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Guide to Traffic Management Part 6

Intersections, Interchanges and Crossings



Guide to Traffic Management Part 6: Intersections, Interchanges and Crossings



Austroads

Sydney 2017

Guide to Traffic Management Part 6: Intersections, Interchanges and Crossings

Third edition prepared by: Lisa Steinmetz and Peter Aumann

Third edition project manager: Dave Landmark

Abstract

The Austroads *Guide to Traffic Management* consists of 13 Parts. It provides a comprehensive coverage of traffic management guidance for practitioners involved in traffic engineering, road design and road safety.

Part 6 (Intersections, interchanges and crossings) is concerned with traffic management at all types of intersections where road users must join or cross another stream of traffic. It focuses on traffic management issues and treatments related to intersections, interchanges and crossings. It does not provide information on the geometric design of the treatment as this is provided in the Austroads *Guide to Road Design Part 4, 4A, 4B and 4C*. Guidance on the management of road sections which are not part of the intersection or interchange is provided in the Austroads *Guide to Traffic Management Part 5: Road Management*.

Part 6 describes the appropriate use of, and design of, the various intersection types and the techniques that need to be applied if efficient and safe intersections are to be provided to the road user. All categories of road use – including cars, trucks, public transport, motorcycles, cyclists and pedestrians, including people who have disability or mobility difficulty, are addressed in the Guide.

Keywords

Traffic management objectives, intersection type, intersection selection, intersection performance, unsignalised, signalised, roundabout, interchange, road user, pedestrians, cyclists, traffic control, road space allocation, lane management, functional design, signs and road markings, interchange, ramp layouts, metering, rail crossings, railway crossing, pedestrian crossing, cyclist crossing, bicycle paths, bicycle path terminal treatments

Edition 3.1 published June 2018

Edition 3.0 published July 2017

Second edition published April 2013

First edition published November 2007

Edition 3.1 corrects the caption to Figure 2.26(c).

Edition 3.0 has been updated to reflect updates in Austroads Guides, as well as recent relevant research, emerging guidance and best practices, including the Safe System approach, Safe System Assessment Framework, vulnerable road users, network operations planning and managed motorways. New commentaries on emerging issues have also been provided including unconventional and innovative intersection designs and the rural intersection active warning system (RIAWS).

ISBN 978-1-925451-89-4

Austroads Project No. NP2023

Austroads Publication No. AGTM06-17

Pages 216

Publisher

Austroads Ltd.
Level 9, 287 Elizabeth Street
Sydney NSW 2000 Australia

Phone: +61 2 8265 3300

austroads@austroads.com.au
www.austroads.com.au



About Austroads

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

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

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

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- Roads Corporation Victoria
- Queensland Department of Transport and Main Roads
- Main Roads Western Australia
- Department of Planning, Transport and Infrastructure South Australia
- Department of State Growth Tasmania
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Acknowledgements

First edition prepared by David Bennett, Peter Croft, Gary Veith, James Luk, Peter Freeman, John Bliss, Bruce Howard, Garry Mason and Milan Prodanovic and project managed by Gary Little. Second edition prepared by Michael Levasseur, Peter Croft, David Bennett, Gary Veith, James Luk, Peter Freeman, John Bliss, Bruce Howard, Garry Mason and Milan Prodanovic and project managed by Steve Brown.

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1. Introduction

1.1 Scope of this Guide

Part 6 of the Austroads *Guide to Traffic Management* has been given the title *Intersections, Interchanges and Crossings* to define the limitations on its scope within the contexts of:

- the 13 different Parts of the *Guide to Traffic Management*
- the nine different Guides series spanning the range of Austroads publications.

The structure and content of the *Guide to Traffic Management* is discussed in *Part 1: Introduction to Traffic Management* (Austroads 2015a). Brief details of the 13 Parts are summarised in Table 1.1.

Part 6 is restricted to traffic management at locations where different traffic streams intersect each other. The following Guides address issues related to other aspects of traffic management:

- *Part 3* (Austroads 2013) – guidance on the importance of traffic data and its analysis for the purpose of traffic management and control within a network.
- *Part 4* (Austroads 2016b) – considers issues at the network level such as needs for heavy vehicles, public transport users, pedestrians, cyclists and private motor vehicles, as well as guidance on network operation planning.
- *Part 5* (Austroads 2014b) – mid-block traffic management issues that apply to a single length of road.
- *Part 9* (Austroads 2016c) – operational management of road space for all users and describes current practice for common systems including traffic signal, congestion management, incident management and traveller information systems.
- *Part 10* (Austroads 2016d) – design and use of traffic control and communication devices.

The scope of *Part 6* is therefore **traffic management** in relation to all types of road intersections, including grade-separated interchanges, as well as rail crossings and pedestrian and cyclist crossings of roads, and bicycle paths and shared paths.

Note that within this Guide, reference to a 'Part' refers to a part of the Guide (as outlined in Table 1.1). Reference to a numbered 'section', pertains specifically to a section of *Part 6*.

In the context of the other Guides within the Austroads range of publications, this Guide is restricted to traffic management advice, and refers only briefly to issues more appropriately addressed in other Guides. It is recognised that it is difficult, if not impossible, to discuss many aspects of traffic management without reference to road design and/or safety issues, but the view is taken that within the *Guide to Traffic Management* any such reference should be brief and be supported by references to the *Guide to Road Design* and/or the *Guide to Road Safety* (refer to scope statements in the *Guide to Road Design* and *Guide to Road Safety*).

Parts 4, 4A, 4B and 4C of the *Guide to Road Design* (Austroads 2017a, 2017b, 2015b, 2015c) pertain to intersections and crossings. They are therefore particularly relevant to *Part 6* of the *Guide to Traffic Management* which provides guidance on traffic management aspects, including the selection of intersection type, including considerations for various road user types. Guidance relating to design parameters is provided in the *Guide to Road Design Parts 4, 4A, 4B and 4C* together with typical layouts of various intersections, interchanges and crossings and other relevant facilities.

Table 1.1: Parts of the *Guide to Traffic Management*

Part	Title	Content
Part 1	Introduction to Traffic Management	<ul style="list-style-type: none"> • Introduction to the discipline of traffic management. • Breadth of the subject and the relationship between the various Parts of the Guide.
Part 2	Traffic Theory	<ul style="list-style-type: none"> • An introduction to the characteristics of traffic flow and the theories, models and statistical distributions used to describe many traffic phenomena. • Processes that practitioners should consider.
Part 3	Traffic Studies and Analysis	<ul style="list-style-type: none"> • Traffic and transport data collection surveys and studies. • Traffic analysis for mid-block situations (including freeways/motorways). • Analysis of signalised and unsignalised intersections, including roundabouts.
Part 4	Network Management	<ul style="list-style-type: none"> • Broad strategies and objectives of managing networks of roads to provide effective traffic management for all road users. • Network needs for heavy vehicles, public transport users, pedestrians, cyclists and private motor vehicles. • Guidance on transport networks and network operation planning.
Part 5	Road Management	<ul style="list-style-type: none"> • Guidance on managing mid-block traffic conditions. • Good practice for access management, allocation of space to various road users, lane management. • Application of speed limits.
Part 6	Intersections, Interchanges and Crossings	<ul style="list-style-type: none"> • Types of intersections and selection of intersection type. • Appropriate use and design of various intersection types. • Traffic management issues and treatments for intersections, interchanges and other crossings.
Part 7	Traffic Management in Activity Centres	<ul style="list-style-type: none"> • Principles for planning the management of traffic in activity centres and associated transport nodes. • Techniques for traffic management in activity centres. • Examples and key considerations for various types of centres.
Part 8	Local Area Traffic Management	<ul style="list-style-type: none"> • Planning and management of road space in a local area. • Guidance on selection, design, application and effectiveness of traffic control measures on an area-wide or at least whole-of-street basis.
Part 9	Traffic Operations	<ul style="list-style-type: none"> • Applications used in traffic operations. • System configuration and operation guidance. • Current practice for common systems including network monitoring, traffic signals, congestion management, incident management, freeway/motorway management and traveller information. • Related systems integration and interoperability issues.
Part 10	Traffic Control and Communication Devices	<ul style="list-style-type: none"> • Signing and marking schemes. • Traffic signs, static and electronic. • Pavement markings and delineation. • Traffic signals and islands.
Part 11	Parking	<ul style="list-style-type: none"> • Parking policy. • Demand and supply. • On-street and off-street parking. • Parking guidance and control devices.
Part 12	Traffic Impacts of Developments	<ul style="list-style-type: none"> • Guidance on the need and criteria for impact assessment. • Detailed procedure for identifying and assessing traffic impacts and mitigating their effects. • Assessment of safety, infrastructure and environmental effects.
Part 13	Road Environment Safety	<ul style="list-style-type: none"> • Principles and management of the safety of road environments within a traffic management context. • Links to relevant sections of the <i>Guide to Road Design</i> and <i>Guide to Road Safety</i>.

Within this Part of the Guide reference is made to Australian Standard AS 1742 *Manual of Uniform Traffic Control Devices (MUTCD)* (see References for details of Parts). In New Zealand the equivalent reference is the *Traffic Control Devices (TCD) Manual* (NZ Transport Agency (NZTA) 2008c)¹.

Within the above limits, the scope of this Guide is broad, addressing traffic interactions at road intersections and crossings across a range of situations that include:

- both urban and rural environments
- freeways, motorways and arterial roads
- all categories of road use by cars, trucks, public transport, motorcycles, cyclists and pedestrians, including people who have vision, mobility or hearing impairments.

1.2 Third Edition of Part 6 of the Guide to Traffic Management

Since the last edition of *Part 6* was published in 2013, practices related to the management of intersections, interchanges and crossings have continued to evolve. Additionally, a number of Parts of the *Guide to Traffic Management*, *Guide to Road Design*, other Austroads Guides, research reports and relevant international publications have become available since the previous edition of *Part 6* was published. This edition has been updated to reflect recent relevant emerging guidance and best practices, including the Safe System approach, managed motorways and network operations planning.

1.3 Safety Objectives

Safety is a prime objective in traffic management. It is pursued in accordance with the Safe System approach which underpins the national road safety strategies in Australia and New Zealand. The Safe System approach to road safety management recognises that humans make errors, that crashes will continue to occur and that humans have a limited tolerance to impact forces (Figure 1.1).

The aim of the Safe System approach is to provide a safer road and traffic environment in which alert and responsible road users should not be killed or seriously injured as a result of a crash. It 'involves careful consideration of' the interrelationship 'between road infrastructure, travel speeds, road users and vehicles' (Austroads 2015d).

The holistic approach to achieving the Safe System vision is presented in Figure 1.1.

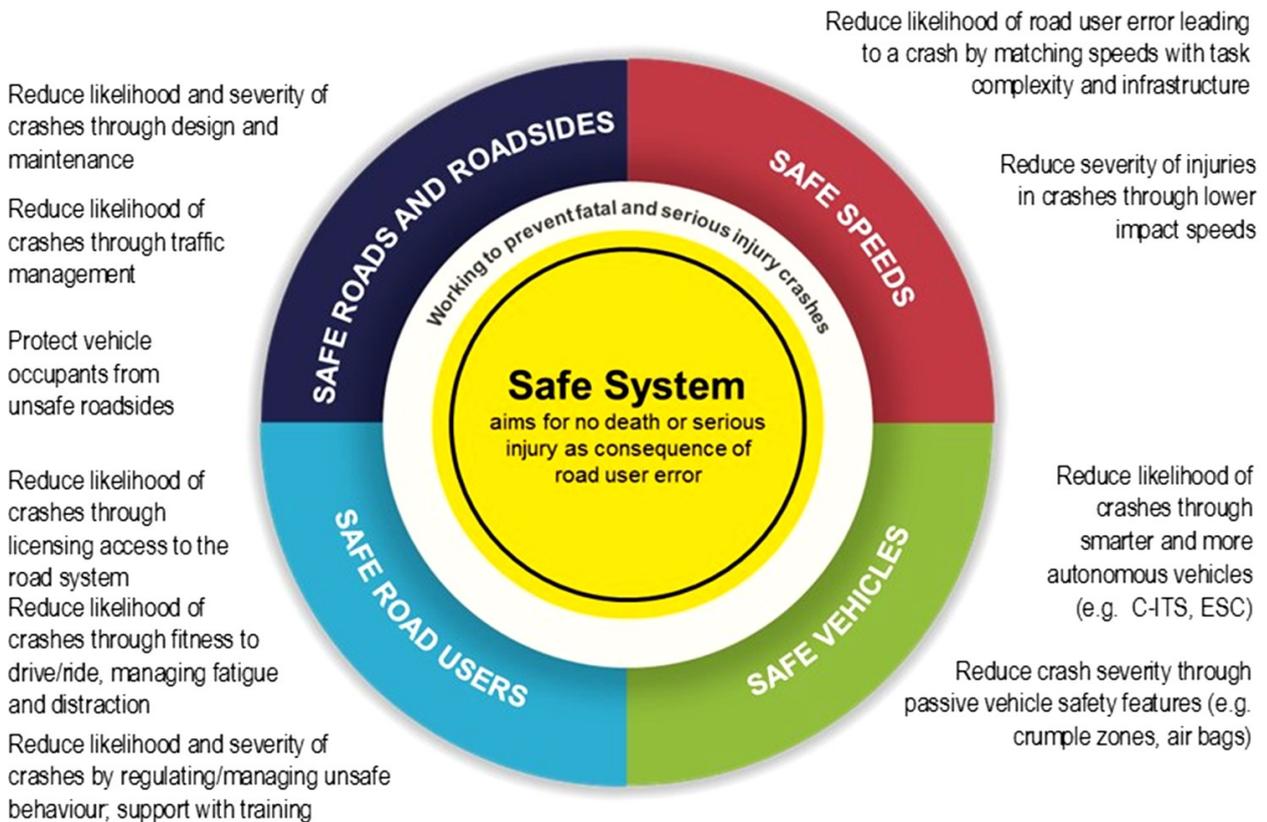
In the context of providing and managing intersection facilities, the Safe System approach aims to ensure that potential collisions are avoided and, if they occur, that the potential crash impact forces do not exceed human tolerances (i.e. aiming to minimise the risk of fatal or serious injury). The Safe Roads and Roadside, and Safe Speeds pillars (see Figure 1.1) are key for providing safe intersections. 'Road infrastructure influences driver selection of speed, and operating speed influences design of the road infrastructure. Thus, any road infrastructure objective seeking safety performance improvement towards the Safe System needs to focus on both pillars' (Austroads 2015d).

Speed at intersections is a critical factor. Pedestrians and cyclists are particularly vulnerable. Safe System critical impact speeds (that represent a 10% severe (fatal or serious injury (FSI) risk) for key crash types are discussed in Section 2.5.1.

The provision of intersection facilities and related features on the approach roads must therefore strive to reduce potential impact speeds to below critical impact speeds. From the pedestrian safety perspective, this is particularly relevant to local roads and streets in the urban network where pedestrian activity, and the potential for conflicts, is greatest.

¹ Note the relevant part of the TCD Manual may be unpublished, in which case refer to the Manual of Traffic Signs and Markings (MOTSAM) (NZ Transport Agency (NZTA) 2010a, 2010b). MOTSAM is being progressively replaced by the TCD Manual (in press).

