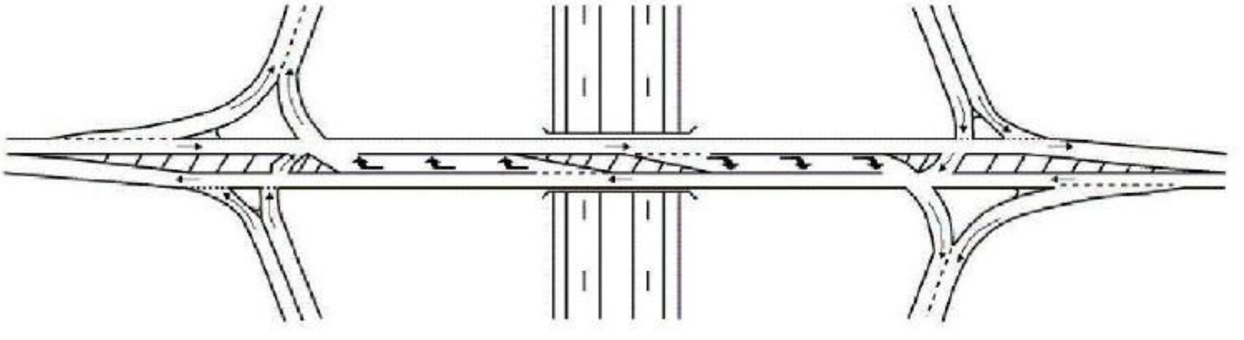
General Comment	Advantages	Disadvantages
• The conventional diamond is the most common form of service interchange and its layout is well-understood by drivers. • Variations are spread diamond (Figure C2.2), with ramps a significant distance apart, and closed diamond (Figure C2.3), with ramp terminals relatively close to the major road alignment.	• Provides high-standard single exits and entrances in advance of and beyond the structure respectively. • Where the major road passes under the minor road, the grades of the ramps assist the deceleration of existing traffic and the acceleration of entering traffic. • Single exit features simplifies major road signing. • There is no need for speed change lanes on or under the structure resulting in reduced cost. • Does not result in weaving on major road. • Ramps can allow for over-height loads that are unable to pass beneath an overpass of the major road. • Design is economical in property use and construction costs.	• Results in conflicting movements on the minor road, which limit capacity and safety. • Right-turns from the minor road may overlap leading to inefficiencies in traffic signal phasing. • Where the minor road crosses over the major road, provision of adequate visibility at the ramp / minor road intersections may be difficult. • There is a possibility of wrong-way movements. • Right-turning traffic from the major road is obliged to stop or give way at the minor road. Additional lanes may be required for storage. If there is no left-turn acceleration lane, left-turning traffic is also obliged to give way. • There is little possibility of allowing for future expansion of the interchange.

SOURCE: (Austroads, 2020b)

Figure C2.1: Conventional Diamond Interchange



(a) Spread diamond

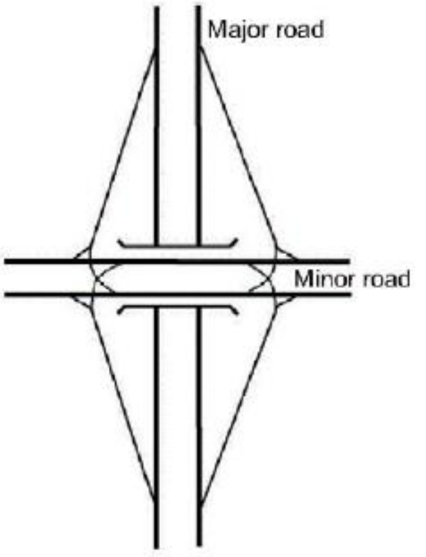


Detail for (a)

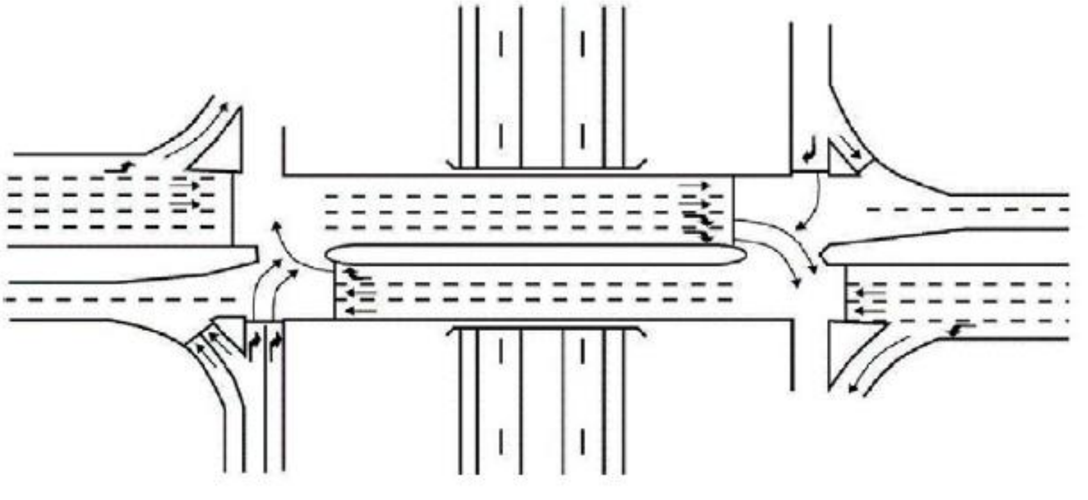
General Comment	Advantages	Disadvantages
• The spread diamond is the most common type in rural Australia. • Typically, ramp terminals are approximately 500 m apart along the minor road, terminals being 250 m either side of the major road centreline to meet safe intersection sight distance (SISD) requirements.	• Where the intersecting road passes over the major road, only one bridge is usually required. • Compared with the closed diamond (Figure C2.3): – Has smaller embankments and lower earthwork's costs. – The right-turn lanes are on an embankment rather than on the bridge, reducing costs. • Unlikely to require additional measures to address sight distance issues, compared to closed diamond interchanges.	• Requires more land than conventional or closed diamond layouts so not as applicable in urban areas as in rural areas.

SOURCE: (Austroads, 2020b)

Figure C2.2: Spread Diamond Interchange



(b) Closed diamond

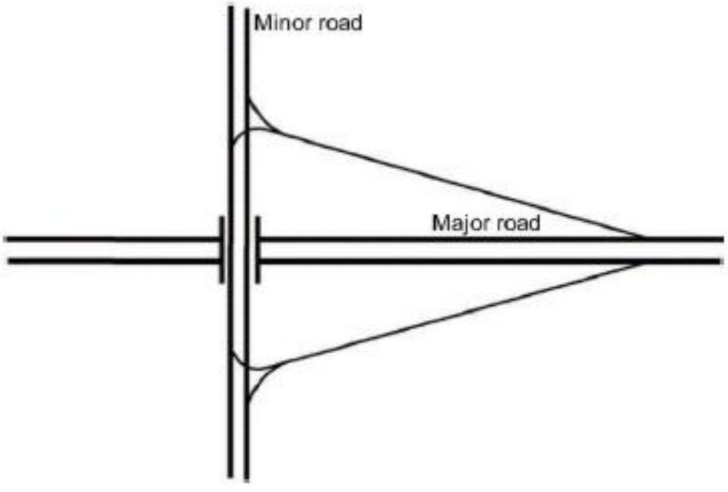


Detail for (b)

General Comment	Advantages	Disadvantages
• The closed diamond has ramp terminals relatively close to the major road alignment. • Common in urban areas because of high land costs and use of sophisticated traffic signal coordination systems.	• Has a smaller land requirement than conventional or spread diamond layouts.	• Effectiveness may be limited by the capacity of the at-grade terminals. • For a minor road over a major road, a closed diamond may need a very wide structure to accommodate back-to-back right-turn lanes (perhaps double turns) and to meet sight distance requirements at ramp terminals. • Measures may be required to ensure that bridge barriers do not impede sight distance on the minor road. • Limited storage between intersections may compromise signal phasing and intersection capacity.

SOURCE: (Austroads, 2020b)

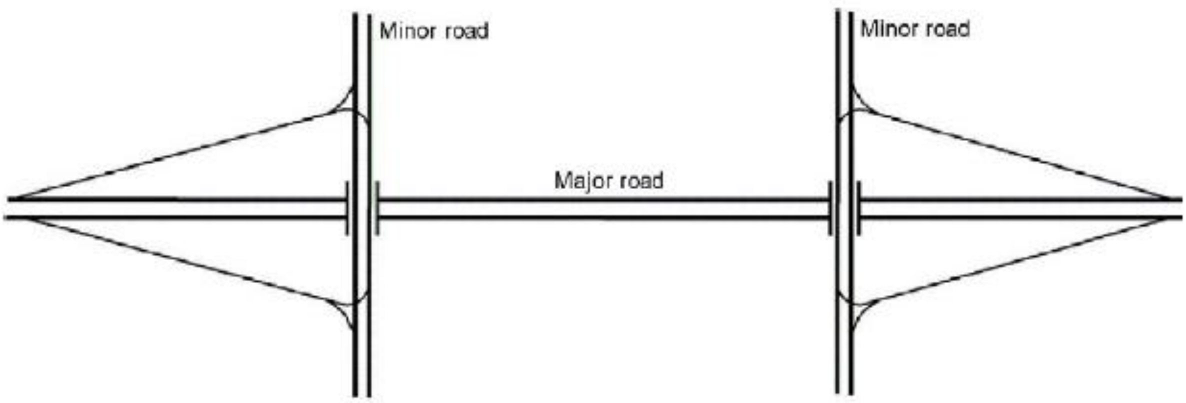
Figure C2.3: Closed Diamond Interchange



General Comment	Advantages	Disadvantages
• The half diamond provides entry to and exit from the major road on only one side of the intersecting road.	• Often used in urban areas where they can be appropriate because of the close spacing of intersecting roads along a freeway. • May also be appropriate because of network requirements and topography. • Simpler intersections because of limited number of movements.	• Not favoured in rural areas because interchanges usually are more widely spaced, and drivers unfamiliar with the area may be disconcerted to find that they cannot re-join the major road at the same interchange at which they left it. • In the case of closed half diamond interchanges, measures may be required to ensure that bridge barriers do not impede sight distance on the minor road.

SOURCE: (Austroads, 2020b)

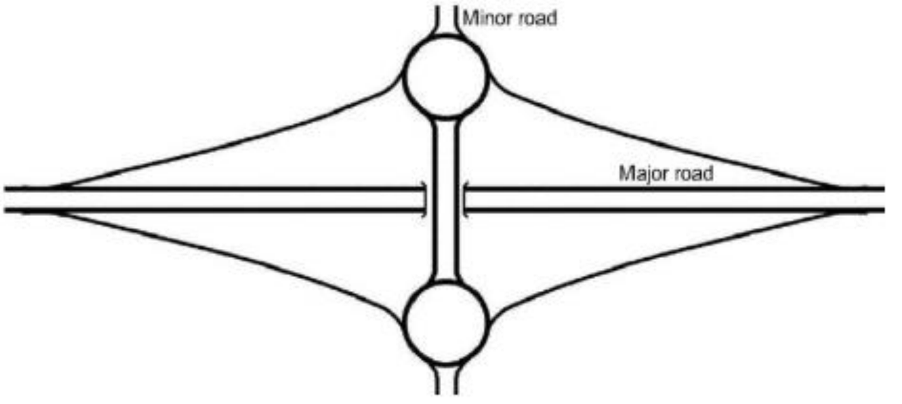
Figure C2.4: Half Diamond Interchange



General Comment	Advantages	Disadvantages
• The split diamond is essentially two half diamonds a short distance apart, each providing entry to (and exit from) the major road in the opposite direction from the other.	• Provides the same advantages as the half diamond but permits access to and from the major road in both directions. • Provides the opportunity to connect the two interchanges via one-way frontage roads.	• Can create navigational problems similar to those for half diamond, as return routes and signage are more complicated, particularly where frontage roads cannot be provided to directly connect the two half diamonds making up the split interchange. • In the case of closed split diamond interchanges, measures may be required to ensure that bridge barriers do not impede sight distance on the minor road.