Figure 1.1: Holistic approach to achieving the Safe System vision



Source: (Austroads 2015d), based on Australian Transport Council (2008), Ministry of Transport (2010) and Office of Road Safety (2009).

In summary, road infrastructure is well-aligned with Safe System objectives if it (Austroads 2015d):

- considers and performs for all relevant road users
- is forgiving of road users' errors
- has fail-safe redundancies
- focuses on the minimisation of fatalities and serious injuries.

1.4 Traffic Management Objectives

The objectives of traffic management are discussed in *Part 1* of the *Guide to Traffic Management*. 'An overall aim of traffic management is to facilitate the operation of traffic on the roads with safety and efficiency, taking into account' needs of all relevant road users (Austroads 2015a).

This aim is particularly relevant to intersections and crossings because:

- a large proportion of road crashes occur at intersections
- the capacity of road systems is often determined by the capacity of its intersections
- conflict between different types of road or rail users often occurs at intersections/crossings.

A summary of traffic management and design objectives for intersections and crossings is presented in Table 1.2.

Table 1.2: Objectives for intersections and crossings

Category	Objective
General	<ul style="list-style-type: none"> • Design the intersection to be as safe as possible. • Accommodate the needs of road users (across all transport modes) and adjacent land uses. A Network Operation Plan (NOP) can provide guidance on setting objectives of intersections and crossings. • Cater appropriately for the movements of road users. • Provide adequate facilities for all road users and their varied needs. • Maximise driver comfort. • Minimise costs. • Minimise adverse environmental effects. • Consistency of approach.
Arterial roads	<ul style="list-style-type: none"> • Ensure adequate capacity. • Minimise delays. • Ensure consistency of design standards and management systems. • Provide a high standard of service to public transport where warranted. • Provide a high standard of service to heavy vehicles (i.e. freight) where warranted.
Local roads	<ul style="list-style-type: none"> • Discourage entry of non-local traffic. • Control vehicle speeds. • Restrict entry of large heavy vehicles, where appropriate. • Provide appropriate access and route conditions for bus services. • Provide adequate access for service vehicles and emergency vehicles.
Rail crossings	<ul style="list-style-type: none"> • Ensure safety for all rail and road users, pedestrians (including people who have a vision, mobility or hearing impairment), cyclists and others. • Minimise and appropriately balance delays for rail users, road users and others.
Pedestrian and cyclist crossings	<ul style="list-style-type: none"> • Protect the vulnerable at road crossings. • Provide safety and efficiency at crossings of footpaths, bicycle paths and shared paths.

The development of an appropriate intersection or crossing may require a traffic engineer or road designer to apply the following principles:

- Consider network operation objectives and, based on these, develop road use priorities for various road users. That is, where and when appropriate, give preference to major traffic movements or specific road or rail users.
- Recognise and understand the human, vehicle, road, rail and environmental factors that apply to the site.
- Provide adequate facilities for all road users and their various needs, including cyclists, pedestrians, public transport patrons, and people whose disability, illness or injury impacts their mobility, including those with sensory disability (e.g. vision or hearing impairment), temporary injury or the elderly.
- Design to accommodate public transport vehicles and heavy vehicles.
- Provide adequate warning of the presence of the intersection or crossing through clear sight lines and appropriate signage.
- Ensure that the layout is easily recognised and consistent and that legal priorities are clear.
- Provide adequate sight distances between conflicting road or rail users.
- Design to accommodate appropriate vehicle operating speeds.
- Minimise the number of conflict points.
- Minimise the relative speed of conflicting movements, taking due cognisance of the impact speeds considered critical for avoiding severe injury for the various crash types.
- Ensure that traffic control devices can be satisfactorily accommodated within the road reservation, medians and traffic islands.

2. Selection of Intersection Type

2.1 General

This section describes the types of intersections available (Section 2.2), factors that may influence the selection of an appropriate type of intersection (Section 2.3), and considerations for specific road user groups (Section 2.4). Intersection selection involves consideration of safety, operational performance or other factors in order to maximise safe mobility (i.e. the safest practicable treatment that also provides an acceptable level of mobility). An evaluation of any planned treatment or new intersection is required to identify potential concerns and allow refinement of options for further consideration (Section 2.5).

For detailed guidance on the layout design of intersection treatments, refer to *Parts 4, 4A, 4B and 4C* of the *Guide to Road Design* (Austroads 2017a, 2017b, 2015b and 2015c).

2.2 Types of Intersections

2.2.1 Considerations

The types of intersections found on the road system can be broadly categorised as:

- at-grade intersections
- grade separated intersections (interchanges).

The basic forms of at-grade intersections are:

- three-leg (e.g. T-intersection)
- four-leg (e.g. cross-intersection)
- multileg (five or more legs).

Within these basic forms an intersection may be:

- signalised or unsignalised which can include roundabouts
- an urban or rural intersection to which different driver expectations and hence different design and traffic management guidelines may apply.

While the broader traffic management considerations are very important, the choice of intersection layout must be considered for safe and efficient operation. Forms of an intersection may be:

- channelised (i.e. providing traffic islands and/or medians) to develop specific types of intersections, or unchannelised
- flared, to provide additional through and/or turning lanes
- unflared.

The types of intersections within the above broad categories and their characteristics are listed in Table 2.1. Further layout considerations – including turning treatments (basic, auxiliary and channelised) and other types of intersection treatments including rural and urban intersection, staggered T-intersection, seagull and wide median treatments – are addressed in this section.

Table 2.1: Summary of road intersection types

Intersection type	Comments	Reference
At-grade intersections		
Roundabout	General – traffic management considerations.	See Section 2 and Section 3
	<ul style="list-style-type: none"> • Are usually very safe for motor vehicles but can be unsafe and intimidating for pedestrians and cyclists. Roundabouts on local streets and collector roads have a high likelihood that pedestrians and cyclists will be present and should therefore be designed to restrict vehicle entry speeds to 20–30 km/h (see Commentary 1). <li style="text-align: right;">[see Commentary 1] • All intersecting traffic circulates clockwise around a central (usually circular) island with priority to the circulating traffic. • Generally uses either single or double-lane configuration. • Regulatory roundabout signs are often used at each roundabout entrance. • Approaches may be signalised to manage entering traffic in order to reduce delays on the subsequent entry. • May be provided with left-turn slip lanes where the intersection angle is acute or where left-turn volume high (with an auxiliary lane). • In appropriate circumstances a ‘by-pass’ lane (similar to a seagull treatment) may be provided so that one through movement does not have to pass through the circulating roadway. It is important that design standards are adequate. • Primary (or transformational) Safe System treatment type which eliminate, as far as practicably possible, the occurrence of fatal and serious injuries. 	<p>For design details, see <i>Part 4</i> and <i>Part 4B</i> of the <i>Guide to Road Design</i> (Austroads 2017a, 2015c).</p> <p>See AS 1742.2.</p> <p>For guidance on Primary (transformational) Safe System solutions see <i>Safe System Assessment Framework</i> (Austroads 2016a).</p>
Signalised	General – traffic management considerations.	See Section 2 and Section 4.
	Basic	See Section 2.2.2.
	<ul style="list-style-type: none"> • Undivided roads intersect at cross, T or multileg intersections. 	<p>For turn treatment warrants, see Section 2.3.6.</p> <p>For design details, see <i>Part 4</i> of the <i>Guide to Road Design</i> (Austroads 2017a).</p>
	Channelised	See Section 2.3.4.
<ul style="list-style-type: none"> • May comprise small median islands to accommodate traffic signals or a complex arrangement of medians and islands. • Operational and capacity issues usually arise at multileg intersections because of the number of signal phases required, and accommodation of right-turns is often impracticable because of the additional phases and turning angles that result. 	<p>For turn treatment warrants, see Section 2.3.6.</p> <p>For design details, see <i>Part 4</i> of the <i>Guide to Road Design</i>.</p>	
Staggered T-intersection	<ul style="list-style-type: none"> • Uses deviation of one or both minor road approaches and channelisation to control vehicle speed across the major road. • Usually is substantially less efficient than a cross-intersection because of overlapping turns from minor roads and longer clearance times. • Left-right configuration generally preferred over right-left (in terms of safety), however offset direction is context dependent. 	<p>See Section 2.2.7.</p> <p>For design details, see <i>Part 4</i> of the <i>Guide to Road Design</i>.</p>

Intersection type	Comments	Reference
	<p>Seagull</p> <ul style="list-style-type: none"> • Refer to unsignalised intersections. • Only one through direction of traffic is signalised unless pedestrian and/or cyclist access is required across major road. 	<p>See Section 2.2.8. For design details, see <i>Part 4</i> of the <i>Guide to Road Design</i>.</p>
	<p>Offset right-turn lanes</p> <ul style="list-style-type: none"> • Refer to unsignalised intersections. • May assist in providing more efficient signal control and aid sight lines for filter right-turns. 	<p>See Sections 2.2.5 and 2.2.6. For design details, see <i>Part 4</i> of the <i>Guide to Road Design</i>.</p>
Unsignalised	<p>General – traffic management considerations.</p>	<p>See Section 2 and Section 5.</p>
	<p>Basic</p> <ul style="list-style-type: none"> • Intersecting roads (with kerbs or shoulders) meet with no auxiliary lanes or channelisation. • Cross-intersections usually controlled by stop or give way signs or line marking. • T-intersections on local roads may have no traffic control devices – legal priority defined in Australian Road Rules or New Zealand Land Transport Rules. • Multileg and Y- intersections should be avoided, if possible, but if used, clarification of priorities is essential. 	<p>See Section 2.2.2. For turn treatment warrants, refer to Section 2.3.6. For design details, see <i>Parts 4</i> and <i>4A</i> of the <i>Guide to Road Design</i> (Austroads 2017a, 2017b). See AS 1742.2.</p>
	<p>Channelised</p> <ul style="list-style-type: none"> • Traffic islands and/or medians used to define vehicle paths into and through intersections. • Usually controlled by stop or give way signs or line marking. • Travel path directions need to be clear for drivers. 	<p>See Section 2.2.4. For turn treatment warrants, see Section 2.3.6. For design details, see <i>Part 4</i> of the <i>Guide to Road Design</i>.</p>
	<p>Staggered T-intersection</p> <ul style="list-style-type: none"> • Generally retrofitted to hazardous rural cross-intersections. • Deviation of one or both minor road approaches and channelisation to control vehicle speed across the major road. • Left-right stagger configuration is generally preferred over right-left (in terms of safety), however offset direction is context dependent. • Often controlled by stop or give way signs or line marking. Particularly on local streets there may be no traffic control devices, in which case, legal priority rule applies (defined in Australian Road Rules or New Zealand Land Transport Rules). 	<p>See Section 2.2.7. For design details, see <i>Part 4</i> of the <i>Guide to Road Design</i>.</p>
	<p>Seagull</p> <ul style="list-style-type: none"> • Generally used only at T-intersections. • Channelised so that traffic from the minor road accepts a gap in the traffic stream from its right in the major road but has either a merge or a dedicated lane to enter the traffic stream from the left. • Controlled by stop or give way signs and line marking. • Caution in use is recommended, particularly in high speed areas. Roundabouts are preferred to seagulls. 	<p>See Section 2.2.8. For design details, see <i>Part 4</i> of the <i>Guide to Road Design</i>.</p>

Intersection type	Comments	Reference
	<p>Wide median treatment (WMT)</p> <ul style="list-style-type: none"> • Has some design features of a roundabout, but a WMT gives priority to major road drivers. • Generally used on high-speed rural divided roads where it is necessary to retain a crossroad and physically control the speed of crossing traffic. • To minimise driver confusion, WMTs and roundabouts should not be alternated along the same route nor used in close proximity to each other. • Controlled by stop or give way signs and line marking. 	<p>See Section 2.2.9. For design details, see <i>Part 4</i> and <i>Part 4A</i> of the <i>Guide to Road Design</i>.</p>
	<p>Two-staged crossing</p> <ul style="list-style-type: none"> • Generally used in rural areas where wide medians of a major road permits storage of vehicles between the carriageways. • Controlled by stop or give way signs and line marking. 	<p>See Section 2.2.5. For design details, see <i>Part 4</i> and <i>Part 4A</i> of the <i>Guide to Road Design</i>.</p>
	<p>Offset right-turn lanes</p> <ul style="list-style-type: none"> • Suitable where there are wide medians. • Controlled by stop or give way signs and line marking. 	<p>See Section 2.2.5 and 2.2.6. For design details, see <i>Part 4</i> and <i>Part 4A</i> of the <i>Guide to Road Design</i>.</p>
	<p>Intersections with service roads</p> <ul style="list-style-type: none"> • Service roads are provided adjacent to divided roads to separate local access traffic movements from traffic on the main carriageways and sometimes adjacent to undivided major roads. • Controlled by stop or give way signs and line marking. 	<p>See Section 2.2.6. For guidance on access issues pertaining to service roads, see <i>Part 5</i> of the <i>Guide to Traffic Management</i> (Austroads 2014b). For design details, see <i>Part 4</i> of the <i>Guide to Road Design</i>.</p>
Interchanges		
Motorway/motorway	<ul style="list-style-type: none"> • Consists of an interchange between freeways or motorways. • All turning movements are via direct, semi-direct or loop ramps. 	<p>See Section 6 and <i>Part 4C</i> of the <i>Guide to Road Design</i> (Austroads 2015b).</p>
Motorway/arterial	<ul style="list-style-type: none"> • Consists of an interchange between a freeway or motorway and a road of lower functional classification. • Generally at-grade intersections are provided at ramp terminals although loop ramps are often used. 	<p>See Section 6 and <i>Part 4C</i> of the <i>Guide to Road Design</i> for design details.</p>
Arterial/arterial	<ul style="list-style-type: none"> • Consists of an interchange between two arterial roads. • At-grade intersections are provided at ramp terminals. • May have mixed use ramps (i.e. access and parking). 	<p>See Section 6 and <i>Part 4C</i> of the <i>Guide to Road Design</i> for design details.</p>

2.2.2 Basic Turn Treatments (Type BA)

BA turn treatments comprise:

- basic right-turn treatments (BAR) on major roads (two-lane undivided roads only)
- basic left-turn treatments (BAL) on major roads (two-lane undivided roads and multilane roads)
- basic left-turn treatments (BAL) on minor roads (lane also used for right-turn movements).

These type of turn treatments are:

- the simplest layouts
- designed to be as compact (and inexpensive) as possible
- most appropriately used where the volume of turning and through traffic is very low and where a channelised treatment is not able to be implemented (only used on two-lane, two-way roads, i.e. it does not apply to multilane roads)
- comprised of carriageways that intersect with an appropriate corner radius and taper to suit the swept path of the design vehicle
- used with any wearing surface
- required to be installed with adequate delineation (regular maintenance may be required)
- required to be located where adequate sight distance is available and good perception of the treatment is provided.

Alternatively, an auxiliary lane may be considered (Section 2.2.3).