SOURCE: (Austroads, 2020b)

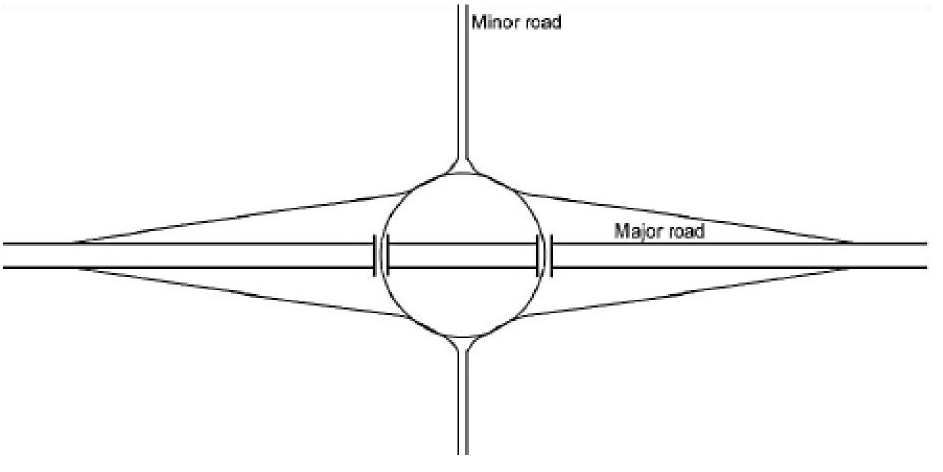
Figure C2.5: Split Diamond Interchange



General Comment	Advantages	Disadvantages
• The intersections of the diamond ramps with the minor road are designed as roundabouts	• With certain mixes of traffic volumes on its various elements, this form of interchange can provide fewer delays and a higher level of safety than alternatives. • Requires a relatively narrow structure since turn pockets are not usually required.	• Requires the availability of sufficient space for its implementation.

SOURCE: (Austroads, 2020b)

Figure C2.6: Diamond Interchange with Roundabout Terminals ("Dog Bone" Type)



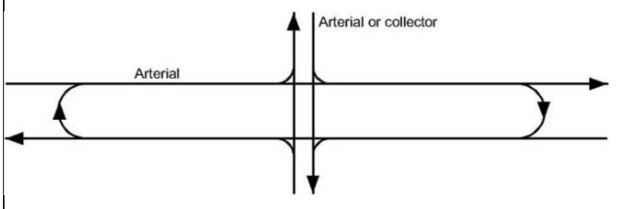
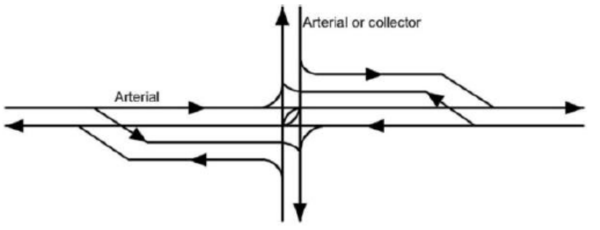
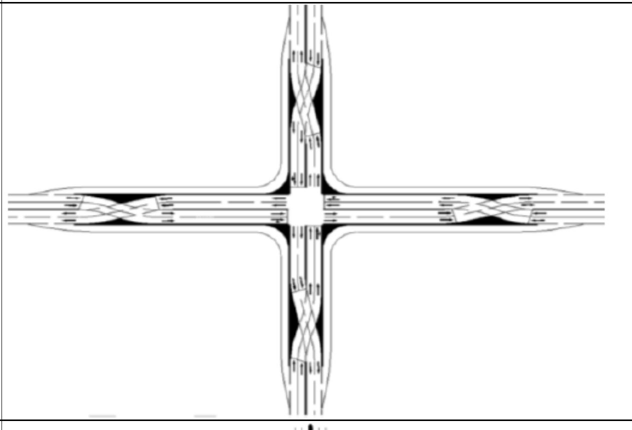
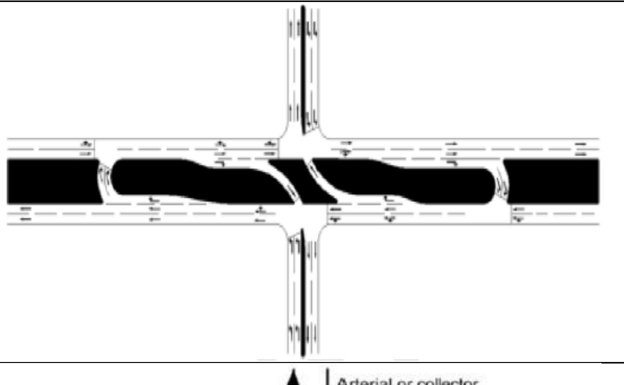
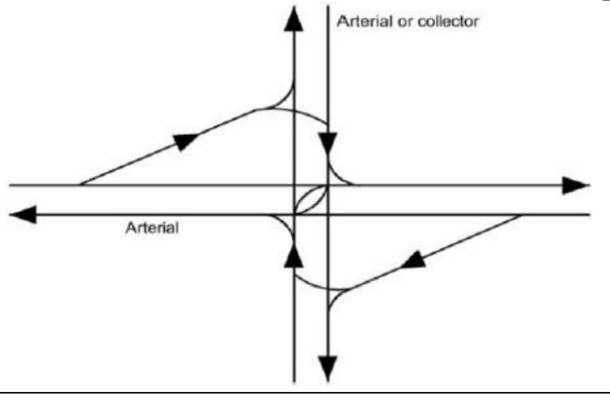
General Comment	Advantages	Disadvantages
• The grade separated roundabout is an alternative to the diamond interchange and is suitable for both urban and rural situations involving moderate requirements for capacity. • The numbers of lanes at entries and exits are comparable to those in a diamond interchange with roundabout terminals. • Oval shaped roundabout enables entries and exits to be positioned at 90° to one another.	• Provides high standard single exits and entrances in advance of and beyond the structure respectively. • Where the major road passes under the minor road, the grades of the ramps assist the deceleration of existing traffic and the acceleration of entering traffic. • Single exit feature simplifies major road signing. • Reduces possibility of wrong-way movements. • Has lower average delay than for signalised diamond for low to moderately high traffic volumes.	• Is higher cost than conventional diamond – two overpasses or underpasses are required. • Large land requirements. • Parapets could interrupt the sight lines of drivers. • May need to widen the bridges to meet sight distance requirements at the exit ramp terminals. • Capacity of the interchange as a whole is limited by the capacity of the roundabout.

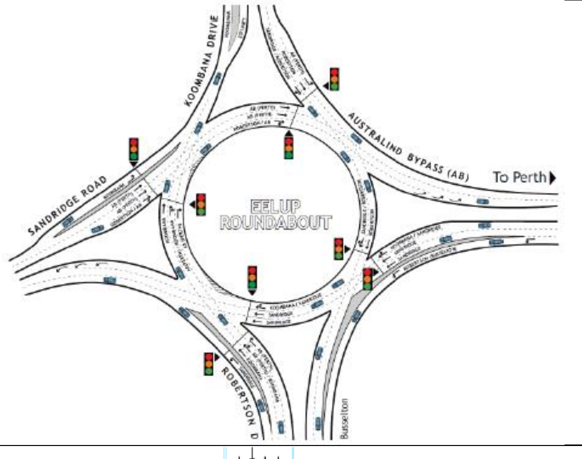
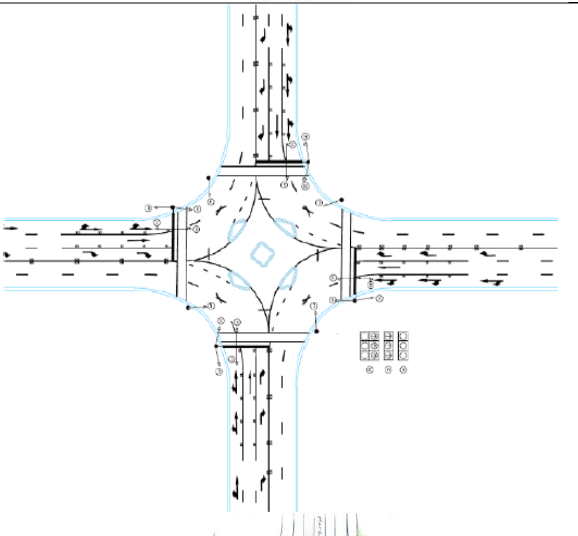
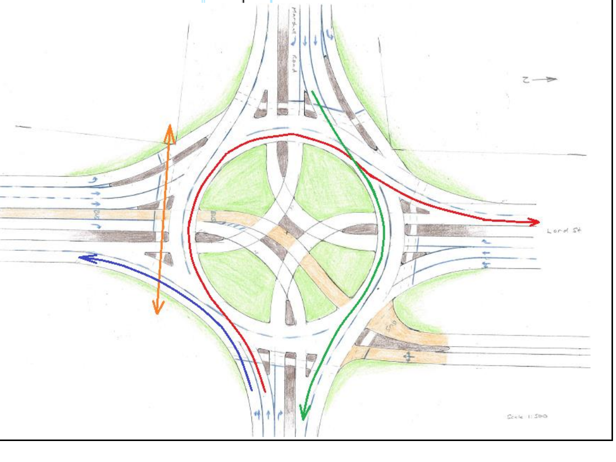
SOURCE: (Austroads, 2020b)

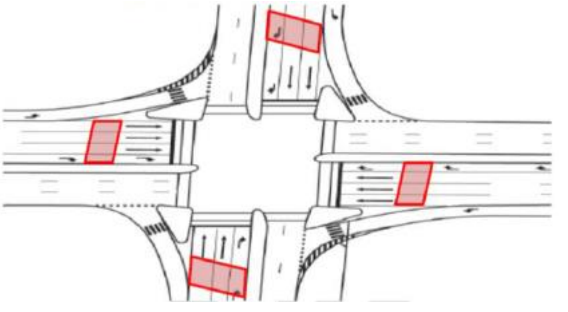
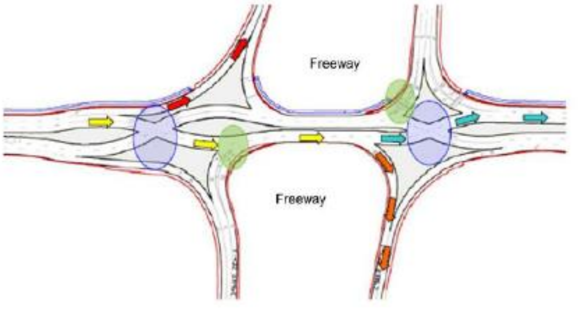
Figure C2.7: Grade Separated Roundabout

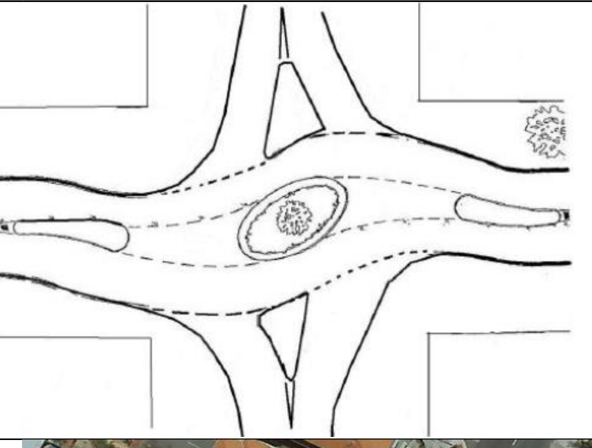
Commentary 3: Unconventional and Innovative Intersection Designs

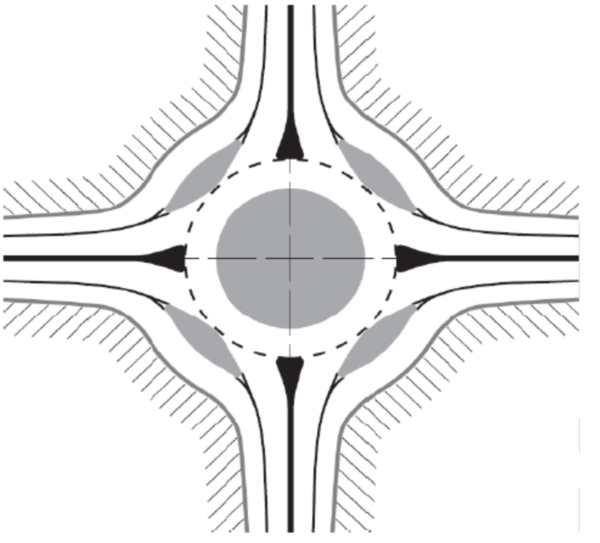
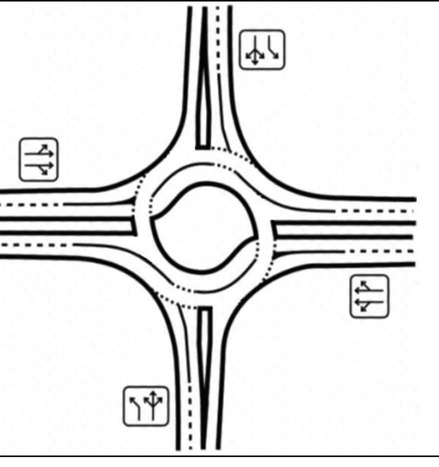
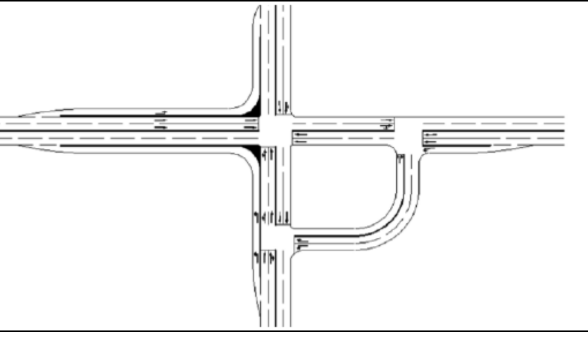
Types of unconventional and innovative intersection designs which seek to either reduce the number of conflict points, reduce through speeds or reduce the angle of conflict are given in Table C3.1 below. These are adapted from (Austroads, 2020b).

Intersection Type	Comments	Figure
Median U-turn intersection	Eliminates right-turns at an intersection by requiring motorists to continue straight through an intersection, use a downstream median U-turn to reverse direction, then return to intersection and make a left-turn.	
Displaced right-turn or continuous-flow intersection	For motorists wishing to turn right, a right-turn lane is positioned to the right of oncoming traffic. Vehicles access the right-turn lane via an upstream mid-block traffic signal.	
Upstream Crossover intersection	Through traffic lanes on two or four approaches cross-over upstream of the intersection, allowing near-side right-turn movements from these approaches. A left-turn slip lane for each leg facilitates left turn movements	
Superstreet intersection	Similar to a median U-turn intersection, but applied to minor street traffic (e.g. collector) turning right. A driver on a collector road wishing to turn right must first turn left onto the arterial road, use a median U-turn to reverse direction and then continue straight through the intersection. Signalised right-turn lanes are provided for traffic on the major road.	
Jughandle intersection	Motorists making a right-turn must first exit left upstream from an intersection and then turn right onto minor road.	

Intersection Type	Comments	Figure
Low-speed signalised roundabout	Suggested for arterial and local roads where lower speed limits and expected travel speeds permit significant entry and circulation speed reductions. Typically these could be considered in urban environments.	
High-speed signalised roundabout	Applicable to high-speed arterials, typically found in outer metropolitan areas. The large format offers further opportunity to reduce impact angles. However, it means that the critical impact speeds for adjacent direction crashes may increase towards 60 km/h at 30° (essentially a merge crash).	
Horizontal deflections on signalised intersection approaches	This is a range of design solutions employing horizontal deflections to capitalise on some of the safety characteristics of a signalised roundabout. E.g. cut-through, squircle and tennis ball. The main point of difference from a signalised roundabout is the conventional operation, i.e. right turns proceed through the centre of the intersection.	

Intersection Type	Comments	Figure
Vertical deflections at intersections and/or on approaches	This solution encompasses various designs such as raised stop bars, speed platforms and raised intersections. The solution may have different design parameters, depending on location and road function, and could cater for very low entry speeds, e.g. in pedestrian areas. For high-speed arterial roads, the design needs to more sensitive to operation and comfort, and may not be able to provide low speeds (e.g. was designed for a 60 km/h traverse on a 70 km/h road with buses). This consideration is also important for safety of motorcyclists, who may lose concentration or balance under severe vertical acceleration.	
Single Point Urban Interchange (SPUI)	This interchange form is used where higher capacity is required, however generally results in greater bridge deck area and therefore cost. They are generally less favourable for pedestrians and cyclists, given the larger intersection footprint and crossing distance required. Examples of SPUIs in Perth include the Tonkin Highway / Kewdale Road and Tonkin Highway / Collier Road interchanges.	
Diverging Diamond Interchange (DDI)/Double Crossover Diamond interchange (DCD))	The principal mechanism of safety improvement is in reduction of right turn conflicts. This is achieved by shifting main traffic movements to the opposite side of the road and executing right turns as turn with care movements. Thus, there are no conflict points for right-turners vs the oncoming traffic. Some reduction in impact speeds may also be attained with the necessary approach deflections.	

Intersection Type	Comments	Figure
Turbine (local roads)	Employs horizontal deflections to manage speeds through intersection.	
Modified roundabout (Peanutabout, Eggabout)	Variations on the round internal island of a roundabout to suit approaching road geometry	 

Intersection Type	Comments	Figure
Flower roundabout	Features a divided left-turn lane to eliminate weaving conflicts within the roundabout.	
Turbo roundabout	Incorporates circulating and approach lane management, using traffic islands, to eliminate weaving conflicts within the roundabout and improve capacity and safety performance of two lane roundabouts	
Intersection narrowing	Similar to channelisation, but at lower cost. May include measures such as a wide painted median to narrow the lanes and encourage reduced approach speeds. This may be supplemented by rumble strips within this median and along the outside of the edge lines of the pavement.	
Quadrant roadway intersection	Intended to reduce right-turn movements at the main intersection by relocating these movements to supplementary intersections	

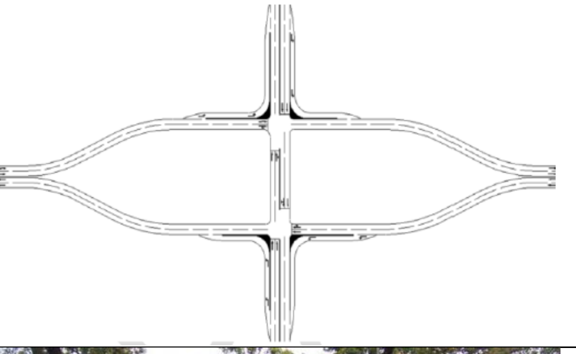
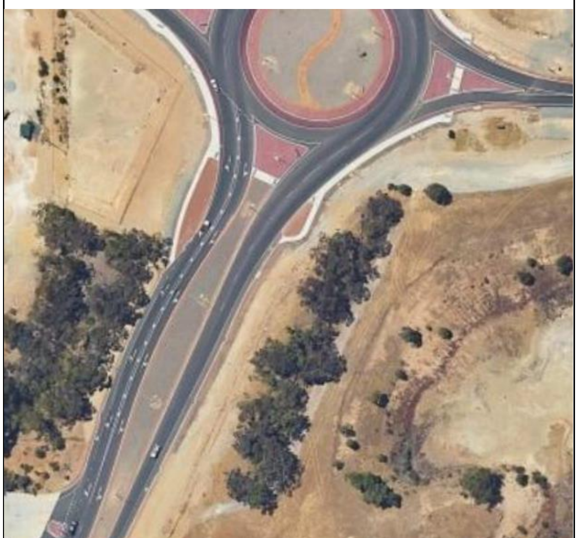
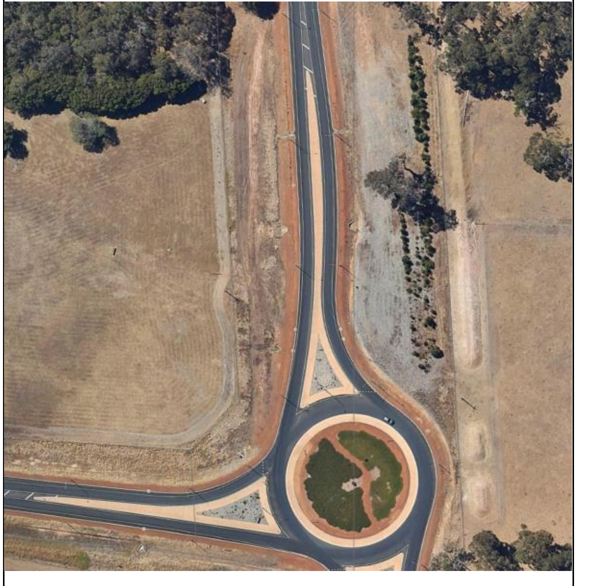
Intersection Type	Comments	Figure
Split intersection	Intersection split to separate right-turning movements. Pre-deflections can be used to slow approaching traffic down.	
Mini roundabout	Small roundabout that features a fully traversable island (generally painted or raised mountable pad) that may be installed where there is insufficient space for a conventional roundabout. Treatments on intersection approaches may be required to help manage vehicle approach speeds.	

Table C3.1 – Unconventional and Innovative Intersection Designs

Commentary 4: Speed Reduction Treatments at Intersections

Potential treatments which seek to reduce approach and through speeds at an intersection are provided in Table C4.1 below, with references to more detailed guidelines where available. For rural and high speed roundabouts which have posted approach speeds of 80 km/h and higher it is mandatory to include supplementary geometric or traffic control device treatments on the approaches to encourage drivers to slow to an appropriate speed before entering the roundabout. Further guidance is provided in the Main Roads Supplement to Austroads Guide to Road Design Part 4B – Roundabouts (Main Roads, 2019b), including features that have the potential to cause instability for High Centre-of-Gravity trucks, along with methodologies to deal with these risks.

Treatment Type	Description and References	Figure
Roundabout pre-deflection	Pre-deflection refers to successive reverse horizontal curves of reducing diameter to gradually slow vehicle speeds approaching a roundabout. This is Main Roads preferred method of speed reduction, particularly on high-speed routes. Refer to the Guideline Drawing - Roundabout Speed Reduction Approach Treatments - Reverse Curves (Main Roads, 2023) for geometric design set out information.	
Raised plateau	A raised plateau (road hump or other vertical displacement device) on the roundabout approach can be combined with pre-deflection to further reduce approach speeds. The plateau height, length and gradient should be adjusted to accommodate various road users, e.g. to cater for cyclists, heavy vehicles and buses.	
Blister island	Suitable for low-speed urban environments, a blister island at a roundabout approach leg is an alternative where geometric or spatial constraints restrict the use of roundabout pre-deflection.	

Treatment Type	Description and References	Figure
Long median islands	A long median island and a kerb on the left side of the approach can provide the perception of a narrowing of the road and 'funnelling' of traffic (Austroads, 2023b).	
Diagonal pavement marking	Diagonal pavement marking in the shoulders can be applied to give the impression of narrowing of the carriageway. Consideration should be given to cyclists as this treatment may encourage them to use the traffic lanes instead of the shoulders.	
RRPMs and chevron line marking between approach lanes	The swept paths of heavy vehicles at roundabouts with multi-lane approaches can be accommodated with chevron line marking and Raised Reflective Pavement Markers installed between the approach lanes, along with heavy vehicle aprons on the inside shoulders. This reduces the perceived width of the lane, and encourages light vehicles to follow the intended entry-path geometry at reduced speeds, and minimises potential conflict angles at the roundabout entry.	

Treatment Type	Description and References	Figure
Wombat crossing	Installed on the approach to a roundabout, this is a form of vertical displacement to encourage reduced vehicle speeds and heightened driver attention. Adequate sight distance is required for both the approach and departure legs.	
Raised pedestrian crossing	Installed on the approach to a roundabout, this is another form of vertical displacement to encourage reduced vehicle speeds and heightened driver attention. Adequate sight distance is required for both the approach and departure legs.	
Raised safety platform	Raised safety platform intersections have been successfully implemented in Victoria, such as the intersection of Hertford Street and Albert Street in Ballarat, and in WA, at the intersection of Stephenson Avenue and Oswald Street, Innaloo as shown. The entire centre of the intersection is raised, with gentle grades on the approach and departures, along with advisory speed limit signs (typically 30km/h to 40km/h) to encourage safer speeds.	
Rumble strips	Applied at high-speed rural intersections on the secondary road approach to draw attention to the downstream intersection (or other potential hazard). This treatment is not usually appropriate in residential areas due to the noise generated. Refer to the Guideline - Rumble Strips (Main Roads, 2017) for further policy and application guidelines.	