Rural basic (BA) turn treatments

Figure 2.1 shows the features of rural BA turn treatments at T-intersections, namely:

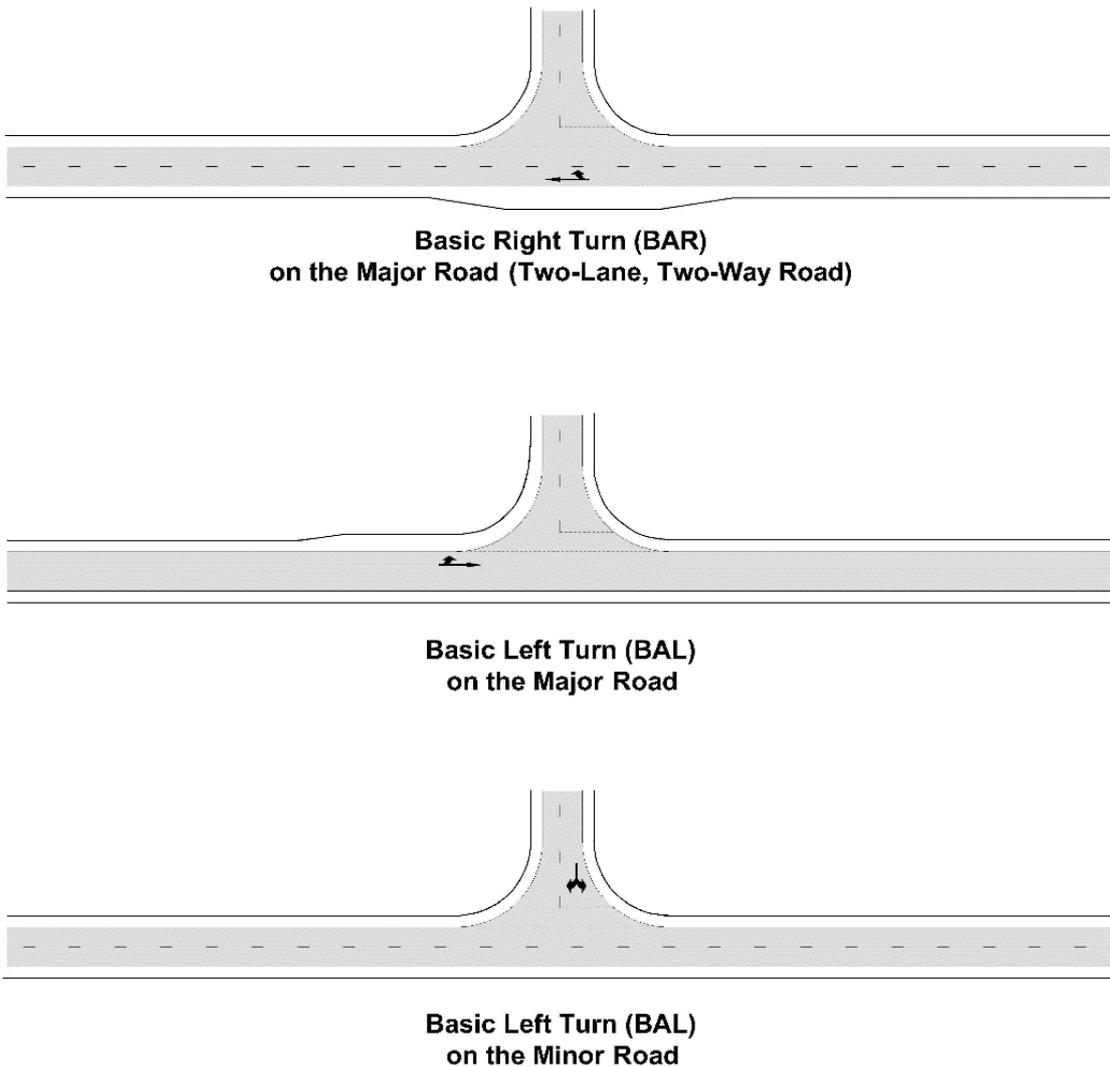
- the BAR treatment features a widened shoulder on the major road that allows through vehicles, having slowed, to pass to the left of turning vehicles
- the BAL treatment on the major road has a widened shoulder, which assists turning vehicles to move further off the through carriageway, thus making it easier for through vehicles to pass
- the BAL turn treatment on the minor road allows turning movements from a single lane with a shoulder that is too narrow to be used by left-turning vehicles (to prevent drivers from standing two abreast at the holding line).

Where the major road is sealed it is preferred that the widened shoulders are also sealed, unless the shoulders can be maintained with a sound and even surface in all weather conditions. Research (Arndt 2004) has shown that BAR turn treatments record a rear-end major vehicle crash rate 52 times higher than do channelised right-turn (CHR) treatments. The research also found that the rear-end major vehicle crash rate decreases substantially with increased median width, regardless of the type of median (painted, raised or depressed). Commentary 2 provides some more information in relation to the findings of Arndt (2004).

[\[see Commentary 2\]](#)

Turning treatment warrants are discussed in Section 2.3.6. For design details of rural BA turn treatments refer to the *Part 4 of the Guide to Road Design* (Austroads 2017a).

Figure 2.1: Rural basic (BA) turn treatments



Note: Diagram illustrates principles, not detailed design. Arrows indicate movements relevant to turn type; they do not represent actual pavement markings.

Source: Adapted from Queensland Department of Main Roads (2006).

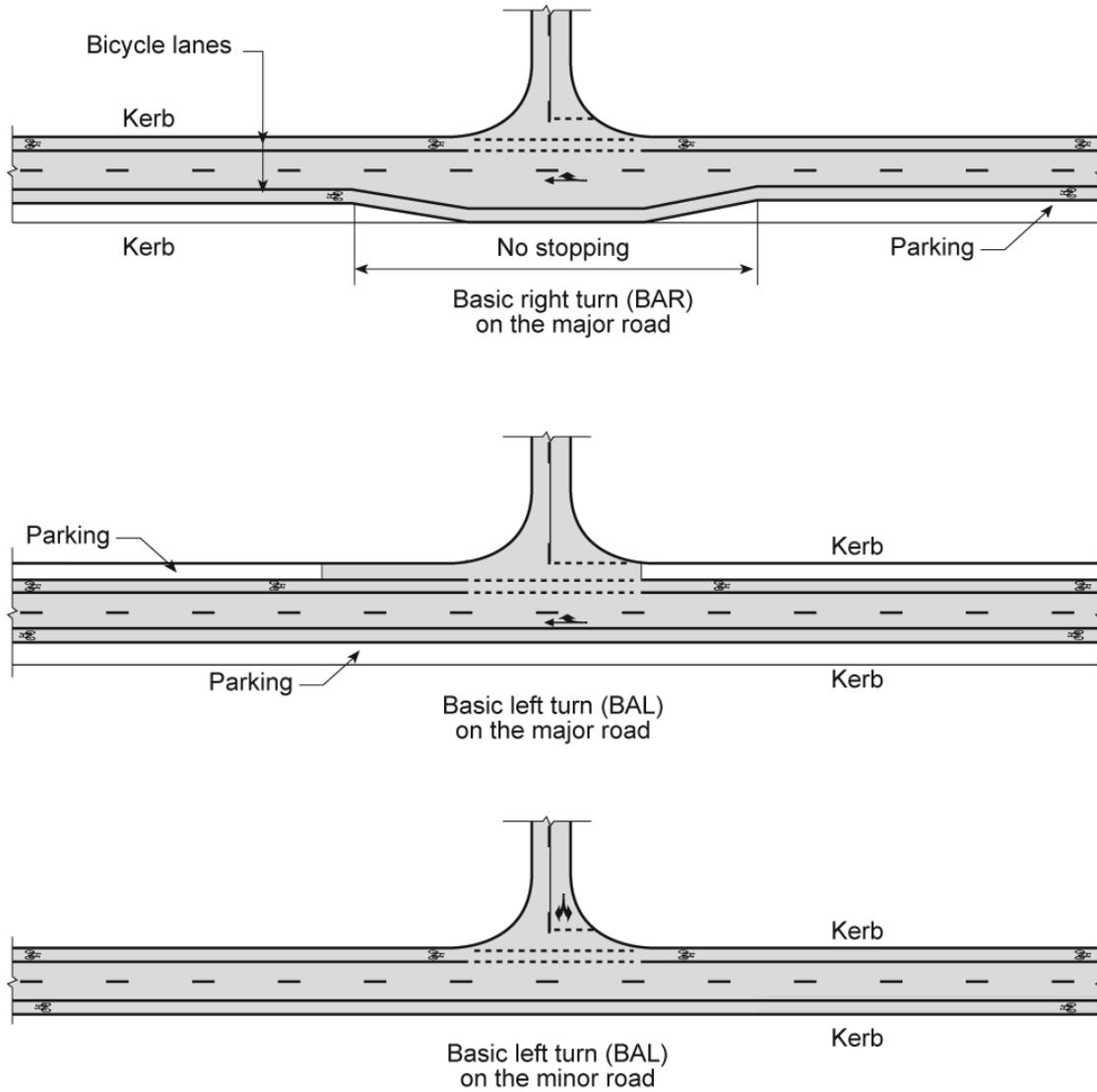
Figure 2.1 shows only basic T-intersection treatments because unsignalised and signalised crossroads should not be provided due to the road safety risk in situations where the posted speed limit is ≥ 90 km/h unless treated with channelisation (e.g. roundabout, wide median treatment) and/or traffic management devices. However, CHR treatments may be applied to existing crossroads where there is a need to shelter turning vehicles on the major road and the risk associated with crossing traffic is considered to be low (e.g. no crashes recorded, very low approach speeds, negligible traffic crossing). This treatment is implemented under extended design domain principles (*Guide to Road Design Part 2: Design Considerations*, Austroads 2015e).

Urban basic (BA) turn treatments

Figure 2.2 shows the features of urban BA turn treatments. It can be seen that:

- the BAR and left-turn treatments are achieved by removing parking space at and near the intersection
- a bicycle lane on a major road may be incorporated into the treatment; it should always be continued through unsignalled intersections.

Figure 2.2: Urban basic (BA) turn treatments



Note: Diagram illustrates principles, not detailed design. Arrows indicate movements relevant to turn type; they do not represent actual pavement markings.

Source: Queensland Department of Main Roads (2006).

While Figure 2.2 shows only T-intersections, the treatment may be adapted to cross-intersections that are common in established urban areas. For design details of urban BA turn treatments refer to *Part 4A* of the *Guide to Road Design* (Austroads 2017b).

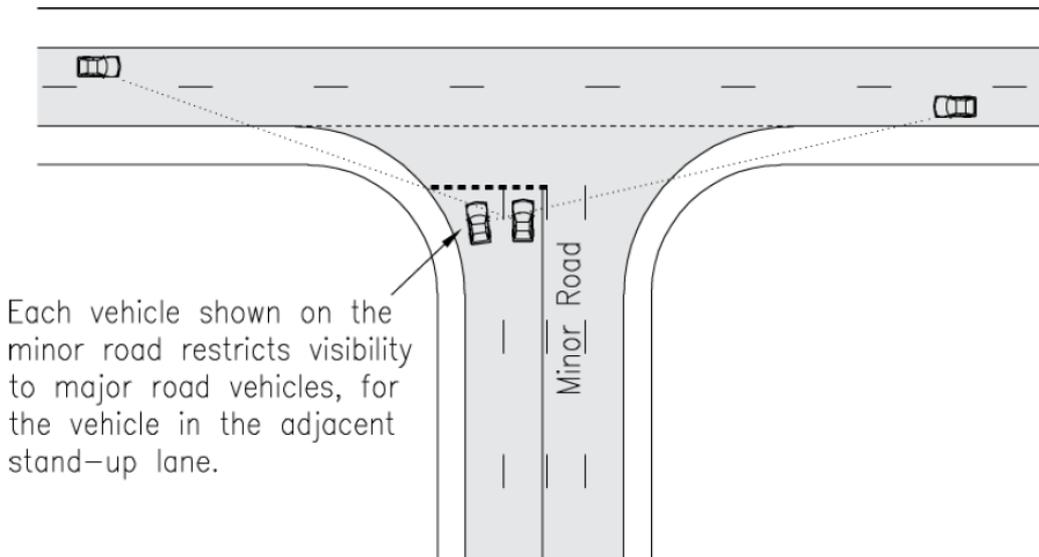
Often, not all of the treatments will be used together at a single intersection. The AUR treatment:

- allows traffic to bypass a vehicle waiting to turn right, or may provide a lane for left-turning traffic, or both
- can only be used on roads which have a sealed surface
- can be confused with an auxiliary lane for overtaking and should only be used at locations where the driver can appreciate the purpose of the lane (e.g. situating such intersections near auxiliary lanes used for overtaking must be avoided)
- has been used where an arterial road meets with sub-arterials, collectors, or local roads (particularly in rural areas where there is a low volume of high-speed through traffic and the volume of turning traffic is sufficient to make a conflict likely)
- is more expensive than basic treatments, however, it can be more cost-effective when long-term crash costs are included in the economic analysis.

Research has shown that the crash rate for drivers entering a major road from a minor road at an unsignalised intersection is significantly higher when there are two stand-up lanes on the minor road (i.e. when there is an auxiliary lane). This is because a vehicle standing in the right lane obscures the view of drivers in the left lane and vice versa (Figure 2.4). For this reason an AUL treatment on the minor road is not preferred at rural or urban sites, particularly at four-way unsignalised intersections. It is therefore desirable that the minor road approach has only one stand-up lane and, if sufficient traffic demand exists, that a channelised left-turn treatment is provided. Further information on this issue is provided in Commentary 3.

[\[see Commentary 3\]](#)

Figure 2.4: Restricted visibility at an unsignalised intersection comprising two stand-up lanes on the minor road



Source: Queensland Department of Main Roads (2006).

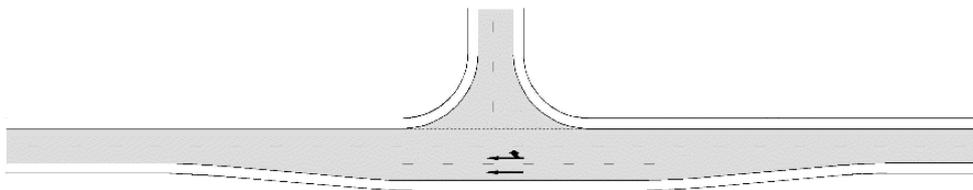
Where additional lanes are required on minor road approaches to provide adequate capacity and reduce queuing and delays, consideration should be given to whether a signalised intersection or a roundabout would provide a more suitable arrangement.

Rural auxiliary lane (AU) turn treatments

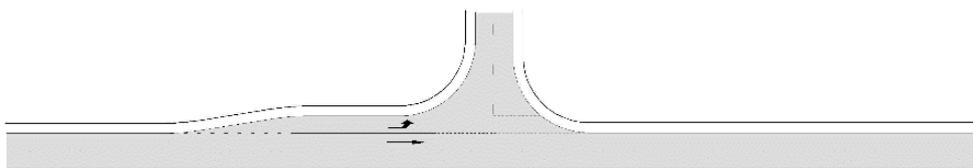
Figure 2.5 shows the features of rural AU turn treatments at T-intersections, namely:

- an AUR turn treatment is created by the use of a short lane with standard painted stripes
- an AUL turn treatment on a major road is a normal indented turn lane
- an AUL turn treatment in a minor road is also a normal indented turn lane.