Table C4.1 – Speed Reduction Treatments at Intersections

11 APPENDICES

Appendix	Title
Appendix A	Examples of Roundabouts with more than Four Legs
Appendix B	Examples of Roundabouts with more than Two Circulating Lanes
Appendix C	Case Study: Eelup Rotary - Designing a Roundabout to Accommodate Large Multi-combinational Vehicles
Appendix D	Case Study: Point Lewis Rotary – Partial Signalisation of a Roundabout using Metering Signals
Appendix E	Quantifying Pedestrian and Cyclist Activity

Appendix A: Examples of Roundabouts with more than Four Legs

Figure A.1: Example of a Single-lane Roundabout with Five Legs, Burpengary, QLD

Figure A.2: Example of Two Single-lane Roundabouts with Six Legs Each Ormeau, Qld

Figure A.3: Example of Two Multi-lane Roundabouts with more than Four Legs

Figure A.4: Example of a Multi-lane Roundabout with more than Four Legs

Appendix B: Examples of Roundabouts with more than Two Circulating Lanes

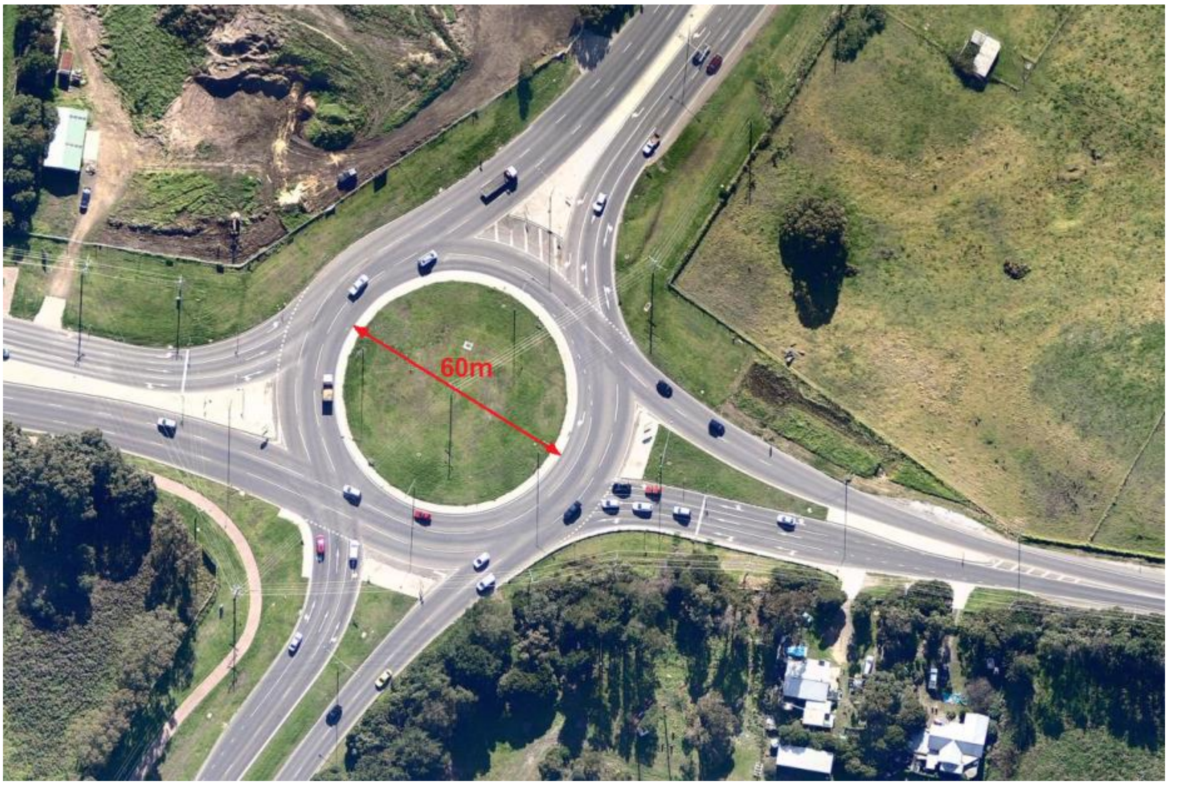


Figure B.1: Example of 3-lane Roundabout in Victoria (Dandenong-Frankston Rd (Dandenong Valley Hwy) / Thompsons Rd. Carrum Downs)

Figure B.2: Example of 3-lane Roundabout in Victoria (Boundary Rd / Governor Rd, Braeside)

Appendix C: Case Study: Eelup Rotary - Designing a Roundabout to Accommodate Large Multi-combinational Vehicles

Background

Prior to signalisation, the Eelup Rotary in Bunbury had an extremely poor crash record (albeit the vast majority of crashes were property-damage only) and was frequently congested during the peak periods. The major problem identified was that large multi-combinational vehicles struggled to "pick a gap" in the circulating traffic stream because of the high traffic volumes and high circulatory speeds. The large central diameter of 180 m contributed directly to the high circulatory speeds. Figure C.1 shows the roundabout prior to upgrading.

Figure C.1: Eelup Rotary in 2011 prior to Upgrading

Design Proposals

An initial proposal to upgrade the roundabout had considered constructing a smaller roundabout within the existing central island in order to reduce the circulatory speeds. However, this would not have provided sufficient capacity and did not address the issue of truck drivers being able to "pick a gap" in the high circulatory flow.

A decision to signalise the roundabout was made based on the ability to utilise the existing pavement area effectively as well as taking advantage of the large internal storage area to store turning traffic. In addition, this catered well for future east-west grade separation plans. In 2011 construction commenced to upgrade the roundabout to a signalised roundabout. The main approaches were flared to three lanes and the circulating roadway was widened to three lanes in three of the four quadrants. In addition, left-turn slip lanes were provided for three of the four movements. The upgraded "roundabout" is shown in Figure C.2.

Figure C.2: Eelup Rotary in 2014 after Upgrading

Current crash records indicate a substantial reduction in the number of crashes and congestion during peak periods, including peak holiday long-weekend periods has largely been eliminated.

One of the key factors for the success of this roundabout was recognising the need to get drivers into the correct lanes prior to the roundabout. This was achieved using overhead advance direction signing, supplemented with pavement markings indicating destinations.

Figure C.3: Eelup Rotary showing Overhead Advance Direction Signs and Supplementary Pavement Markings

Appendix D: Case Study: Point Lewis Rotary – Partial Signalisation of a Roundabout using Metering Signals

Background
Prior to the installation of metering signals, Point Lewis Rotary on Mounts Bay Road / Riverside Drive, Perth experienced extreme congestion during the peak periods:

- During the a.m. peak period, traffic on the northern approach (main a.m. peak movement) was blocked by the lesser west-to-east traffic flows from the western approach. The resulting queues extended back to the Mounts Bay Road freeway off-ramp and sometimes backed up onto the northbound Mitchell Freeway as well.
- During the p.m. peak period, traffic on the northern approach was sometimes blocked by traffic backing up into the roundabout from the eastern downstream exit, which leads onto the freeway.
- The existing geometry provided for slip lanes for the west-to-north as well as east-to-west movements. There were limited opportunities for further geometric improvements to address the capacity issues.

Figure D.1 shows the layout of the roundabout prior to the installation of the metering traffic signals.

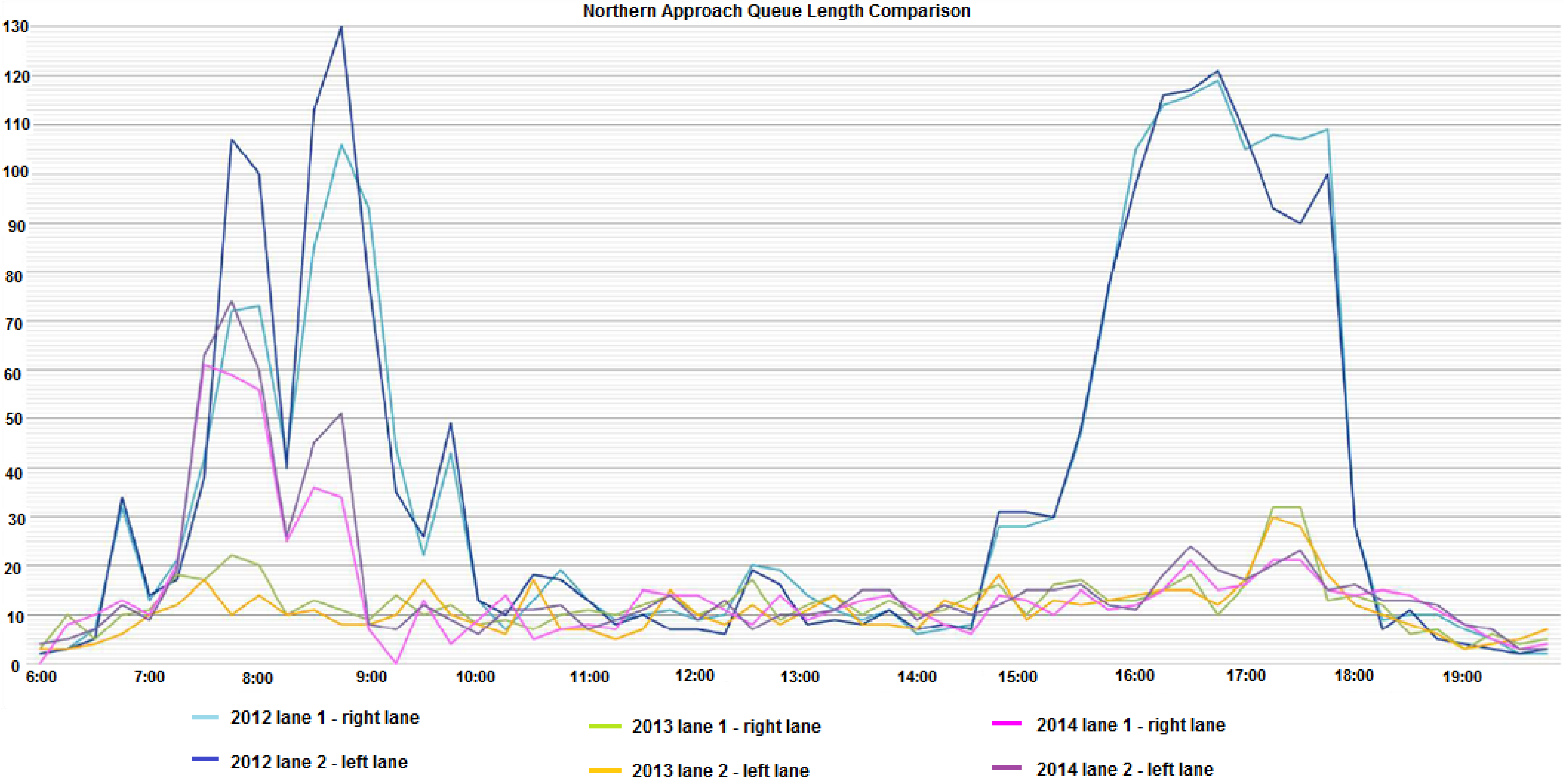
Figure D.1: Point Lewis Rotary prior to Installation of Roundabout Metering Signals

Design proposal
The implemented solution consisted of installing roundabout metering signals on the western approach. These are activated either by the traffic queued on the northern approach or by traffic backing up from the freeway on the eastern exit. The current layout is shown in Figure D.2. The STOP line is located a minimum of 19 m from the roundabout hold line.

Figure D.2: Point Lewis Rotary after Installation of Roundabout Metering Signals

<u>Post Implementation Results</u>

Figure D.3 shows the maximum queue lengths on the northern approach, as measured in 2012, 2013 and 2014. The morning maximum queue lengths have decreased by over 40% from 2012 to 2014. The 2014 afternoon peak maximum queue lengths have decreased in size significantly; the maximum queue length is approximately 20% of the size of the 2012 afternoon peak maximum queue length. To date there has been virtually no negative feedback regarding the partial signalisation of this roundabout. Congestion has reduced significantly and by all accounts the implementation of roundabout metering may be considered a success.



Source: (Donald Veal Consultants, 2014)

Figure D.3: Point Lewis Rotary – Northern Approach (Lanes 1 & 2) – Maximum Queue lengths for 2012, 2013 and 2014

Appendix E: Quantifying Pedestrian and Cyclist Activity

This guideline considers an intersection as "Safe System compliant" under the following circumstances:

- For intersections with significant vulnerable road user activity, a safe crossing facility shall be provided. Where there is a possibility of a right-angle collision between passenger vehicles, the through-traffic speed should ideally be restricted to less than 50 km/h. Where the crossing facility relies on a driver giving way to a pedestrian (e.g. turning traffic at an intersection, zebra or wombat crossing), the speed of the traffic at the potential conflict point should ideally be restricted to less than 30 km/h.
- For intersections with little or no vulnerable road user activity, the through speed should ideally be restricted to less than 50 km/h, where there is a possibility of a right-angle collision between passenger vehicles.

The term "significant" is defined in the document "Position Paper – Quantifying Pedestrian and Cyclist Activity", April 2021 (D23#786115), along with the circumstances under which the number of vulnerable road users (pedestrians and cyclists) would be considered "significant".

The definition of "significant" does not imply that the number of objects being described (in this case, the number of vulnerable road users) necessarily needs to be high; however, the number does need to be "sufficiently high". This means that the magnitude of the number implied by the term "significant" depends on the context in which it is used.

The magnitude of what is deemed a "significant" number of pedestrians relates to the risk of exposure to traffic. The use of the term "significant" is related to circumstances where there is a perception that vulnerable road users are exposed to a higher risk. This generally relates to the following factors:

- Exposure of vulnerable road users to vehicular traffic – higher vulnerable road user activity and vehicular traffic volumes mean greater risk.
- Vehicle speeds – higher impact speeds between vulnerable road users and vehicles result in greater risk. Impact speeds between vulnerable road users and vehicles are considered safe system compliant below 30 km/h.

Based on the above, the number of vulnerable road users (pedestrians and cyclists) is considered "significant" under the following circumstances:

- **The probability of a conflict between a crossing vulnerable road user and the through traffic is likely to be greater than 5%.**
- **The probability of a conflict between a circulating cyclist any entering and circulating vehicle is likely to be greater than 5%.**
- **Irrespective of the number of vulnerable road users, if the intersection is located on a road or street that has a high place value in terms of the Movement and Place framework.**

The methodologies use to quantify the risk of pedestrian and cyclist exposure to traffic, and further details on the Movement and Place framework, are outlined below.

Methodology to Quantify Pedestrian and Cyclist Crossing Exposure to Traffic

One way to quantify the risk of crossing pedestrian's exposure to traffic is to calculate the probability of a pedestrian crossing a section of road coming into conflict with a vehicle travelling along the road. The New Zealand Transport Agency (NZTA) document *"Guidelines for the Selection of Pedestrian Facilities"*, (New Zealand Transport Agency, 2007) provides a methodology for estimating the average pedestrian waiting time based on the distribution of critical gaps in the traffic stream for various traffic volumes. This methodology uses the Poisson distribution for random traffic arrivals and may also be used to determine the probability of a specific number of arrivals during a specified time period (usually the "critical gap").

The "critical gap" is determined as the time it would take an average pedestrian to cross the section of road in question and is a function of:

(a) Crossing distance
(b) Mean walking speed
(c) A confirmation time for pedestrians (analogous to perception – reaction time for drivers)
(d) A factor of safety.

The mean walking speed, in turn, is dependent on the number of elderly (slower walking) pedestrians and the confirmation time is dependent on the proportion of sensitive road users (elderly and children under 12 years old).
The "critical gap" time defined above is used here as the potential "conflict time" between pedestrians and vehicles. Appendix A summarises the methodology used to determine the critical gap, or pedestrian crossing time[6]. (Austroads, 2023a) also provides an equation for calculating the critical safe gap (t_c) in the traffic stream for pedestrians to safely cross the road, which is slightly more conservative than the NZTA approach, as it allows for an additional 3 s clearance time, and additional 1.6 m crossing distance based on pedestrian set back from the pavement edge or kerb line.
The equations and analysis below are based on the NZTA approach:

$t_{cp} = 0.95d_c + 1.5$……………………………………………….(1)

Where,

d_c = the crossing distance in m.

If the distribution of traffic and pedestrian (and cyclist) arrivals is assumed to be random, then based on Poisson's equation the probability of "at least one arrival" can be calculated for various traffic and pedestrian flows as follows.

The Poisson Probability Distribution is given by:

$P(x\,;\,m) =$ for x = No. of events during a specified time period = 0, 1, 2, etc…………(2)

Where,

[6] *The same principles and methodology may be applied for cyclists crossing a roadway. The exposure time is likely to be less, although this will vary significantly depending on the experience and expertise of the rider. To be conservative, it is assumed that cyclists dismount and walk across the road, in which case the exposure time will be the same as for pedestrians.*

m = the average number of events during the specified time period (in this case the specified time period is defined by Equation (1))
The probability that "at least one" event occurs during the specified time period can be expressed mathematically as:

$P(x \geq 1) = 1 – P(x = 0) = 1 – Exp(-m)$……………………………………………………….(3)

This can be calculated for various pedestrian (and cyclist) and traffic flows for a particular crossing distance. The probability of a pedestrian or cyclist crossing *at the same time* that a car arrives is then given by the product of the probability that at least one pedestrian / cyclist arrives and the probability that at least one vehicle arrives.

As an example, consider the following scenario:

- Crossing distance = 6 m (single carriageway – one direction)
- Vehicular flow rate = 1500 vph
- Pedestrian / cyclist flow rate = 40 peds / cyclists per hour

From Equation (1), the "specified time period" $t_{cp} = 0.95d_c + 1.5 = (0.95 \times 6) + 1.5 = 7.2$ secs.

<u>For Pedestrians and Cyclists</u>

The average number of pedestrian / cyclist arrivals in the "specified time period" = m = 40 x 7.2 / 3600 = 0.08

The probability of "at least one" pedestrian or cyclist arriving during the specified time period is given by:

$P(X\geq1) = 1 – (P(X=0) = 1 – Exp(-0.08) = 1 – 0.923 = 0.077$

<u>For Vehicles</u>

The average number of vehicle arrivals in the "specified time period" = m = 1500 x 7.2 / 3600 = 3
The probability of "at least one" vehicle arriving during the specified time period is given by:

$P(X\geq1) = 1 – (P(X=0) = 1 – Exp(-3) = 1 – 0.05 = 0.95$

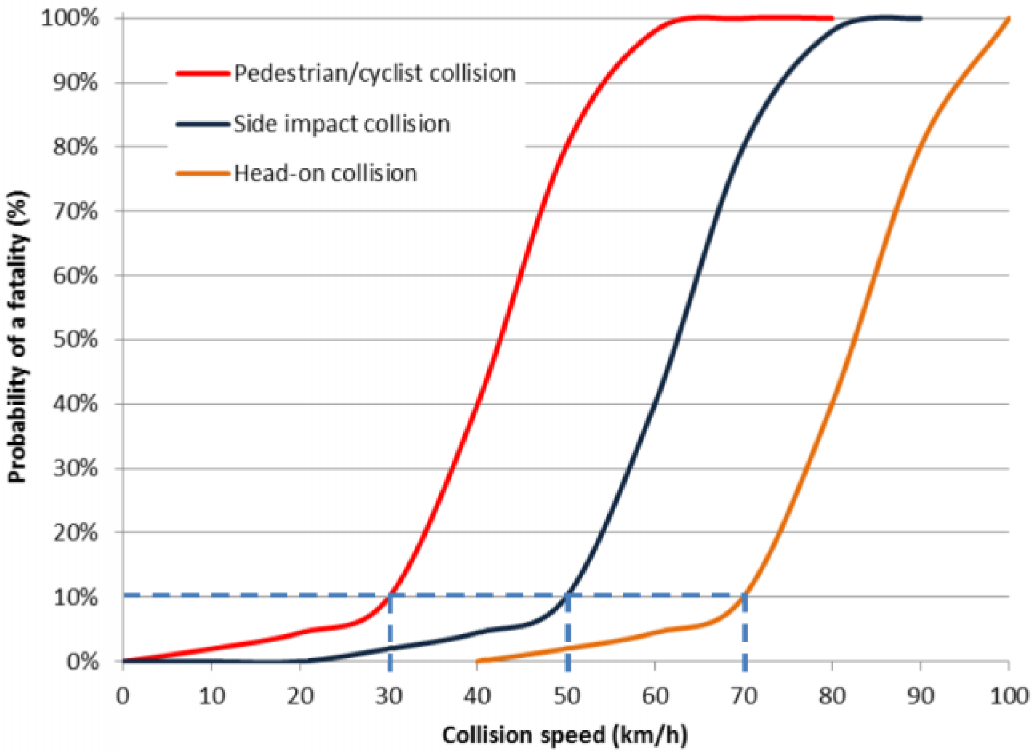
<u>For Vehicles and Pedestrians / Cyclists combined</u>

The probability of a pedestrian or cyclist crossing *at the same time* that a car arrives is given by the product of the probability of "at least one" pedestrian / cyclist crossing x the probability of "at least one" vehicle arrives = 0.077 x 0.95 = 0.073.

i.e. For the given number of 1500 vehicles and 40 crossing pedestrians / cyclists as well as a crossing distance of 6 m, there is a 7.3% probability that a vehicle and a crossing pedestrian / cyclist could be in conflict with one another[7].

The previous example determined that there would be a 7.3% probability of a pedestrian wanting to cross at the same time that a car arrives, i.e. a 7.3% probability of a potential conflict. The question is "What would be an acceptable level of potential conflict"? To answer this, we turn to how the Safe System Speeds have been determined.

Safe System Speeds have typically been determined based on a 10% probability of a fatal outcome in the event of a collision and have been derived from the Wramborg curves. This is illustrated in Figure E.1.



SOURCE: Austroads (2018)

Figure E.1: Relationships between Collision Speed and Probability of Fatality for Different Crash Configurations

It is clear from the above figure that there is a 10% probability of a fatality at:

- 30 km/h for a collision between a car and a pedestrian or cyclist,
- 50 km/h for a right angle collision between passenger vehicles, and
- 70 km/h for a head on collision between passenger vehicles.

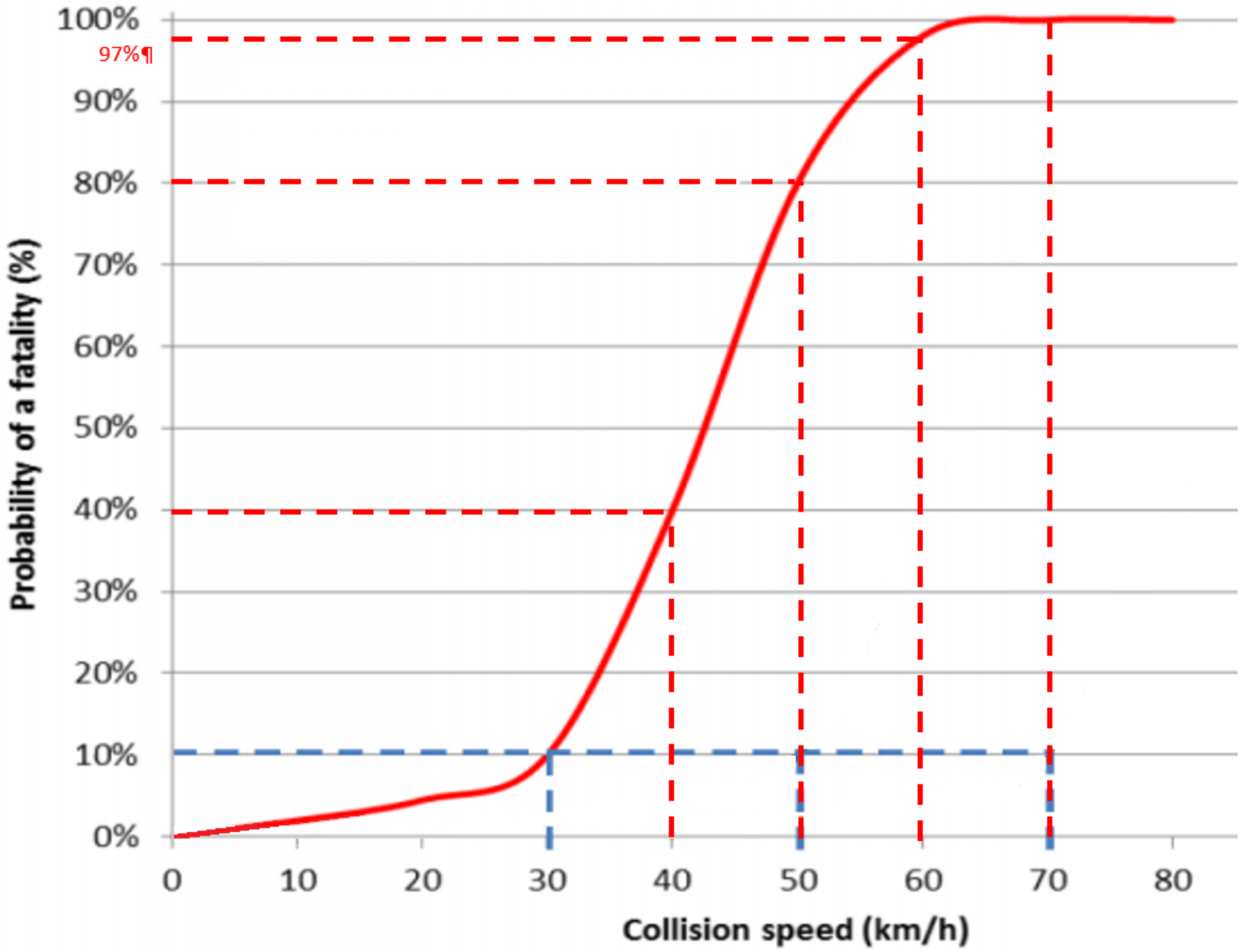
The focus for this discussion is on the red curve showing that there is a 10% probability of a fatality between a car and a pedestrian / cyclist, provided the speed of the car is approximately 30 km/h. The

[7] In reality, the pedestrian / cyclist is likely to see an approaching vehicle and only cross when there is a sufficient gap. However, for the purposes of this exercise we need to determine "what is an acceptable probability of conflict?" based on the assumption that the pedestrian fails to see the approaching car.

question is “How do we interpret situations where the speed of the car is greater than 30 km/h?” Intuitively, we would expect the risk to be higher.

Figure E.2 shows the probability of a fatality for a collision between a car and a pedestrian or cyclist for speeds greater than 30 km/h:

- For a collision speed of 40 km/h, the probability of a fatality is approximately 40%.
- For a collision speed of 50 km/h, the probability of a fatality is approximately 80%.
- For a collision speed of 60 km/h, the probability of a fatality is approximately 97%.
- For a collision speed ≥70 km/h, the probability of a fatality is approximately 100%.