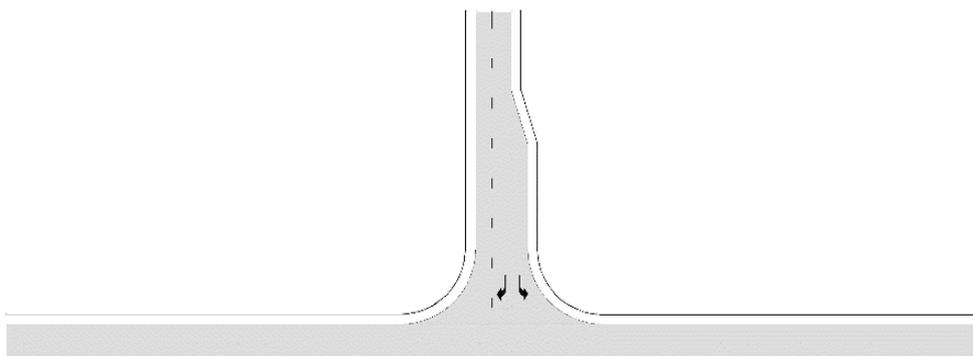
Figure 2.5: Rural auxiliary lane (AU) turn treatments



**Auxiliary Right Turn (AUR)
on the Major Road (Two-Lane, Two-Way Road)**
This turn type not as safe as a channelised treatment
at unsignalised intersections



**Auxiliary Left Turn (AUL)
on the Major Road**
CHL treatment is preferred at unsignalised
intersections to ensure a clear line of sight for vehicles
turning from the minor road.



**Auxiliary Left Turn (AUL)
on the Minor Road**
This turn type is undesirable at unsignalised intersections
because it is not as safe as a single lane approach.
CHL treatment preferred.

Notes:

Diagram illustrates principles, not detailed design. Arrows indicate movements relevant to turn type; they do not represent actual pavement markings.

Not used by some jurisdictions.

Source: Queensland Department of Main Roads (2006).

As mentioned previously for unsignalised intersections:

- Generally, a CHL treatment is to an AUL treatment, particularly where sight distance may be impeded. Consequently a CHL treatment should be used wherever practicable to ensure a clear line of sight for drivers at the intersection:
 - For a minor road at unsignalised intersections, an AUL treatment is not preferred as a vehicle in the right lane obscures the view for drivers in the left lane (Figure 2.4). Consequently, on the minor road approach the preferred configuration is for one stand-up lane (basic treatment) or, where practicable, a CHL.
 - For a major road at unsignalised intersections, an AUL treatment is also not preferred as drivers turning left from the major road can impede the sight distance for drivers waiting in the minor road. Therefore, a CHL is preferred on the major road (Figure 2.5).
- The AUR treatment is not favoured by some jurisdictions due to the exposure of right-turning drivers to rear-end collisions. This is particularly an issue in high-speed rural situations.

Turning treatment warrants are discussed in Section 2.3.6. For design details of rural AU turn treatments refer to *Part 4* and *Part 4A* of the *Guide to Road Design* (Austroads 2017a, 2017b).

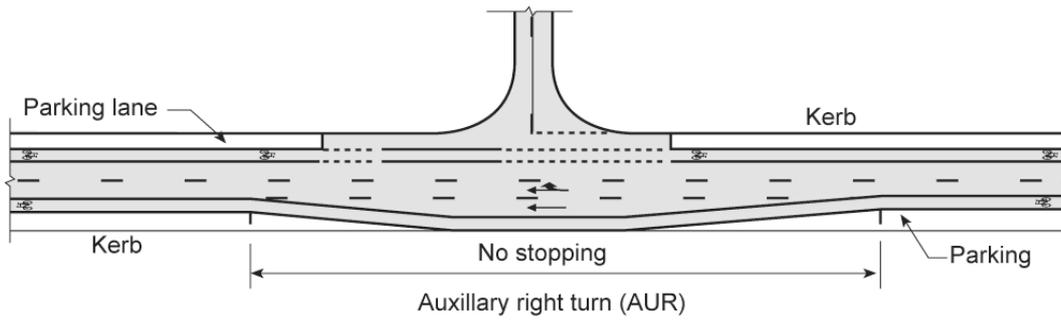
Urban auxiliary lane (AU) turn treatments

Figure 2.6 shows the features of urban AU turn treatments at T-intersections, namely:

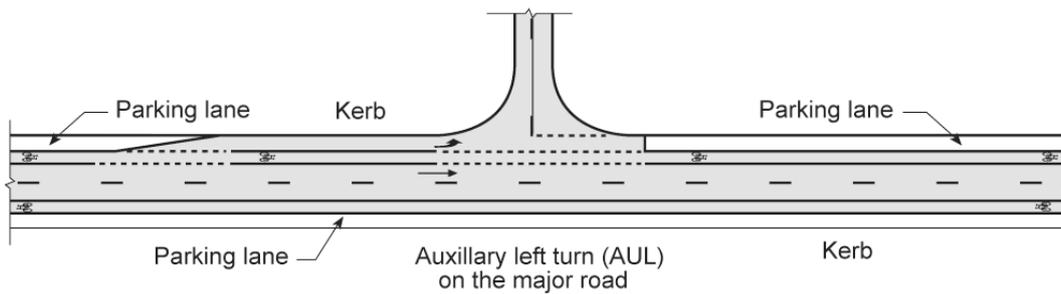
- an AUR turn treatment is created by the addition of a short section of traffic lane with standard painted stripes
- an AUL turn treatment on a major road may be a normal indented turn lane or be shielded by a parking lane, depending on the situation
- an AUL turn treatment in a minor road may also be a normal indented turn lane or be shielded by parked cars, depending on the situation.

Turning treatment warrants are discussed in Section 2.3.6. For design details of urban AU turn treatments refer to Austroads (2017b).

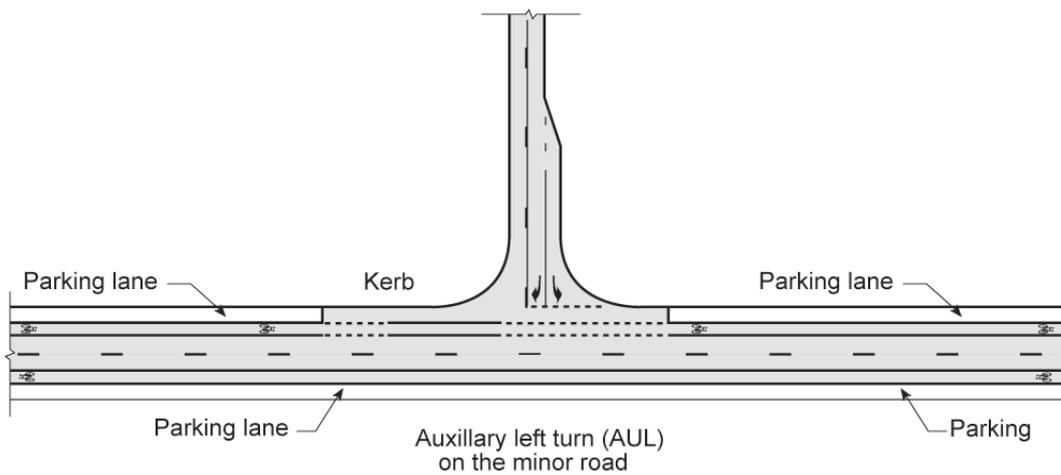
Figure 2.6: Urban auxiliary lane (AU) turn treatments



This turn type not as safe as a channelised treatment at unsignalised intersections



CHL treatment is preferred at unsignalised intersections to ensure a clear line of sight for vehicles turning from the minor road



This turn type is undesirable at unsignalised intersections because it is not as safe as a single lane approach. CHL treatment preferred

Notes:

Diagram illustrates principles, not detailed design. Arrows indicate movements relevant to turn type; they do not represent actual pavement markings.

Not used by some jurisdictions.

Source: Adapted from Queensland Department of Main Roads (2006).

2.2.4 Channelised Turn Treatments (Type CH)

The CH turn treatment has conflicting vehicle travel paths separated by raised, depressed, or painted medians and/or islands. Auxiliary lanes are often used in conjunction with channelisation. Travel path directions need to be clear for drivers in order to avoid potential confusion.

Channelised turn treatments comprise (Figure 2.7):

- a right-turn treatment (CHR) on a major road
- a left-turn treatment (CHL) on a major road
- a left-turn treatment (CHL) on a minor road.

Often, not all the treatments will be used together at a single intersection. For example, a CHR treatment may have full-length deceleration turning lanes or it may have a shorter length, in which case it is referred to as a CHR(S) treatment (see Section 2.3.6 for warrants).

The advantages of using CHR turn treatments in lieu of AUR treatments include:

- reduction in 'rear-end major road' crashes and 'overtaking-intersection' vehicle crashes (where a vehicle turning right is hit by an overtaking vehicle (Appendix A); with an AUR treatment a stationary right-turning vehicle on a tight horizontal curve or over a crest is vulnerable, whereas the island in a CHR treatment guides through drivers past the right-turning vehicle
- provision of fewer types of turn treatments and thus more consistent intersection layouts
- provision of a refuge for pedestrians crossing a major road
- increase in the average design life of turn treatments compared to AUR turn treatments
- allaying concerns from the motoring public that more CHR turn treatments should be provided on high-speed roads to improve safety.

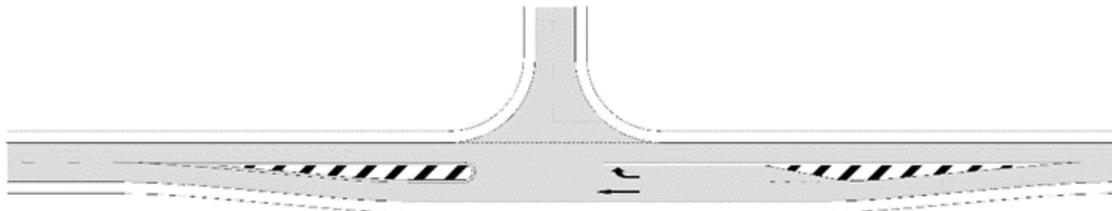
CHR(S) turn treatments can only be used with line marking. The good safety performance of the CHR(S) occurs by removing potentially stationary turning drivers from the through traffic stream. This treatment is suitable where there are low to moderate through and turning volumes. For higher volume sites, and sites where there is limited visibility of the treatment (e.g. over smaller to moderate size crests), a full-length CHR turn treatment is preferred which should have the same longitudinal dimensions to a rural CHR (*Part 4* and *Part 4A* of the *Guide to Road Design*, Austroads 2017a, 2017b).

The CHR(S) treatment is not intended to be used with raised or depressed islands. Right-turning drivers often travel onto the painted chevron to exit the through traffic stream as soon as possible. This is a desirable feature, as it reduces the likelihood of rear-end crash as all through traffic is required to deviate through an alignment designed to suit the operating speed.

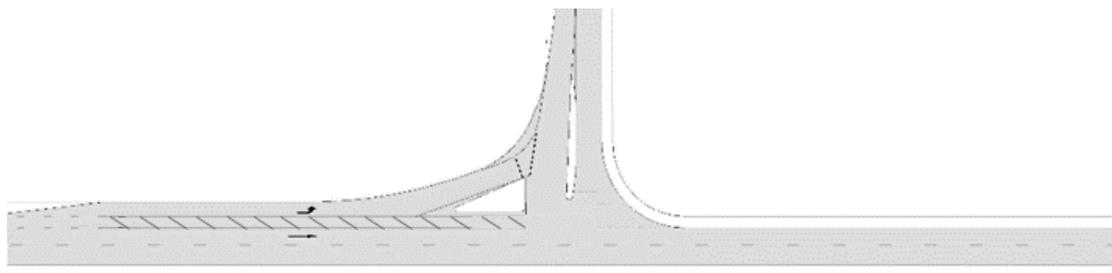
Rural channelised turn treatments (Type CH)

Figure 2.7 shows typical rural CH treatments at T-intersections. Turning treatment warrants are discussed in Section 2.3.6. For design details, refer to (Austroads 2017b).

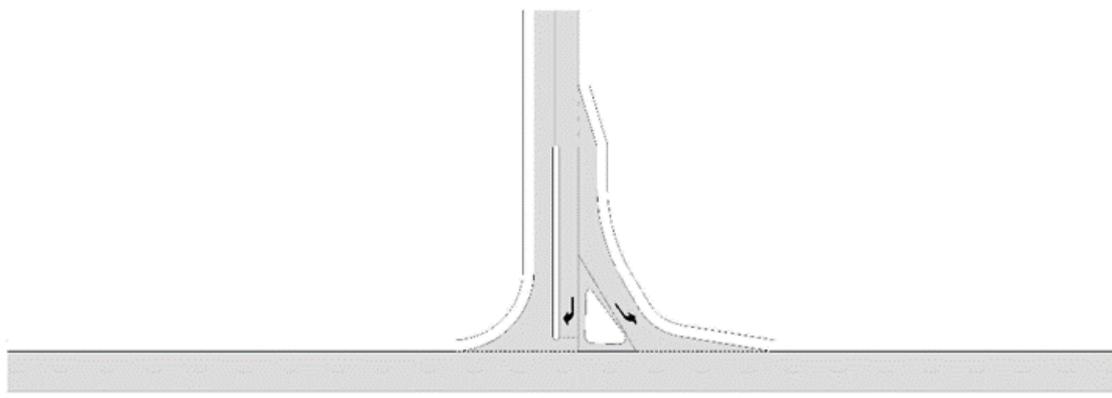
Figure 2.7: Rural channelised (CH) intersection turn treatments



**Channelised Right Turn (CHR)
on the Major Road**



**Channelised Left Turn (CHL)
on the Major Road**



**Channelised Left Turn (CHL)
on the Minor Road**

Notes:

Diagram illustrates principles, not detailed design. Arrows indicate movements relevant to turn type; they do not represent actual pavement markings.