SOURCE: Austroads (2018)

Figure E.2: Relationships between Collision Speed and Probability of Fatality for a Collision between a Car and a Pedestrian or Cyclist

Based on the above, if the internationally - accepted probability of a fatality is 10% (at 30 km/h), then at higher speeds, it makes sense to reduce the number of potential collisions in order to reduce the potential number of fatalities. It is proposed that the reduction should be proportionate to the ratio of the probability of a fatality at 30 km/h divided by the probability of a fatality for the particular operational speed. Based on this the acceptable probability of a potential collision for various speeds is given by:

- For a collision speed of 40 km/h, the acceptable probability of a collision is 10% x 10/40 = 2.5%.
- For a collision speed of 50 km/h, the acceptable probability of a collision is 10% x 10/80 = 1.25%.
- For a collision speed of 60 km/h, the acceptable probability of a collision is 10% x 10/97 = 1.03%.
- For a collision speed ≥70 km/h, the acceptable probability of a collision is 10% x 10/100 = 1.0%.

To return to the previous example. For a given number of 1500 vehicles and 40 crossing pedestrians / cyclists as well as a crossing distance of 6 m, there is a 7.3% probability that a vehicle and a crossing pedestrian / cyclist could be in conflict with one another. If the operational speed is less than 30 km/h, then it can be argued that this is less than the 10% probability of a fatality currently accepted to meet safe system requirements and the number of pedestrians or cyclists is not significant. However, if the operational speed is greater than 30 km/h, say 50 km/h, then the probability of a potential collision should be less than 1.25%. Since the actual probability of a potential collision is 7.3%, the number of pedestrians / cyclists is considered "significant".

Based on this methodology, a series of graphs were drawn for various operational speed and crossing distances to determine whether the number of pedestrians and / or cyclists crossing is significant or not. These are shown in Figures E.3(a) to E.3(e). For the previous example (1500 vehicles, 40 pedestrians or cyclists, 6 m crossing), the plotted point in Figure E.3(a) falls below the 6 m crossing line indicating that the number of pedestrians or cyclists is "not significant". However, if the operational speed is 40 km/h, or greater, then the plotted point falls off charts E.3(b) to E.3(e) (no. of pedestrians or cyclists is too high) and the number of pedestrians or cyclists is significant.

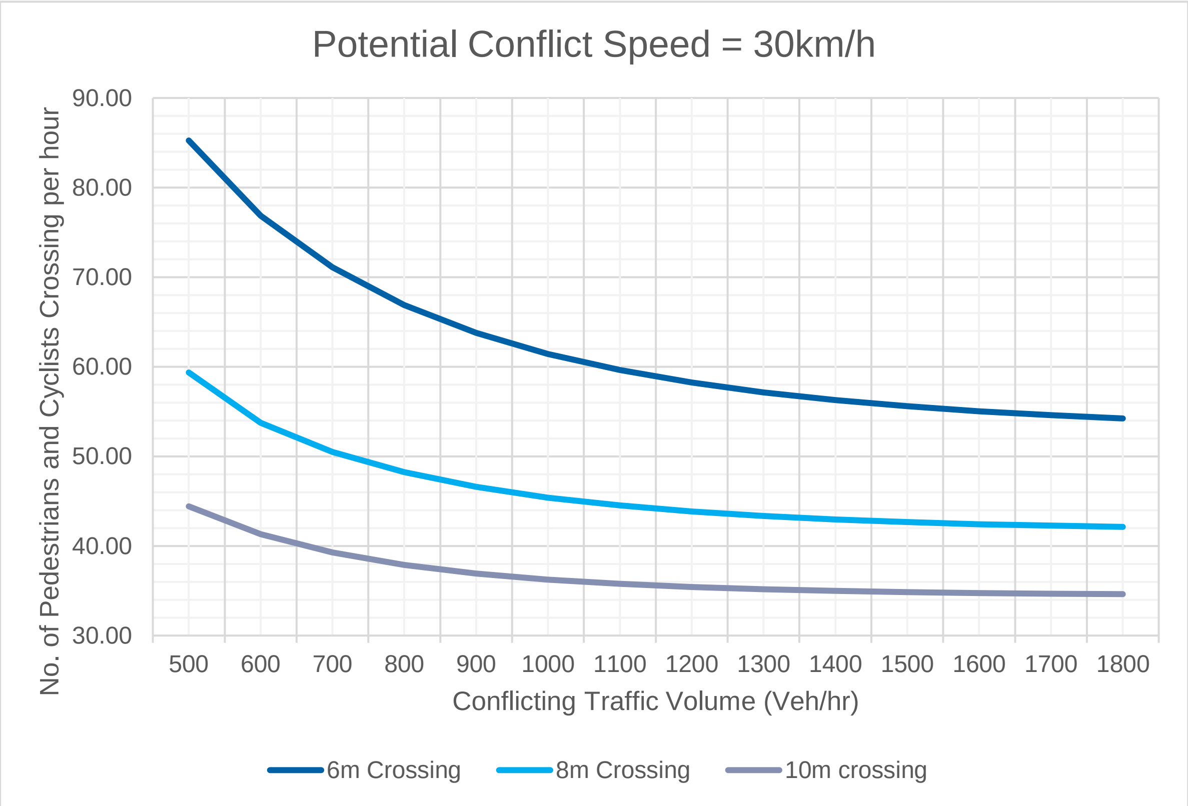


Figure E.3(a): 10% Probability of Conflict between Pedestrians & Cyclists Crossing a Single Carriageway and Through Traffic (30 km/h)

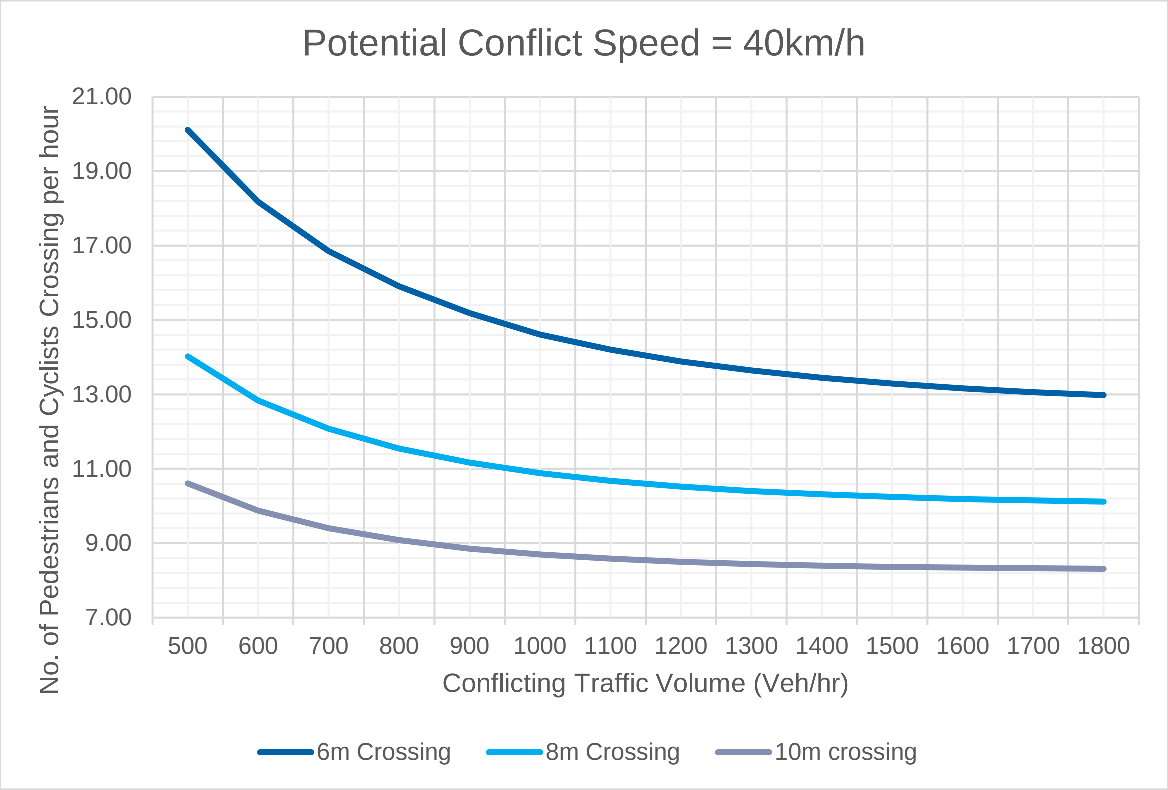


Figure E.3(b): 2.5% Probability of Conflict between Pedestrians & Cyclists Crossing a Single Carriageway and Through Traffic (40 km/h)

Figure E.3(c): 1.25% Probability of Conflict between Pedestrians & Cyclists Crossing a Single Carriageway and Through Traffic (50 km/h)

Figure E.3(d): 1.03% Probability of Conflict between Pedestrians & Cyclists Crossing a Single Carriageway and Through Traffic (60 km/h)

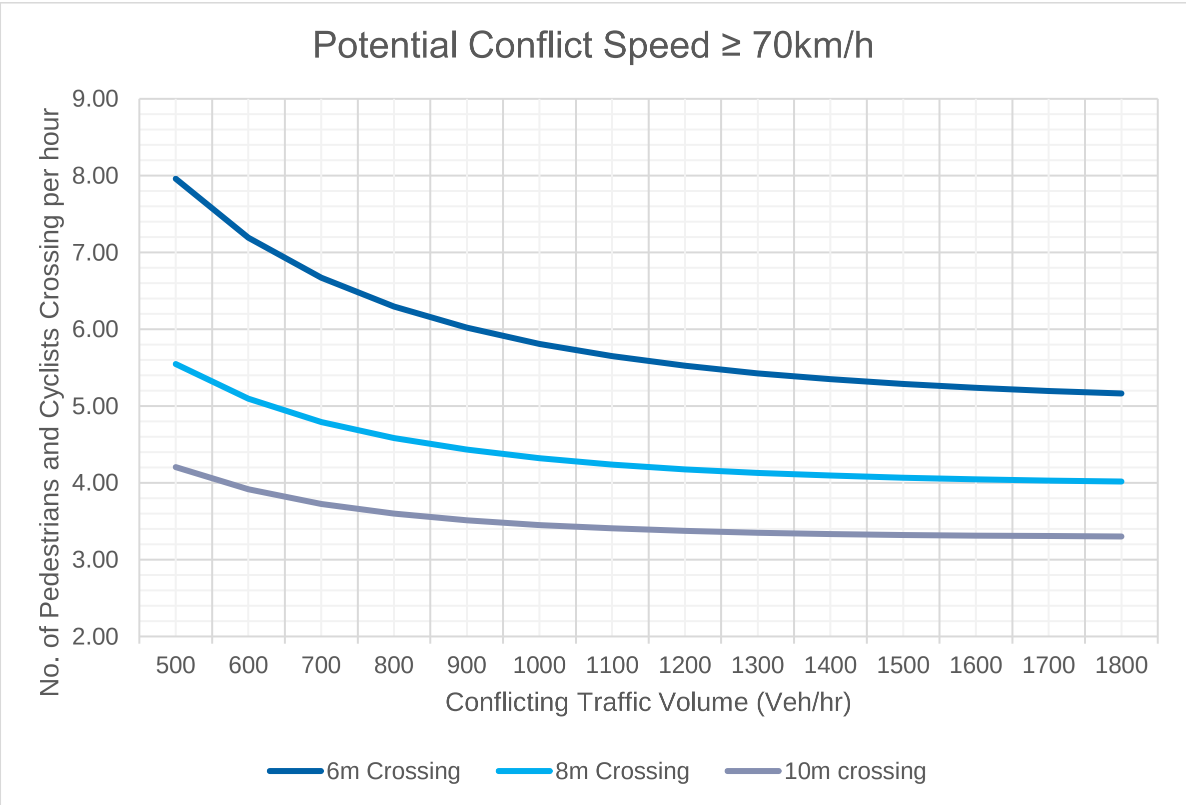


Figure E.3(e): 1.0% Probability of Conflict between Pedestrians & Cyclists Crossing a Single Carriageway and Through Traffic (≥70 km/h)

Based on the principles used to derive the graphs, the following definition of "significant vulnerable road users" is proposed with respect to the number of vulnerable road users crossing a roadway:

The number of vulnerable road users wishing to cross a roadway is considered 'significant' if the probability of a conflict between the crossing vulnerable road user and the through traffic is likely to be greater than:

- **10% if the operational speed is ≤30 km/h**
- **2.5% if the operational speed is between 30 and 40 km/h**
- **1.25% if the operational speed is between 40 and 50 km/h**
- **1.03% if the operational speed is between 50 and 60 km/h**
- **1.0% if the operational speed is ≥ 70 km/h**

Methodology to Quantify Cyclist Exposure to Traffic at Roundabouts

The previous section covers the scenario when pedestrians or cyclists wish to ***cross*** a road facility. A similar process can be used to determine the risk of exposure of cyclists to entering and circulating traffic at a roundabout. With reference to Figure E.4 below, for the cyclist movement south to north (black arrow), the conflicting traffic movements are shown from each of the other legs. Note that the through and right turning traffic from the same southern leg (orange arrow) is also shown as conflicting.

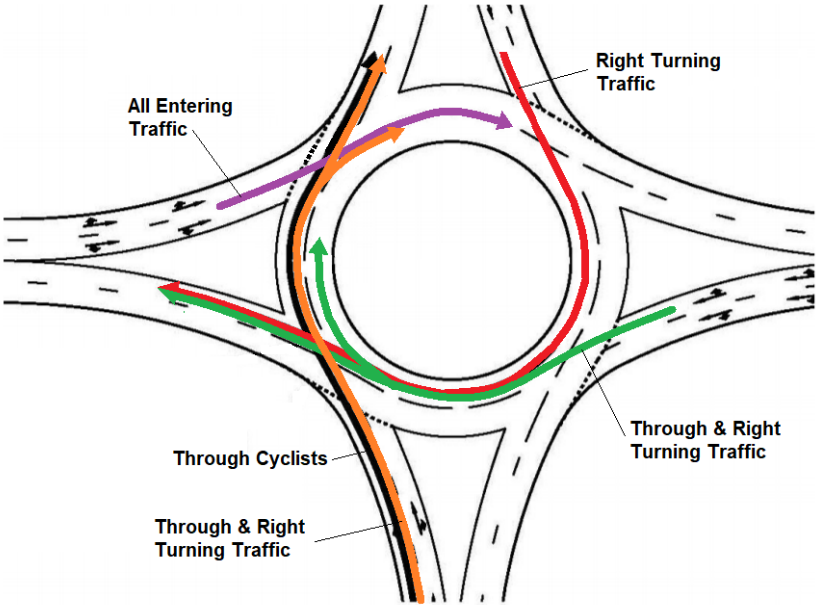


Figure E.4: Conflicting Traffic for a South to North Cyclist Movement

The length of time that the cyclist is exposed to circulating and entering traffic can be calculated for a range of outside diameters based on the following assumptions:

- The cyclist travels half the circumference of a circle (this is valid for smaller splitter islands).
- The cyclist travels at a speed of 20 km/h (Austroads design speed for cyclists of 30 km/h does not take into account starting from a stopped position).
- The cyclist path is approximately 1.75 m off the outside edge (middle of lane).

Again, assuming a random arrival rate and applying Poisson's equation, the probability of a potential conflict between a south to north cyclist movement and entering and circulating traffic can be calculated. This is shown in Figures E.5a to E.5c over the page for 10%, 2.5% and 1.25% potential conflict probabilities for various roundabout diameters, corresponding to traffic entering speeds of 30, 40 and 50 km/h respectively. This is based on the "acceptable probability" for various conflict speeds derived earlier from the Wramborg curves.

Intuitively, as the roundabout gets larger, the exposure time increases and the risk of a conflict increases. Consequently, the number of cyclists required to generate a particular conflict probability decreases with increasing radius, i.e. for a given entry speed, the 'significant number' of cyclists decreases with increasing roundabout size.

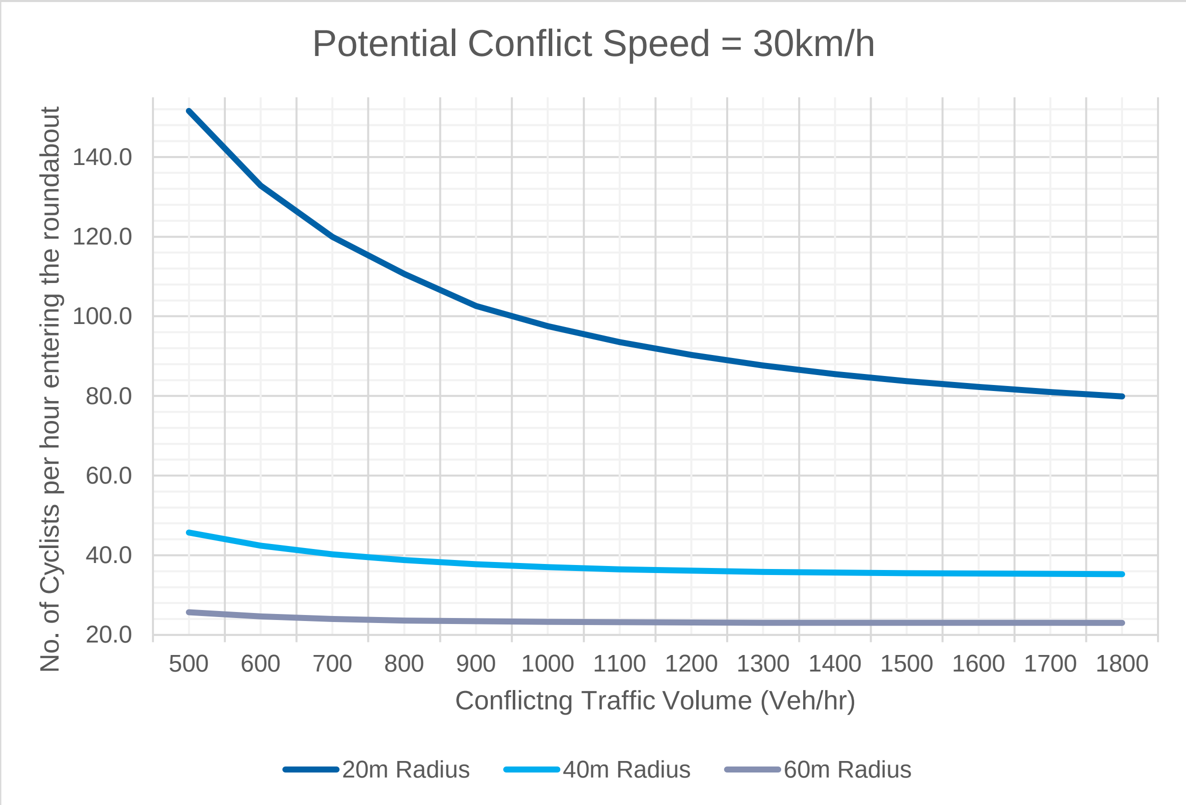


Figure E.5a: 10% Probability of a Potential Conflict between a Through Cyclist Movement and Traffic Entering and Circulating at 30km/h

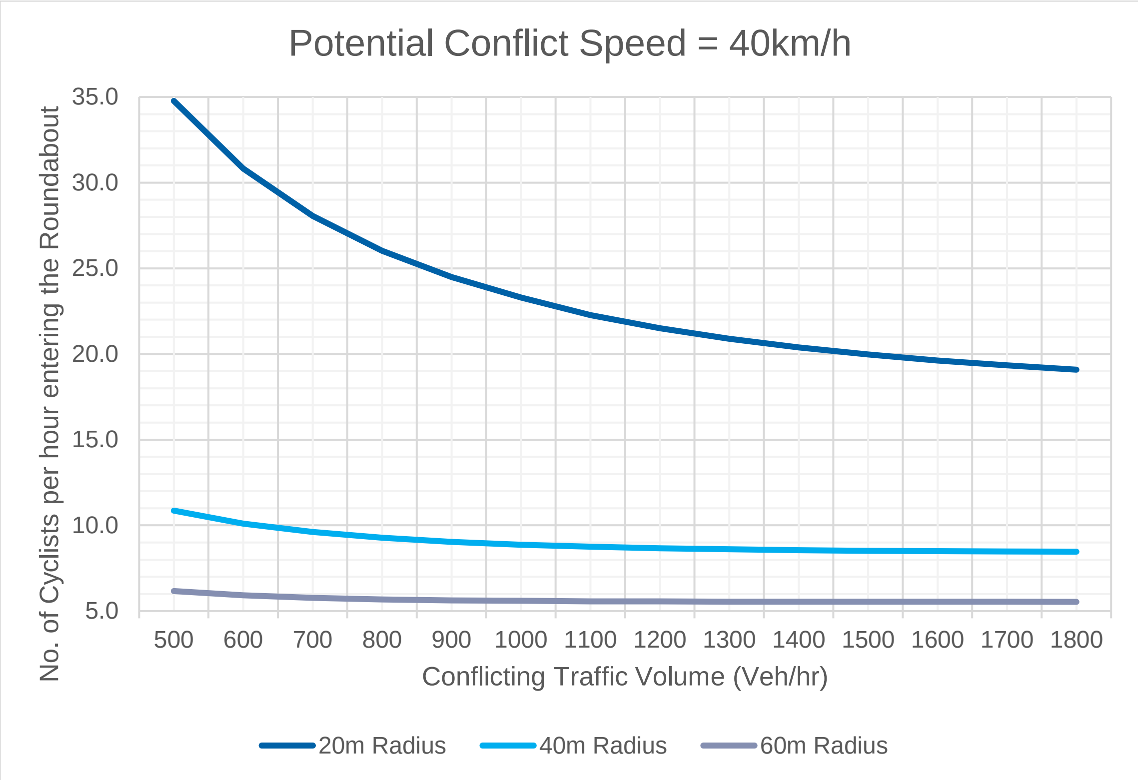


Figure E.5b: 2.5% Probability of a Potential Conflict between a Through Cyclist Movement and Traffic Entering and Circulating at 40 km/h

Figure E.5c: 1.25% Probability of a Potential Conflict between a Through Cyclist Movement and Traffic Entering and Circulating at 50 km/h

Based on the principles used to derive the graphs above, the following definition of a "significant number of cyclists" is proposed with respect to the number of cyclists using a roundabout:

The number of cyclists using a roundabout is considered 'significant' if the probability of a conflict between the circulating cyclist and the entering and circulating traffic is likely to be greater than:

- **10% if the operational speed is ≤30 km/h**
- **2.5% if the operational speed is between 30 and 40 km/h**
- **1.25% if the operational speed is between 40 and 50 km/h**

Figures E.3a to E.3e and E.5a to E.5c may be used as a guide in order to quantify the "significant" number of vulnerable road users for basic situations. It should be noted that the methodology for Figures E.3a to E.3e includes for 10% elderly pedestrians in the walking speed and 50% elderly and / or young users in the "confirmation time".

While Figures E.5a to E.5c are derived for "through" cyclists negotiating approximately half the roundabout, the exposure time for right-turning cyclists can be similarly calculated and an appropriate diameter equivalent to the exposure time can be used. The conflicting traffic would also need to include all entering traffic from all legs, except for the left-turning traffic from the adjacent upstream leg.

Methodology for Quantifying Vulnerable Road Users Based on the Movement and Place Framework

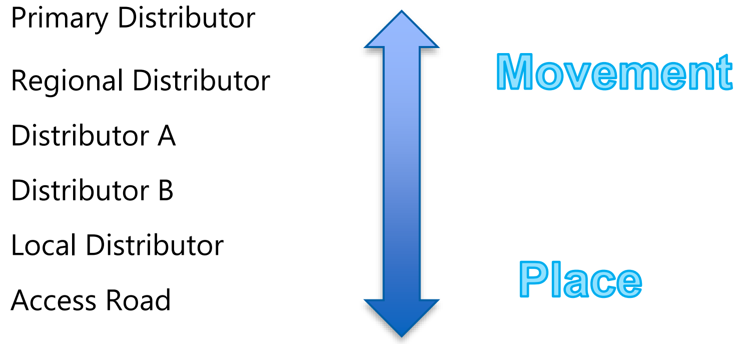
As an alternative to considering when specific facilities should be provided for vulnerable road users based on "significant" use or exposure to higher risk, what if the provision of facilities for vulnerable road users is considered more from the functional hierarchy, or purpose of the road?

Roads serve two main purposes; they can serve as a conduit facilitating the movement of people, goods and services, and they can act as places for people, and many roads serve both purposes. Previously, the road functional hierarchy was defined in terms of the road's ability to provide "movement" and "access" functions. This hierarchical system was totally orientated towards the requirements of vehicles and often resulted in a poor street environment for pedestrians.

Currently, the functional road hierarchy is defined in terms of "movement" and "place". This recognises that the role of a road is not only for the movement of people and goods in vehicles but has intrinsic value as a destination and acknowledges the role of roads to cater for pedestrians and cyclists.

Understanding the characteristics of the location, the intersection's strategic significance within the road network and the community value of a place, will allow designers to choose the appropriate type of pedestrian crossing facility that meets the needs of all users.

In Western Australia, Metropolitan roads are categorised according to the following functional hierarchy. With the movement and place concept, generally, the higher the road hierarchy classification, the greater the movement value of the roadway and vice versa.



However, it is not a simple linear relationship; there are roads that have both a high movement and place value and vice versa. In WA, Government Departments are still in the process of developing an appropriate Movement and Place Framework. The Movement and Place Framework shown in Figure E.6 (Austroads, 2016) provides a basis for considering a road against key characteristics associated with movement (known as transport, link or similar) and place (known as location, land use, or similar) and promotes a strategic, integrated approach to guide corridor planning across the planning and transport portfolios.

Source: Guide to Traffic Management Part 4: Network Management (Austroads 2016a)

Figure E.6: Movement and Place Framework

Locations with a high place value and low movement value, such as café strips, generally have a high number of pedestrians. In these locations speeds are typically lower, drivers are more aware of pedestrians and are generally more cautious. Pedestrians would expect a high level of service and would not tolerate high delays.