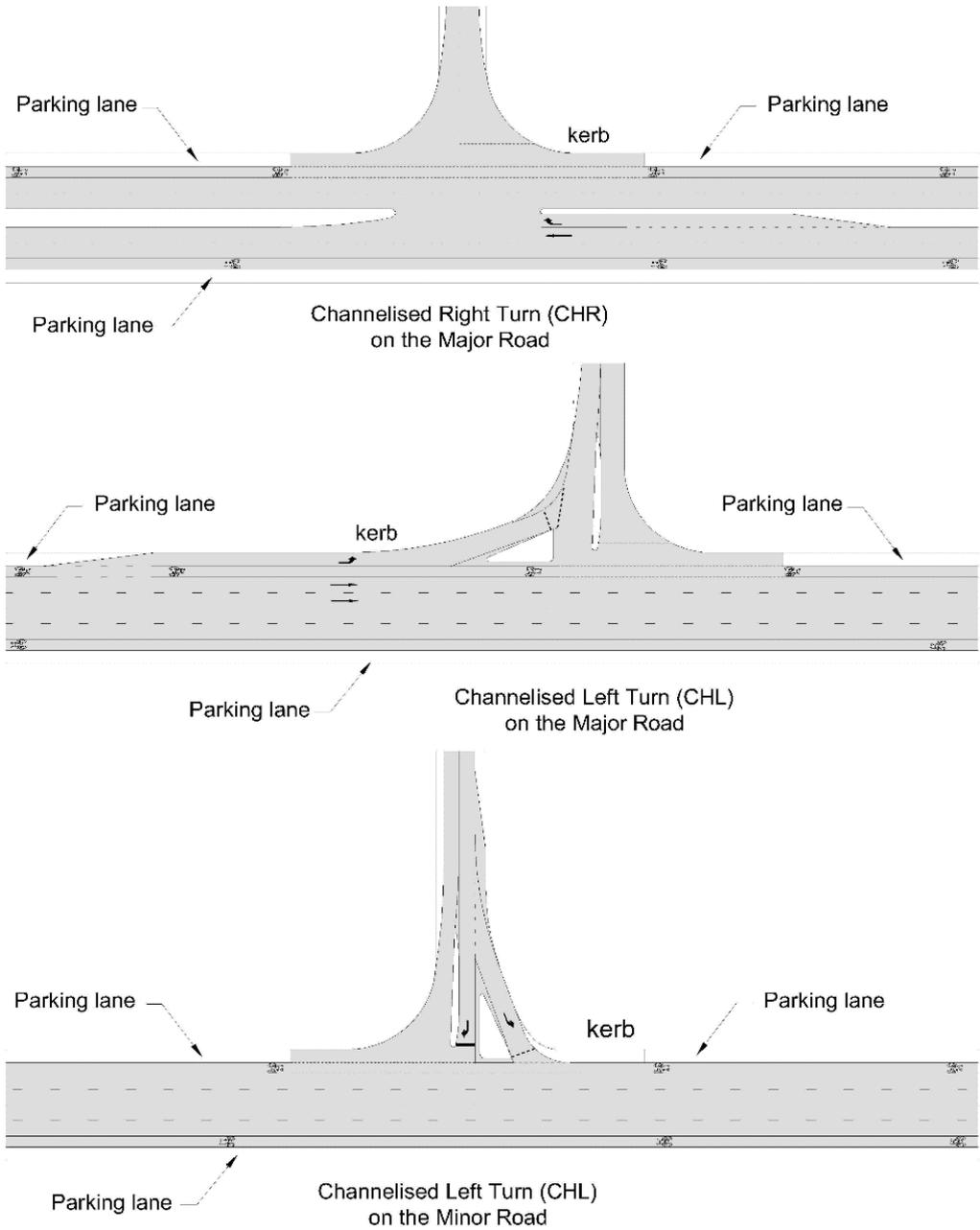
'Channelised left turn (CHL) on the Major road' figure illustrates separation to enable drivers on minor road to have a clear view of traffic on through road approaching from their right. The width of separation needs to be assessed to ensure adequate sight lines are available past left turning traffic.

Source: Adapted from Queensland Department of Main Roads (2006).

Urban channelised (CH) turn treatments

Figure 2.8 shows channelised (CH) turn treatments for urban situations which may or may not be signalised. The treatments are similar to rural treatments except that the dimensions will reflect the lower speed environment, and kerb and channel, parking and bicycle lanes are likely to be included. Turning treatment warrants are discussed in Section 2.3.6. For design details, refer to *Part 4* and *Part 4A* of the *Guide to Road Design* (Austroads 2017a, 2017b).

Figure 2.8: Urban channelised (CH) intersection turn treatments



Notes:

Diagram illustrates principles, not detailed design. Arrows indicate movements relevant to turn type; they do not represent actual pavement markings.

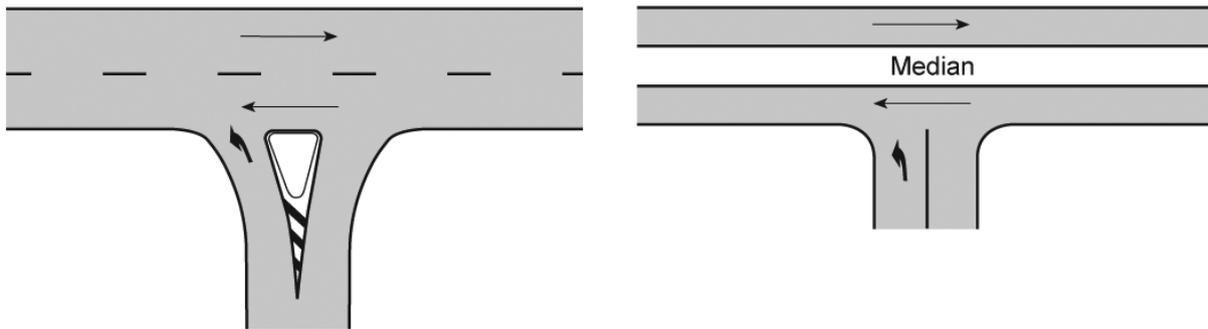
In the middle diagram, the bicycle lane also provides separation to enable drivers on minor road to have a clear view of traffic on through road approaching from their right. The width of the bicycle lane should meet minimum bicycle lane widths (see Part 3 of the *Guide to Road Design*, Austroads 2016e), and for separation purposes the width needs to be assessed to ensure adequate sight lines are available past left turning traffic.

Source: Queensland Department of Main Roads (2006).

Left-in/left-out (LILO) turn treatments

A left-in/left out turn treatment (LILO) is a form of channelised left turn treatment (CHL) that also incorporates right-turn bans. LILO treatments generally improve safety by reducing the number of conflict points. They can also help efficient network operation by helping improve traffic flow. Figure 2.9 shows example LILO treatments which use channelisation or median closures. They can be implemented in urban or rural environments and may also include protected acceleration and deceleration lanes where required. When implementing LILO intersections, designers must make adequate and safe provision for displaced right-turning vehicles. This may be achieved by providing downstream U-turn opportunities.

Figure 2.9: Left-in/left out (LILO) turn treatments



(a) double right turn ban by channelisation (reinforce with signs)

(b) double right turn ban by raised median or barrier

Note: Diagram illustrates principles, not detailed design. Arrows indicate movements relevant to turn type; they do not represent actual pavement markings.

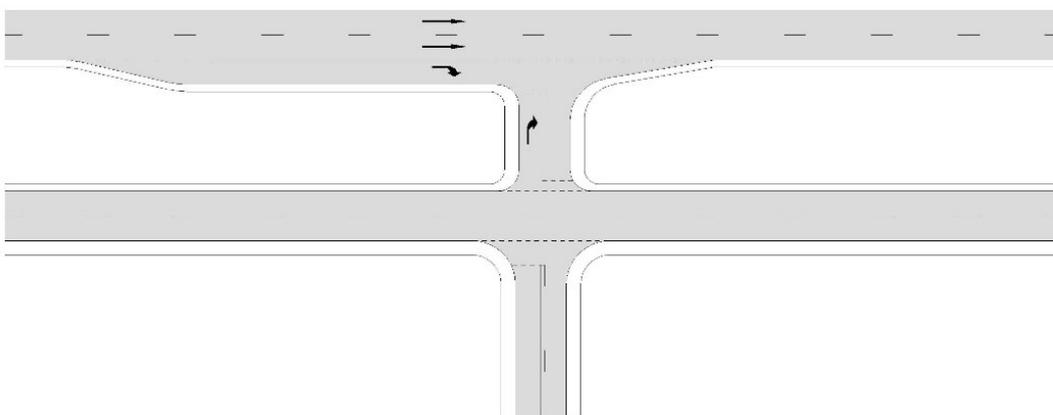
Source: Based on Austroads (2017b).

2.2.5 Intersection Treatments – Rural Divided Roads

Two-staged crossing

This layout is suitable on roadways with wide medians when the volume of right-turning traffic is small and the traffic volumes on the through route are high. Right-turning traffic from the minor road undertakes the turning manoeuvre in two stages. A simple two staged crossing is shown in Figure 2.10. For road design details of a two staged rural crossing treatment refer to Part 4A of the Guide to Road Design (Austroads 2017b).

Figure 2.10: Two-staged crossing



Note: Diagram illustrates principles, not detailed design. Arrows indicate movements relevant to turn type; they do not represent actual pavement markings.

Source: Queensland Department of Main Roads (2006).

One disadvantage of two-staged crossings is that it is difficult to provide for large vehicles turning from the major road as it may be difficult to accommodate the required swept path. To design for this occurrence would result in an excessive width of the crossing within the median; for example, a 30 m wide median would be needed to store a B-double. However, where a very wide median exists it may be practicable to provide an additional island in the median opening based on the swept path of the particular design vehicle.

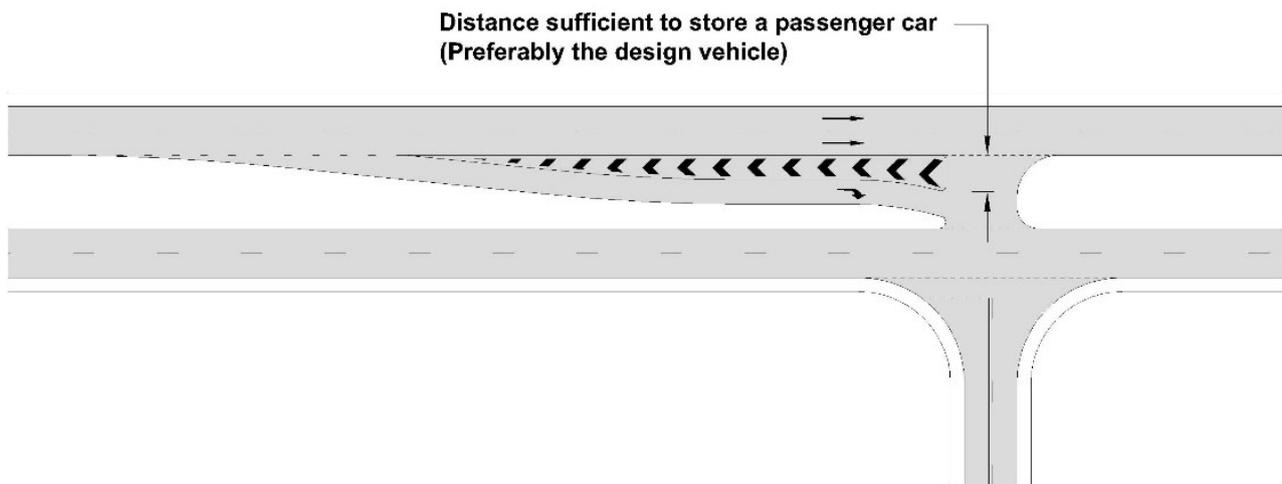
The need to accommodate large vehicles in median openings, together with a desire to reduce the crossing speed at crossroads on rural divided highways, led to the development and use of the wide median treatment in Victoria (Section 2.2.9), a treatment that may not be favoured in other jurisdictions.

Offset right-turn lanes

Where a wide median exists at an intersection, a treatment involving offset right-turn lanes may be appropriate as shown in Figure 2.11. It is suitable for use on rural and urban roads and may be signalised where necessary.

A further advantage of offset right-turn lane treatments is that they provide improved sight lines for a right-turning driver to see past a vehicle waiting to turn right from the opposite direction. The treatment could also be advantageous to older drivers as it accommodates their slower decision times and declining motion perception abilities (Veith 2004).

Figure 2.11: Offset right-turn lane at a T-intersection



Note: Diagram illustrates principles, not detailed design. Arrows indicate movements relevant to turn type; they do not represent actual pavement markings.

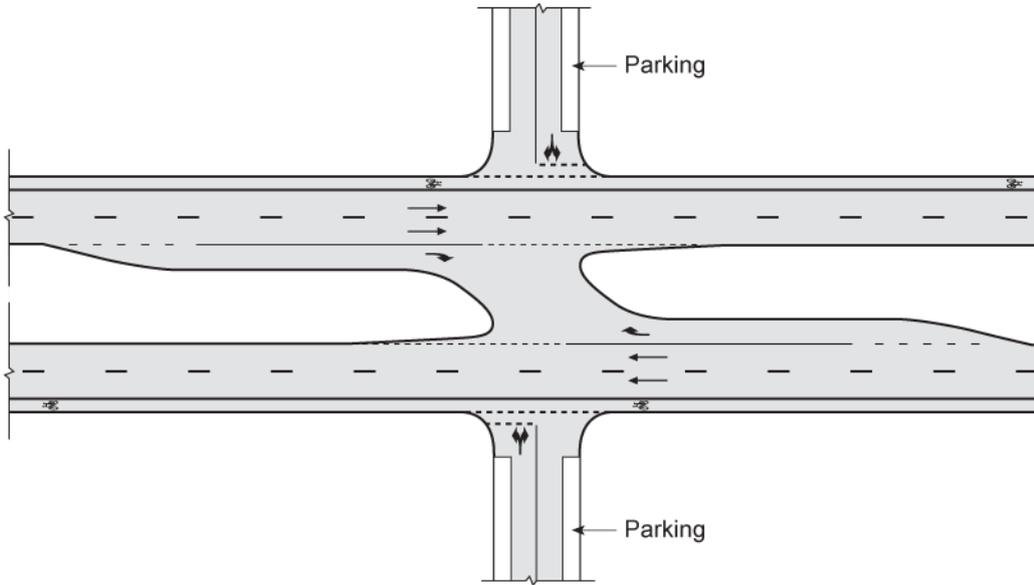
Source: Queensland Department of Main Roads (2006).

2.2.6 Intersection Treatments – Urban Divided Roads

Basic median opening

Figure 2.12 shows a typical arrangement for an unsignalised intersection between a divided major road and a minor road. In some cases the treatment may not have a bicycle lane, or it may have a bicycle/car parking lane treatment. The parking in the minor road should be set back in accordance with statutory regulations or traffic operational requirements.

Figure 2.12: Urban intersection between a divided road and a minor road



Notes:

Depending on the available space it may not be practicable to provide bicycle lanes.

Also applies to six-lane divided roads.

Where appropriate, parking lanes may also be provided adjacent to bicycle lanes.

Median should be ≥ 7 m wide to shelter cars.

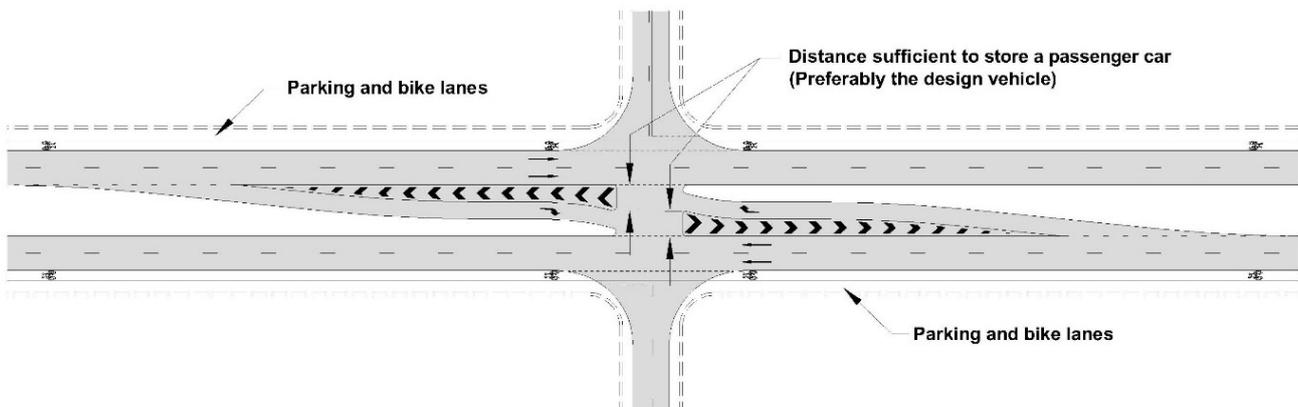
Diagram illustrates principles, not detailed design. Arrows indicate movements relevant to turn type; they do not represent actual pavement markings.

Urban offset right-turn lanes

Urban offset right-turn lanes can have similar advantages to rural offset right-turn lanes (Section 2.2.5) when used at unsignalised intersections. However, they can also be used at signalised intersections. They have the advantage of preventing overlapping of the right-turning movements within the median opening. This results in a more efficient signal system (i.e. through channelization, the opposing right turns become a diamond turn).

Figure 2.13 shows an example of offset right-turn treatment on an urban divided road. Bicycle and parking lanes should be provided where road space can be made available, as shown in this example. While the channelisation indicates painted islands it is generally preferable to use raised islands on major urban roads.

Figure 2.13: Offset right-turn lanes at an urban cross-intersection



Note: Diagram illustrates principles, not detailed design. Arrows indicate movements relevant to turn type; they do not represent actual pavement markings.

Source: Queensland Department of Main Roads (2006).

Intersection layouts with service roads

Service roads are often provided adjacent to divided roads to separate local access traffic movements from traffic on the main carriageways. They are also sometimes provided adjacent to undivided major roads. Service roads should be terminated at signalised intersections (and unsignalised intersections that have median openings) for safety and capacity reasons.

Service roads should generally operate as one-way carriageways because of the operational problems associated with intersections and headlight glare to the left of drivers on major carriageways. Further explanation of these problems is provided in Commentary 4.

[\[see Commentary 4\]](#)

Two-way service roads may be used where:

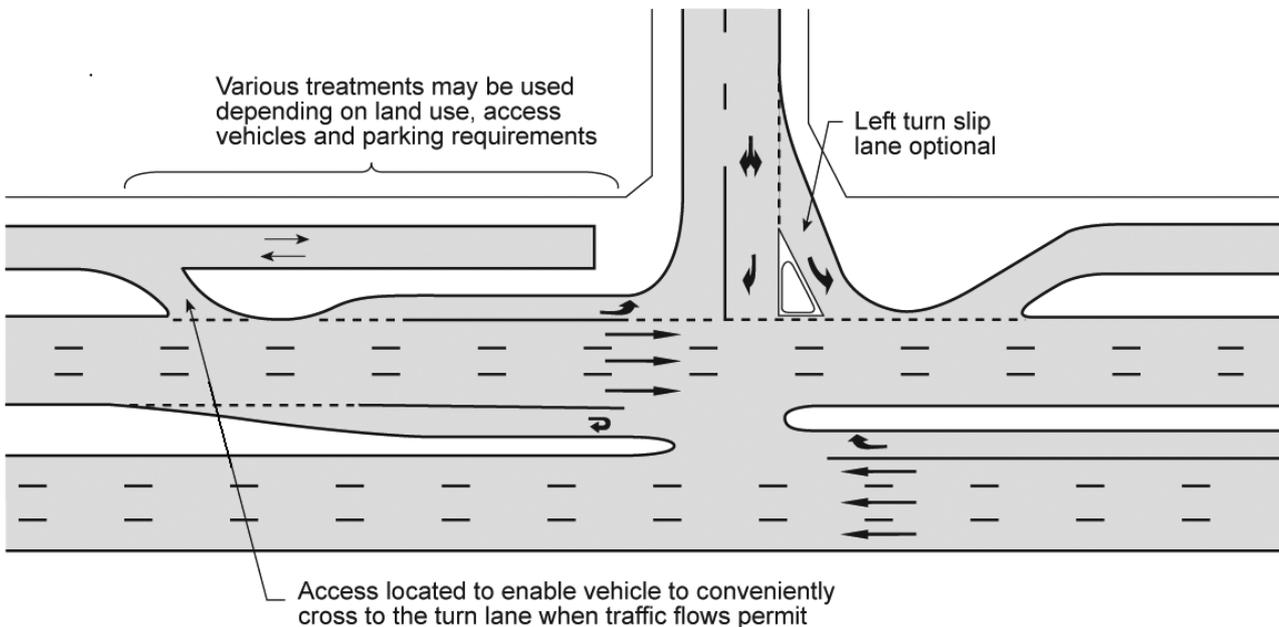
- the outer separator is wide enough to ensure that operational problems do not eventuate at minor intersections and also to accommodate a screen to prevent headlight glare
- they form short sections immediately prior to or beyond an intersection that functions as a property access.

A conceptual layout of a typical service road termination at an unsignalised intersection is shown in Figure 2.14. It can be seen that various treatments may be adopted depending on site conditions and traffic characteristics.

Exits from the service road to the major carriageway should desirably be angled at 70° so that drivers align their vehicles at the appropriate observation angle (as for the high entry angle left-turn). However, this may not be possible to achieve where the outer separator is narrow or larger vehicles use the opening.

Details for the design of service road treatments are provided in *Part 4* of the *Guide to Road Design* (Austroads 2017a).

Figure 2.14: Service road termination at an unsignalised intersection



Notes:

Simple left-turn treatment may be provided from minor road if volumes do not justify a CHL treatment. Diagram illustrates principles, not detailed design. Arrows indicate movements relevant to turn type; they do not represent actual pavement markings.

2.2.7 Staggered T-intersections

Unsignalised cross-intersections (i.e. four legs) record high crash rates for the through movements from the minor road. Staggered T-intersections are used as a safer alternative to four-way unsignalised intersections either by:

- setting out the alignment of the minor roads on new major roads to form a staggered T-intersection
- realigning one or both minor road legs of an existing intersection.

Some further information on this treatment is provided in Commentary 5.

[\[see Commentary 5\]](#)

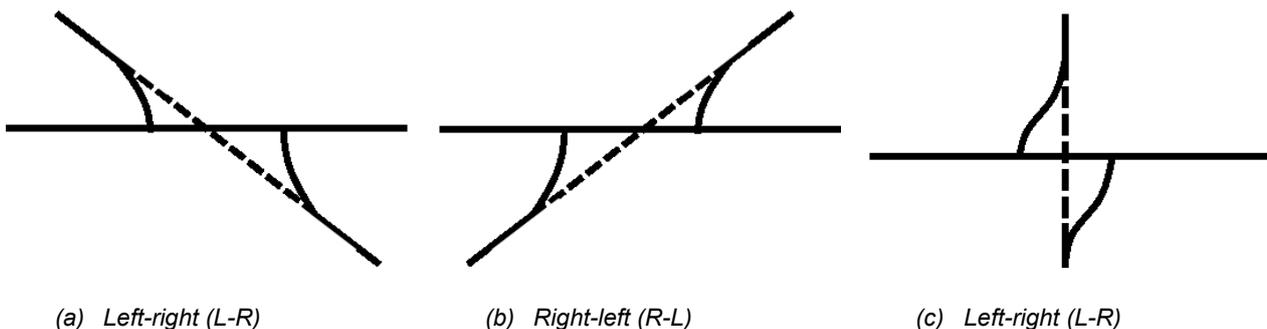
There are two types of staggered T-intersections defined by the order of the turning movements of drivers crossing the major road from the minor roads, namely:

- a left-right staggered T-intersection (preferred configuration)
- a right-left staggered T-intersection.

Traffic management considerations relating to the treatments are provided in Table 2.1. A staggered T-intersection should not be provided where traffic analysis indicates that it is likely to operate at or near capacity early in its design life. Consideration should also be given to drivers' ability to perceive and understand the intersection (taking into account sight distance and other potential issues) when selecting the intersection type (including stagger direction). While a left-right stagger is the preferred configuration, the direction of stagger of minor roads may also be influenced by existing site conditions, traffic volumes, and road alignment; for example, converting a skewed cross-intersection to a staggered-T. If a perpendicular cross-intersection is to be converted to a staggered T-intersection then either a right-left or left-right can be accommodated. In this case a left-right stagger is preferred (Figure 2.15).

The stagger distance (distance between minor roads) must be sufficient to accommodate deceleration and storage length. The right-turn lane on the major road must also accommodate the design vehicle without blocking the through lane. Guidance on stagger distance and storage length is included in *Part 4* of the *Guide to Road Design* (Austroads 2017a).

Figure 2.15: Example staggered T-intersection configurations



Left-right staggered T-intersection treatments

The left-right staggered T-intersection treatment requires drivers to initially turn left into the major road and then to turn right into the opposite minor road leg. Recent research indicates that the left-right staggered T treatment configuration is preferred over a right-left configuration, due to lower crash risk, over a right-left configuration (see Commentary 5).

A left-right staggered T-intersection treatment may be selected where:

- there is a high risk of high-speed right-angle crashes at a basic cross-intersection, and the provision of a grade separation or roundabout is not feasible
- the direction of stagger of minor roads is conducive to its use
- land acquisition is acceptable.

The left-right staggered T-intersection may be safer than the right-left staggered T because:

- Drivers moving from minor roads across the major road do so by selecting gaps in two one-way traffic streams and crossing one lane at a time, rather than a gap in two-way traffic across a much larger distance.
- Manoeuvres are relatively simple compared to the 'reverse curve' type of manoeuvre required in the right-left stagger.
- Where the stagger distance is minimal, some right-left staggered treatments may result in drivers adopting an illegal path to 'straighten out the intersection' by driving to the right of median islands.

Auxiliary right-turn (AUR) lanes should be provided for drivers turning right from the major road, allowing right-turning vehicles to store. Assessment of queue lengths should be undertaken to ensure this does not negatively impact the operation of the intersection, e.g. a left-right staggered T-intersection should probably not be used where queue lengths are long and the distance between the staggered minor legs is short which may lead to sub-standard AUR lengths. If a BAR treatment has to be used, then sufficient sight distance for through traffic on the main leg to any turning vehicles should be provided to allow safe operation of the intersection.

Right-left staggered T-intersection treatments

The right-left staggered T-intersection treatment requires drivers to initially turn right into the major road, then left into the opposite minor road leg. This treatment is suitable only for low-volume situations.

A right-left staggered T-intersection treatment may be selected where:

- there is a high risk of high-speed right angle crashes at a basic cross-intersection, and the implementation of a grade separation, roundabout or left-right staggered T is not feasible. The intersection could be expected to operate below capacity throughout the intended design life of the treatment
- the aim is to minimise land acquisition from abutting property.

The right-left treatment requires less land than that a left-right stagger and it costs less, particularly when treating an existing intersection. However, the higher crash risk associated with the right-left configuration, compared to the left-right configuration, needs to be taken into account when selecting an intersection layout.

Right-left staggered T-intersections store crossing vehicles on the minor legs. As traffic on the minor legs has to give way to both directions on the major route, calculations to establish delay may be necessary. If excessive delay is anticipated an alternative treatment, such as a roundabout, should be considered as drivers may take risks and crashes may result.

Rural staggered T-intersection treatments

Preferred layouts for right-left and left-right staggered T-intersections are illustrated in Figure 2.16 and Figure 2.17 respectively. Both types of staggered T-intersection can be provided on two-lane two-way roads or divided roads. Where it is desirable to minimise the stagger distance of a left-right staggered T-intersection due to site conditions or land availability, then the right-turn lanes may be overlapped as shown in Figure 2.18.

The stagger distance is particularly important for the right-left stagger on a two-lane two-way road Figure 2.16(a). The distance should be:

- small enough to enable an efficient crossing manoeuvre in a single movement (i.e. not staged)
- large enough to cut off the possibility of high-speed crossing movements from minor roads.

For a right-left staggered T-intersection on a divided road it is desirable to provide left-turn lanes for traffic turning into the minor roads as shown in Figure 2.16(b). This is because this arrangement does not require crossing traffic to travel along the through lane, thus reducing the risk of rear-end crashes.

For a two-lane, two-way road the left-right staggered treatment shown in Figure 2.17(a) is preferred to that in Figure 2.18(a). This is because it results in less deviation of the through lanes on the major road. The stagger distance for a left-right treatment should be based on the deceleration and storage distance required for traffic turning right from the major road, either for back-to-back right-turns (Figure 2.17) or overlapping right-turns (Figure 2.18).

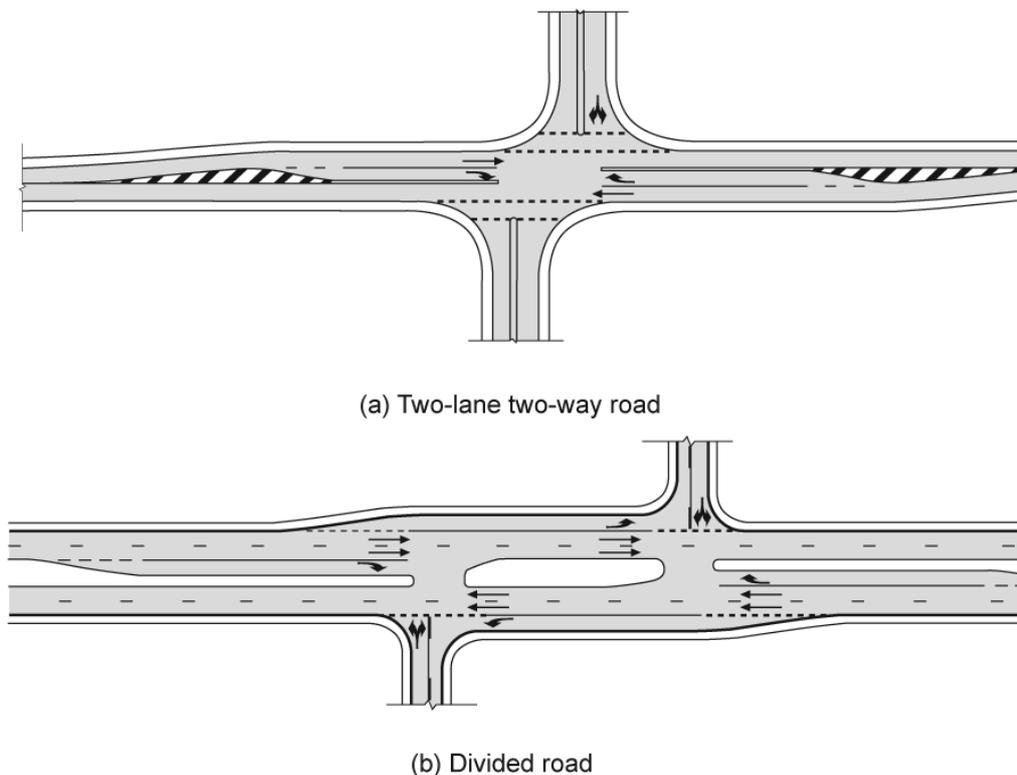
Design details such as the required length of lanes are discussed in *Part 4 of the Guide to Road Design* (Austroads 2017a).

Urban staggered T-intersection treatments

The principles applied to rural staggered T-intersection treatments are also applied to urban situations. The main differences include generally lower design speeds, the incorporation of bicycle and pedestrian facilities, the presence of parking and the use of kerbs. This type of treatment may be used on all roads from local to arterial.