Locations with a low place value and high movement value, such as at intersections along primary distributer roads, generally have higher speeds and a low number of pedestrians. Because of the high traffic volumes, pedestrians would expect longer delays.

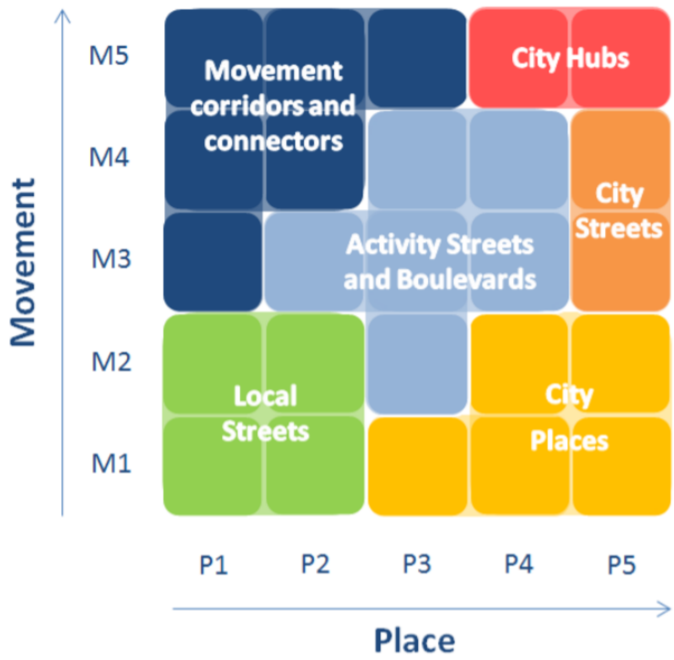
There are locations with a high place value and high movement value, such as town centres on primary distributor roads or CBD environments. In these locations, the safety of the pedestrians must be the most important consideration but at the same time, every effort should be made to minimise the impact of the pedestrian crossing on traffic efficiency.

In summary, within the "movement and place" framework, roads with a higher "place" value would be expected to prioritise the movement of pedestrians (and cyclists) over the movement of vehicles. On the other hand, roads with a higher "movement" value would be expected to prioritise the movement of vehicles over the movement of pedestrians (and cyclists).

While this prioritisation may impact on the Level of Service of one group of road users over another, this does not imply that the safety of any road users should be compromised.

Catering for Vulnerable Road Users within the Movement and Place Framework

Austroads has done research work on integrating the safe system with movement and place for vulnerable road users (Austroads, 2020c). This research has chosen the Victorian framework, largely because it is a simple version comprising of only six main Movement and Place families. This is shown in Figure E.7 below.



Source: (Austroads, 2020c)

Figure E.7: Proposed Movement & Place Framework Showing Road / Street Families

The following descriptions of the six Movement and Place families appear in a Department of Transport publication (Department of Transport and VicRoads, 2019).

City Hubs
Successful City Hubs are dense and vibrant places that have a high demand for movement. They are also places providing focal points for businesses and culture. City Hubs should aim to reduce the impact of high traffic volumes while accommodating high pedestrian numbers, multi-modal journeys and access to public transport and essential emergency services.

City Streets
Successful City Streets should provide a world-class pedestrian friendly environment. They aim to support businesses, on-street activity and public life while ensuring excellent connections with the wider transport network.

City Places
City Places are roads and streets with high demand for pedestrian activities and lower levels of vehicle movement. City Places are places communities value and for people and visitors to enjoy.

Activity Streets and Boulevards
Successful Activity Streets and Boulevards provide access to shops and services by all modes. There is high demand for movement as well as place with a need to balance different demands within the available road space. Activity Streets and Boulevards aim to ensure a high quality public realm with a strong focus on supporting businesses, traders and neighbourhood life.

Movement Corridors and Connectors
Successful Connectors should provide safe, reliable and efficient movement of people and goods between regions and strategic centres and mitigate the impact on adjacent communities.

Local Streets
Successful Local Streets should provide quiet, safe and desirable residential access for all ages and abilities that foster community spirit and local pride. They are part of the fabric of our neighbourhoods, where we live our lives and facilitate local community access.

Safety Measures for Vulnerable Road Users within a Movement & Place Framework

The Austroads' document provides tables listing pedestrian and cyclist safety measures grouped by location type and alignment with Safe System principles.[8] for intersections and mid-block locations. The table for intersections is given on the following page.

From the table it is clear that, within the Movement and Place framework, roads / locations that have been identified as having a high "Place" value require safety measures for pedestrians and cyclists that are aimed primarily at reducing speeds to 30 km/h, or lower.

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[8] *Austroads **Invalid source specified.** has developed a "Safe System Assessment Framework" which uses a matrix to assess different major crash types (those identified as the predominant contributors to fatal and serious crash outcomes) against the exposure to that crash risk, the likelihood of it occurring and the severity of the crash should it occur.*

At intersections									
Safe System treatment	Exposure	Likelihood	Severity	City Hubs	City Streets	City Places	Activity Streets & Boulevards	Movement Corridors & Connectors	Local Streets
Signalised intersections with 'Scramble' phasing (30 km/h speed limit)		✓	✓	✓	✓		✓		
Limit access by mode	✓	✓	✓	✓		✓			
Raised signalised intersections with 30 km/h ramps		✓	✓	✓	✓		✓		
Safety platforms (30 km/h or lower) on all approaches		✓	✓	✓	✓	✓			✓
Geo-fencing technology for trams, trucks and other large vehicles		✓	✓	✓	✓	✓	✓		
Signalised roundabout with exclusive turn phases for public transport, cyclists and pedestrians		✓	✓	✓			✓	✓	
Grade-separation of pedestrians and cyclists from vehicular traffic		✓		✓					
Roundabouts with 20/30 km/h wombat crossings		✓	✓		✓	✓	✓	✓	✓
Threshold platforms at intersections with side-streets		✓	✓	✓	✓	✓		✓	
Raised intersections with 30 km/h (or lower) platforms		✓	✓	✓	✓	✓	✓	✓	✓
Signalised 'tennis ball' intersections (30 km/h design)		✓	✓					✓	
All-way stop signs		✓	✓			✓		✓	✓
Restricted access intersection	✓	✓	✓			✓		✓	✓

Source: (Austroads, 2020c)

Table E.1: Listing of Pedestrian and Cyclist Safety Measures at Intersections and Alignment with Safe System Principles

Speed Environment within a Movement & Place Framework

Main Roads has recently updated the online document "Speed Zoning – Policy and Application Guidelines" (Main Roads WA, 2022) to allow for a road's form and function in terms of Movement and Place to identify the appropriate Target Speed(s)[9].

The matrix presented in Table E.2 provides a high-level overview of suitable Target Speeds for different categories of roads within the broader WA network.

Level of Movement Function		Level of Place Value				
		Highest	High	Moderate	Low	Lowest
	Increasing significance	Indicative Target Speed (in km/h):				
	Primary/Regional Distributor*	50-60	50-70	60-80	80-100	100-110
	District Distributor A/B	40-50	50-60	60-80	80-100	100-110
	Local Distributor	30-50	40-60	60-70	80-100	100-110
	Access Roads	10-50	30-50	50-70	80-100	100-110

*Except for School Zones, which are 40 km/h.

Table E.2: Movement and Place Framework and Target Speed Range

The Movement and Place framework illustrated in Table E.2 contains a wide range of actual roadway types. The expanded Table E.3 provides indicative Target Speed values for specific types of roads that exist within the Movement and Place Framework. This expanded table is intended to supplement Table E.2, and is to be used in place of AS 1742.4-2008 Table 2.1.

Table E.2 and E.3 clearly show that Target speeds should be reduced with increasing Place value.

Movement Function	Place Value	Typical Road Application	Key Features	Indicative Target Speed
Access and Local Distributor Roadways				
Access	Highest	Pedestrian mall, extremely narrow urban thoroughfares, Shared Zones	Confined area where movement of pedestrians and cyclists has priority over motor vehicles. Generally the volume of traffic is very low.	10
Access	Highest (within destination)	Shared Spaces/ Pedestrian Priority Areas	Areas where pedestrians and cyclists intermingle with motor vehicles.	20

[9] *The Target Speed is the speed considered appropriate for a roadway in light of its form, function, environment, and risk profile. It is the maximum desired Operating Speed of traffic during periods of free flow.*

Movement Function	Place Value	Typical Road Application	Key Features	Indicative Target Speed
Access	Highest to High	Recreational Precincts, Safe Active Streets	Confined areas where pedestrians and cyclists intermingle with motor vehicles.	30
Access and Local Distributors	Highest	Town Centre / Commercial streets or areas	Areas with high pedestrian activity or very strong existing place functions including extensive on-street activity. Must have traffic calming infrastructure to reinforce a low speed environment. Pedestrians and vehicles separated.	30-50
Access and Local Distributors	High	Neighbourhood Streets	Narrow streets with significant residential development, on street parking, adjacent neighbourhood parks and playgrounds, etc.	40-50
Access and Local Distributor	Moderate	Industrial precincts	Wider/unmarked carriageways, mix of heavy and light vehicle traffic, limited pedestrian activity.	50-70
Access and Local Distributors	Moderate to Low	Low standard roads in rural/ semi-developed areas	Minor roads in partially built-up areas	60-80
Access and Local Distributors	Low	Rural or remote roads	Low standard/higher risk roads in rural/regional environments	80-100
Access and Local Distributors	Lowest	Rural or remote roads	Rural roads with limited development and roadside hazards	110
District Distributor Roadways				
District Distributors A or B	Highest to High	Town Centre street and areas	Distributor roads in Activity Centres/Town centres with high Place values	30-60
Movement Function	**Place Value**	**Typical Road Application**	**Key Features**	**Indicative Target Speed**
District Distributor A or B	High to Moderate	Typical Undivided Arterial within Urbanised Area	Speed limit for most undivided district and primary distributor roads in built-up areas with direct access from abutting development.	50-60
District Distributor A or B	Moderate	Typical Divided Arterial within Urbanised Area	High standard urban Distributor roads, generally divided carriageways having provision to safely store turning or crossing vehicles. May have some direct access to the road from abutting development.	60-70

Movement Function	Place Value	Typical Road Application	Key Features	Indicative Target Speed
District Distributor A or B	Moderate	Local Roads in Semi-Rural/Rural Residential Areas	Undivided roads having low levels of direct access from abutting development.	60-80
District Distributor A or B	Low to Lowest	High Standard Divided Urban Arterial Roads	High standard urban roads, divided roads having provision to safely store turning or crossing vehicles and minimal access from abutting development directly to the main carriageways.	80
District Distributor A or B	Low	Rural Roads	Undivided rural roads having low levels of direct access from abutting development.	110
Primary and Regional Distributor Roadways				
Primary /Regional Distributor	Highest	Town Centre street and areas	Distributor Roads in Activity Centres/Town centres with high Place values	40-60
Primary /Regional Distributor	High	Urbanised areas	Primary Distributors with direct access in urban areas	50-70
Primary /Regional Distributor	Moderate	Urbanised areas	Primary Distributors in urban or semi-urban areas	60-80
Primary /Regional Distributor	Low	Rural Roads	Rural roads not compliant with current design standards (e.g. winding roads, rural roads with high demonstrated risk factors)	80-100
Primary /Regional Distributor	Low to Lowest	Urban Freeways/ Highways and Rural Roads	High standard urban freeways and highways. May be applied on undivided rural roads.	80-110
Primary /Regional Distributor	Lowest	High Standard Freeways/Highways and Rural Highways	Default speed limit for roads in non built-up areas.	110

Table E.3: Typical Target Speeds Range for Road Types

Quantifying a "Significant" No. of Vulnerable Road Users within a Movement & Place Framework

The discussion above has illustrated the current trend towards adopting a "harm minimisation" approach with respect to vulnerable road users within the Movement and Place framework; essentially those areas that have high vulnerable road user activity (or would be expected to attract vulnerable road users) require lower speeds.

The critical point here is that it is not so much the number of vulnerable road users that is important but rather the recognition that roads (and associated intersections) with high place value should be designed to cater for pedestrians and cyclists, regardless of the number.

Following on from this, the definition of a "significant" number of vulnerable road users may be expanded as follows:

The number of vulnerable road users using an intersection is considered "significant" if the intersection is located on a road or street that has a high place value, regardless of the actual number of vulnerable road users.

In the absence of a local framework, the Movement and Place Framework shown in Figure E.7 may be used and guidance on appropriate facilities may be obtained from Table E.1. Table E.2 may be used to identify an appropriate range of target speeds, bearing in mind the following:

- The aspirational safe operating speed where there is a possibility of a collision between a vulnerable road user and a passenger car is 30 km/h, and
- There are methods to reduce the operating speed through intersections below that of the posted speed limit (e.g. pre-deflection, Raised Safety Platforms, wombat crossings etc.)