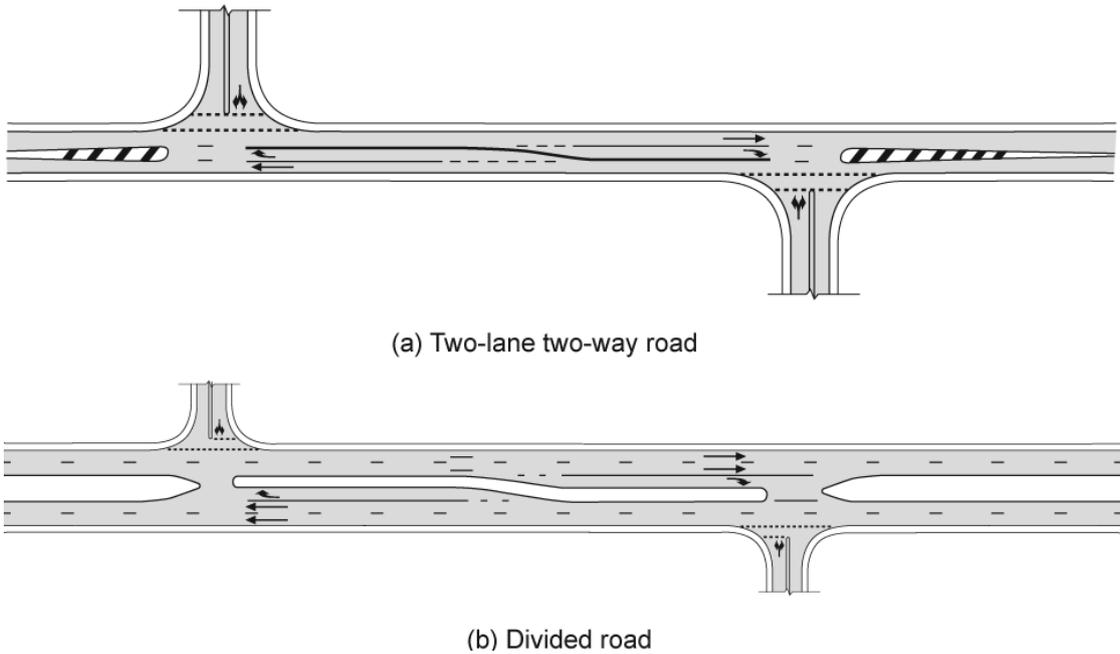
On local roads staggered T-intersection treatments can be used as a measure to reduce the ‘permeability’ of the area for through traffic. However, on urban traffic routes a cross-intersection may be a better arrangement if it is likely that traffic signals will be required in the future to improve capacity or reduce delays. Signalised staggered T-intersections are generally less efficient than signalised crossroads because of the ‘overlapping’ right-turns and associated phasing.

Figure 2.16: Right-left staggered T-intersections



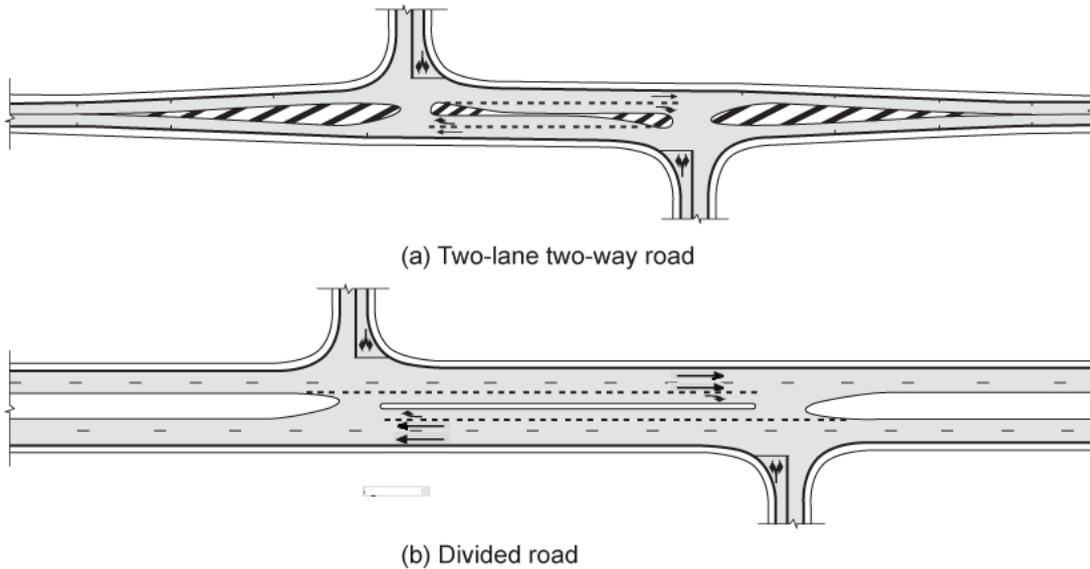
Note: Diagram illustrates principles, not detailed design. Arrows indicate movements relevant to turn type; they do not represent actual pavement markings. See Part 4 of the Guide to Road Design (Austroads 2017a) for design details.

Figure 2.17: Left-right staggered T-intersections with back-to-back right-turns



Note: Diagram illustrates principles, not detailed design. Arrows indicate movements relevant to turn type; they do not represent actual pavement markings.

Figure 2.18: Left-right staggered T-intersections with overlapping right-turns



Note: Diagram illustrates principles, not detailed design. Arrows indicate movements relevant to turn type; they do not represent actual pavement markings.

Source: Adapted from Queensland Department of Main Roads (2006).

2.2.8 Seagull Treatments

Rural seagull treatments

Seagull treatments are generally only provided at T-intersections. The preferred layout of a seagull treatment is shown in Figure 2.19. Seagull intersections usually work well where right-turning traffic from a minor road would be delayed for extended periods due to the small number of coincident gaps on the major road, particularly if upstream events on both of the major road legs cause traffic to arrive at the intersection in platoons.

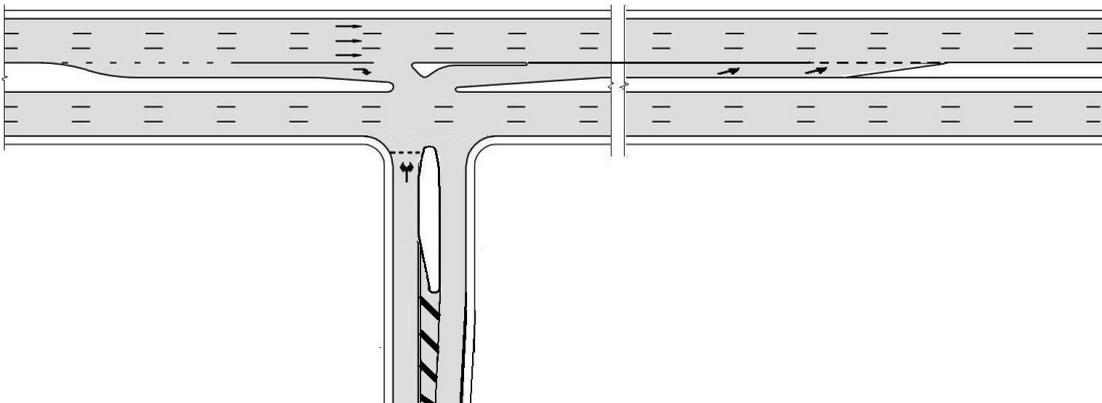
A decision to provide a seagull treatment should be based on traffic analysis that demonstrates that the treatment would operate satisfactorily and be advantageous in terms of safety. However, caution in the use of seagull treatments is recommended, particularly in high-speed areas. Travel paths through the seagull treatment need to be clear for all approaching drivers. Issues may also exist where road geometry or islands mask the road surface. Roundabouts are generally preferred to seagull treatments.

A seagull treatment may be appropriate where:

- a substantial volume of traffic turns right from a minor road of a T-intersection, to the extent that a two-stage right-turn through a conventional median opening would not operate satisfactorily
- traffic turning right from the minor road has adequate gaps in traffic on the nearer carriageway, and is able to merge satisfactorily with the traffic on the other carriageway
- it is unlikely that an access (driveway or road) from a major traffic generator will be proposed adjacent to the major road and opposite the minor road within the design life of the treatment.

When the volume of right-turning traffic is small, it is preferable to store vehicles, one at a time, in the median. This requires a two-staged crossing treatment as shown in Figure 2.10.

Figure 2.19: Seagull treatment (preferred)

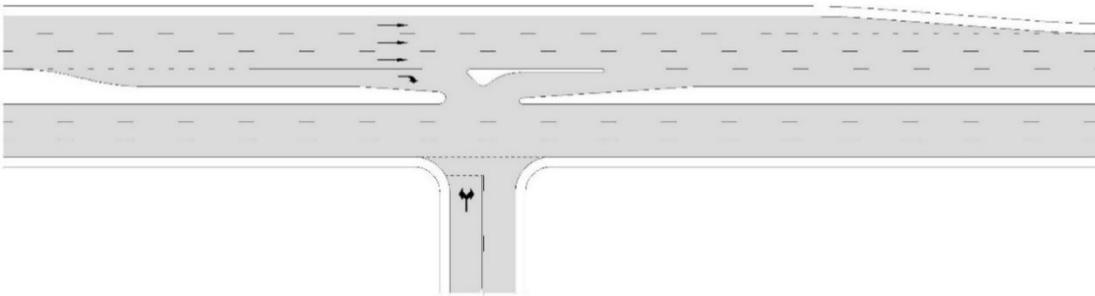


Note: Diagram illustrates principles, not detailed design. Arrows indicate movements relevant to turn type; they do not represent actual pavement markings. See Austroads (2017b) for design details.

Source: Queensland Department of Main Roads (2006).

Whilst the treatment shown in Figure 2.19 is preferred in most cases, in cases where the number of right-turning vehicles from the minor road is high relative to the number of through vehicles with which it must merge (i.e. a similar design hour flow in each stream), the layout in Figure 2.20 may be more appropriate. This treatment can be advantageous where the carriageway on a major road increases from, for example, two lanes to three lanes at the seagull intersection. When this alternative layout is used, and the cross-section of the major road does not change, then the merge for through traffic should be located at an appropriate distance downstream of the treatment (say 500 m to 700 m).

Figure 2.20: Seagull treatment (alternate)



Note: Diagram illustrates principles, not detailed design. Arrows indicate movements relevant to turn type; they do not represent actual pavement markings. See Part 4 of the Guide to Road Design (Austroads 2017a) for design details.

Source: Queensland Department of Main Roads (2006).

Urban seagull treatments

The principles applied to the design of seagull treatments are the same for urban and rural applications. However, urban treatments generally have kerbs rather than shoulders on the left edges, they are generally designed for lower operating speeds, and they may be signalised on one carriageway.

Signalised seagull treatments have been used at high-volume urban intersections where two right-turn lanes operate from the minor road. In this case the double right-turn traffic has to merge within the median prior to entering a dedicated lane or prior to merging with the main carriageway traffic. Traffic analysis is necessary to confirm that the seagull is the most appropriate treatment in such situations.

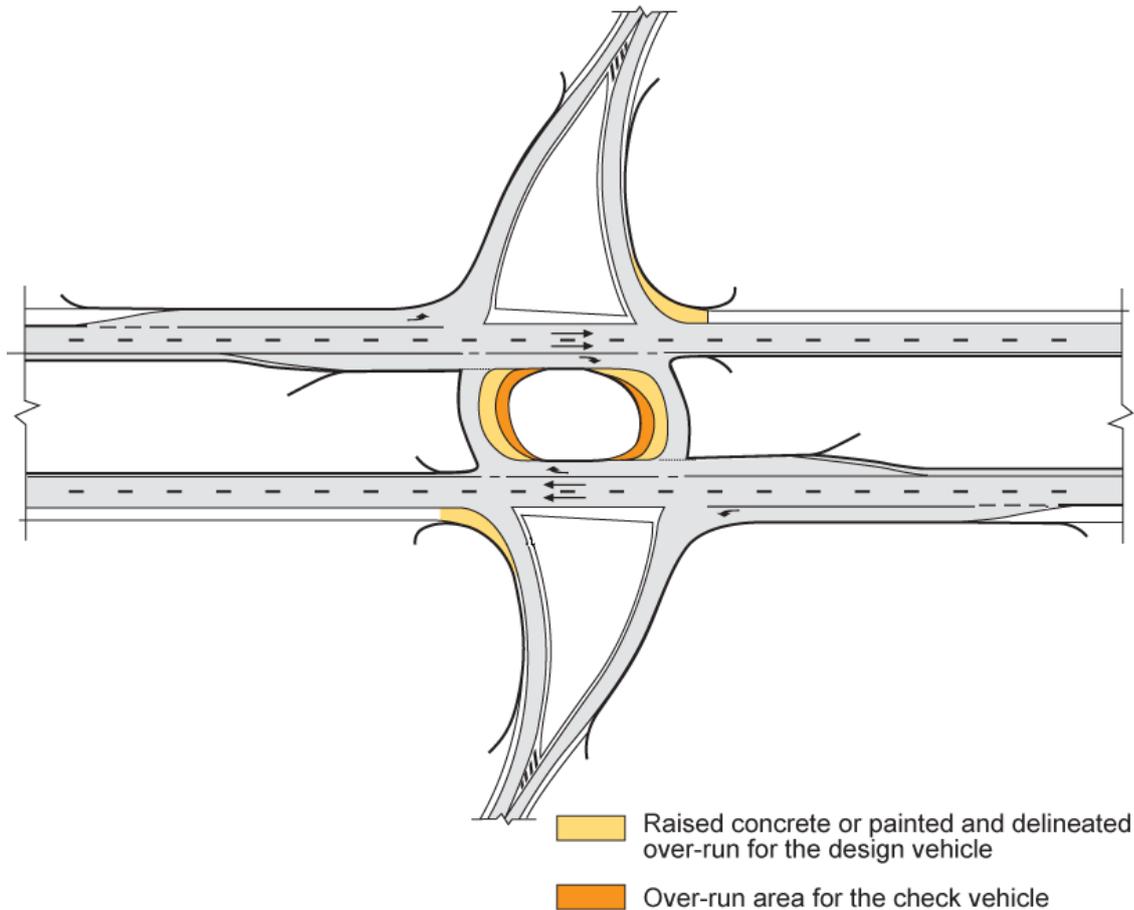
An issue that limits the suitability of seagull treatments in urban areas is the need to provide for the movement of pedestrians and cyclists across the major road, and the possible need to provide access to major development opposite the minor road.

2.2.9 Wide Median Treatments

Wide median treatments (WMT) were developed for use on high-speed rural divided roads where it is necessary to retain a crossroad and therefore to physically control the speed of crossing traffic. The treatment is illustrated in Figure 2.21; it shows how minor road entries are designed with horizontal curvature and large islands to reduce the speed of drivers approaching and entering the intersection.

The WMT has some similar design features to roundabouts. However, the WMT provides priority for drivers on the major road, whilst a roundabout requires major road drivers to give way to vehicles circulating on the roundabout. To ensure that there is no confusion created for drivers, WMTs and roundabouts should not be alternated along the same route nor used in close proximity to each other. Traffic management considerations for wide median treatments are discussed in Section 2.3.7.

Figure 2.21: Wide median treatment



Note: Diagram illustrates principles, not detailed design. Arrows indicate movements relevant to turn type; they do not represent actual pavement markings.

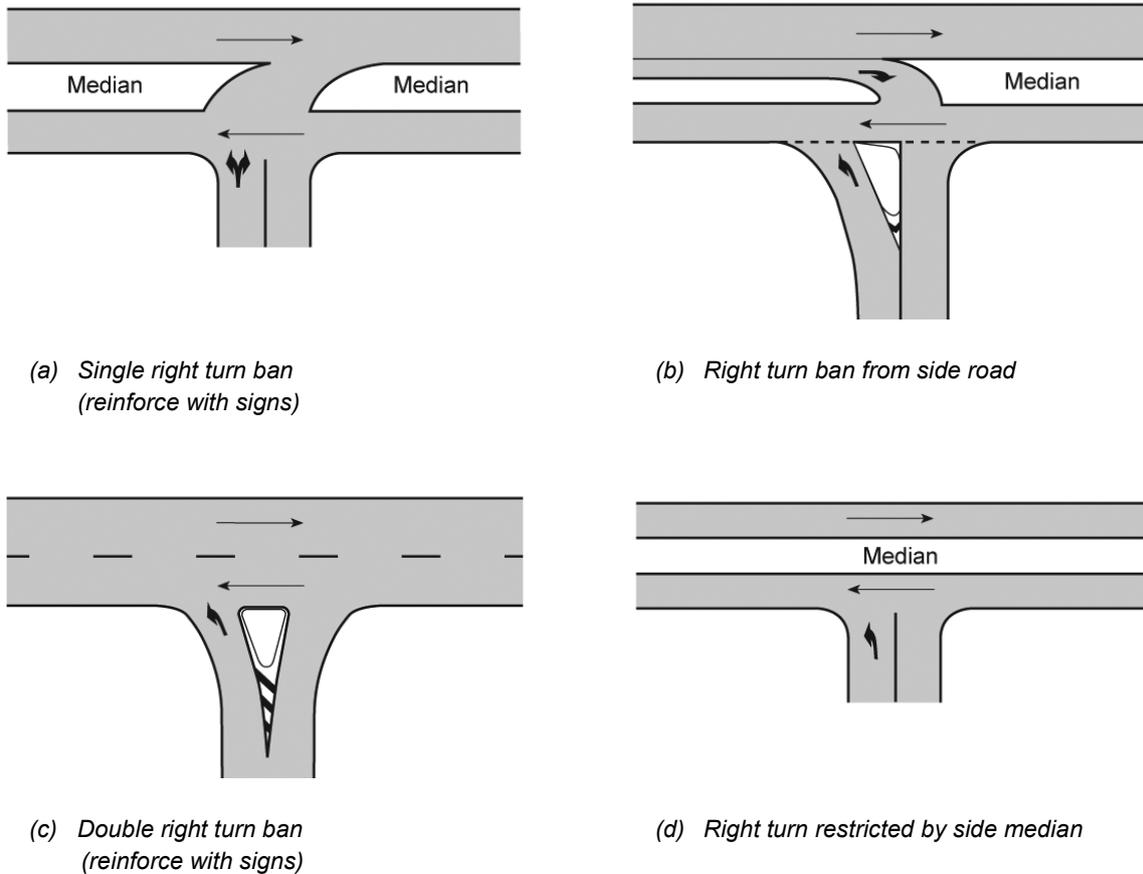
Source: Adapted from VicRoads (2011).

2.2.10 Channelised Intersections with Right-turn Restrictions

Right-turns at urban intersections can be banned through the use of appropriate traffic control devices and/or restricted through geometric design. The assessment of intersection control options, including the banning of right-turns, is discussed in Section 2.3.3.

Whilst it is desirable to provide for all movements at intersections between arterial roads, it is often preferable to restrict right-turn movements at selected minor road intersections along arterial routes in order to provide an appropriate level of service for arterial road traffic. Figure 2.22 illustrates how channelisation can be used at urban intersections to restrict certain right-turn movements and to discourage wrong-way movements. These treatments require the appropriate traffic control devices to be installed (e.g. regulatory signs). Other options to restrict turn movements are discussed in Section 2.3.3.

Figure 2.22: Use of channelisation to ban right-turns



Note: Diagram illustrates principles, not detailed design. Arrows indicate movements relevant to turn type; they do not represent actual pavement markings.

2.3 Intersection Selection

2.3.1 Introduction

This section describes the factors that may influence the selection of an intersection type. It provides an evaluation process to assist practitioners in the development of options and the selection of the most appropriate intersection treatment.

The selection of an appropriate intersection treatment in any given situation can be complex, because it involves considerations of safety, operational performance or other factors. The provision of the safest practicable treatment that also provides an acceptable level of mobility is paramount in all situations, i.e. seeking to maximise safe mobility. The relative safety and needs of all road users (including people with disability or mobility difficulty), particularly pedestrians and cyclists, should be considered as their needs may be a significant factor in the choice of treatment and the type of traffic control adopted.

The overall aim is to provide a safe and cost-effective intersection treatment that meets operational needs, within any constraints that may exist.

The process of selecting an appropriate intersection type and treatment includes consideration of:

- safety of all road users (light and heavy vehicles, motorcyclists, pedestrians and cyclists)
- traffic volumes, capacity, delay and level of service, both generally and for specific road users
- planning policy and objectives
- traffic management strategies or objectives for the road network or corridor
- compatibility with adjacent intersection treatments
- topography at the site
- the natural and built environment (including rural/urban, number of legs and through lanes, available space, adjacent property access and land use)
- speed environment
- road hierarchy
- public transport
- community views
- economic considerations and project life.

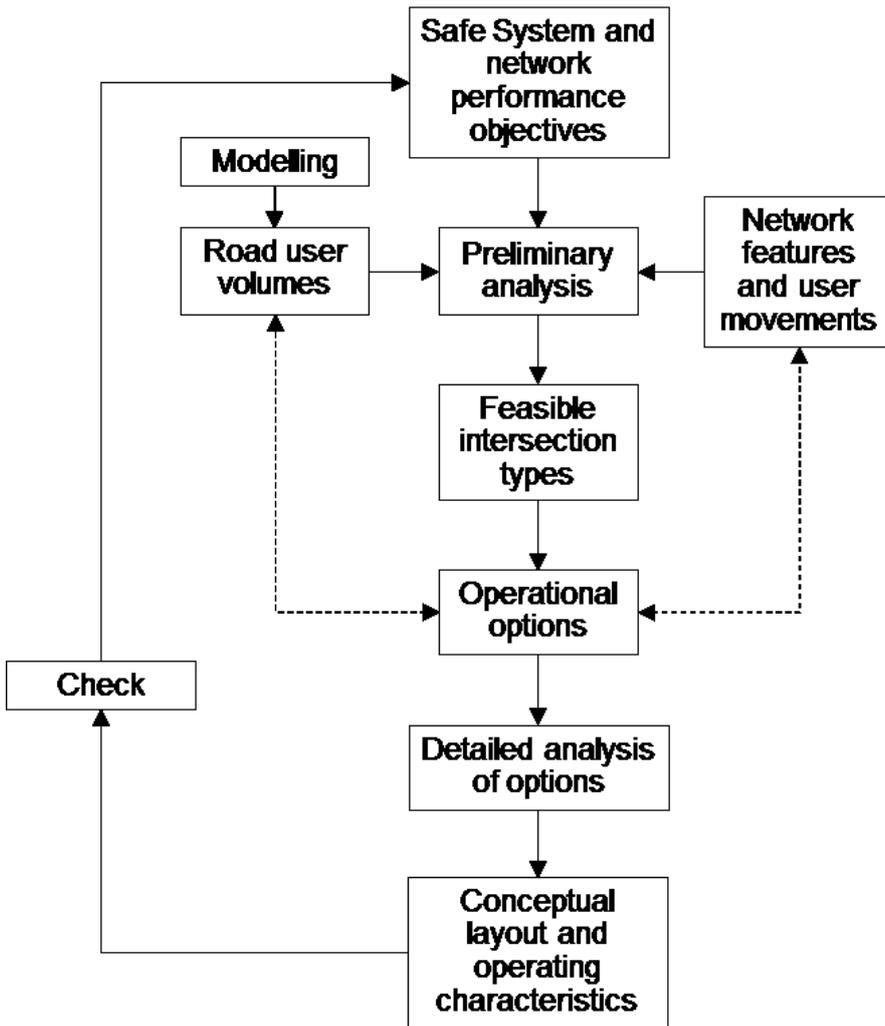
Greenfield sites often have more flexibility in selection of the intersection and control type. The intersection type (outlined in Section 2.3.4) may be determined prior to the selection of the appropriate control type (see Section 2.3.3). Brownfield or urban renewal sites may have more constraints, and so there may be limitations on what changes can be made to an intersection.

2.3.2 Selection Process

Figure 2.23 shows the process that should be followed to determine the most appropriate type of intersection or interchange, and to develop the most appropriate conceptual layout and operating characteristics.

It can be seen from Figure 2.23 that network considerations may have a substantial influence on the type of treatment and operation adopted at sites in urban areas. However, this is not generally the case for rural intersections and interchanges, or intersections that are isolated. The requirements at these sites are usually based on the assessment of historical data rather than modelling techniques that take future transport network and land use changes into account.

Figure 2.23: Intersection selection process



Note: This flowchart outlines the basic process, and does not include all the checks that may be included, for example Road Safety Audit (at all stages of concept development and design), environmental assessment or economic evaluation.

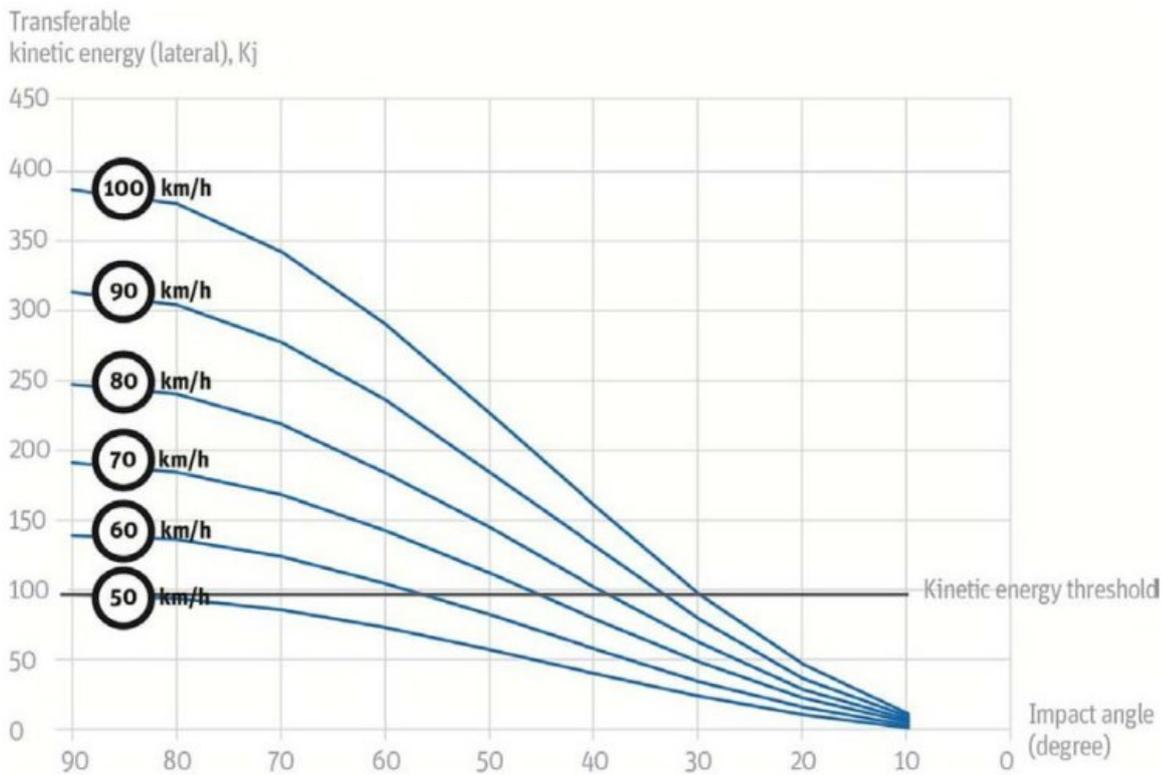
Safe System and network performance objectives

The Safe System and network performance objectives set the scene for the way in which the intersection should be designed and managed. As noted in Section 2.3.1, the provision of the safest practicable treatment that also provides an acceptable level of mobility is paramount in all situations.

The key objective of the Safe System approach is to ensure that, in the event of a crash, impact forces do not exceed human tolerances (i.e. minimising the risk of fatal or serious injury, see Section 1.3). Further to the Safe System objectives, the impact of all potential crashes should be taken into consideration. All crashes cost something; even minor crashes can close an intersection. When upgrading or changing an intersection, practitioners should be mindful not to introduce new crash types or increase the frequency of existing types where possible (i.e. not at the expense of potential fatal or serious injury crashes).

In terms of crash likelihood and severity, intersection safety performance, is predominantly influenced by approach speed, impact angle and opportunity for conflict (Austroads 2015d; Candappa et al. 2015). The influence that impact angles and travel speed have on transferable kinetic energy (and therefore the impact forces experienced during a collision) is illustrated in Figure 2.24. These forces ultimately influence the level of injury sustained by those involved in a crash. It was noted in a recent Austroads project, *Understanding and Improving Safe System Intersection Performance*, (Austroads in press) that ‘approach speed is similar to impact speed’ during a crash, and that ‘acceptable approach speeds depend on the type and vulnerability of road users and the impact angle’. It was also noted that a crash at a 90° angle tends to result in the most severe injury outcomes. Opportunity for conflict related to the number of conflict points within an intersection. While the higher potential number of conflict points generally reflects a lower safety performance, it should be noted that different types of conflict points are associated with different crash potential (mainly influenced by traffic volume and sight distance) and severity (influenced by approach speeds and impact angle). Approaches for minimising the potential for conflict within an intersection are discussed in Section 2.5.1.

Figure 2.24: Influence of impact angle and travel speed on transferable kinetic energy



Source: ITF (2016), based on Candappa et al. (2015).

The *Safe System Assessment Framework* (Austroads 2016a) can be used to help guide safety considerations for intersection selection. The steps involved in applying the framework are summarised in Table 2.2.

Table 2.3 outlines the Safe System treatment hierarchy for intersection types (Austroads 2016a). It should be noted that:

- Primary (transformational) solutions are preferred from a Safe System perspective as these eliminate, as far as practicably possible, the occurrence of fatal and serious injuries.
- Supporting treatments may be considered when primary solutions are not ‘feasible due to project constraints dictated by budget, site, conflicting road user needs, or the environment; if so, the next safest project-feasible solution needs to be identified (supporting solutions)’ (Austroads 2016a).

In terms of network operation, objectives may involve providing priority for certain road user groups, or balancing priorities for multiple groups. For example:

- providing a high level of performance for private vehicles
- providing priority for on-road public transport over private travel. This will be reflected in the allocation of space and time within the intersection layout and operation plan
- the need to accommodate cyclist facilities may also influence the choice of intersection
- the need to accommodate for pedestrians, particularly for people who have a vision, mobility or hearing impairment, to cross the road or access major public transport infrastructure. At some locations it will be necessary to provide greater priority and hence more time within traffic signal phasing arrangements. Within central areas of cities and towns, access to some roads at intersections may be removed to create pedestrian malls.

Strategic plans for cities and towns and for the roads within them, may dictate the function of the intersection and hence the type of layout and intersection operational requirements. For example, some intersections may be situated on bypass routes whereas others will provide for access and distribution of traffic within the central area.

A NOP can provide guidance on setting objectives for intersections and crossings. For further guidance, refer to the *Guide to Road Transport Planning* (Austroads 2009b) and the *Guide to Traffic Management Part 4: Network Management* (Austroads 2016b).

Table 2.2: Safe System Assessment Framework summary

Stages	Summary
1. Assess objectives	The first step is to identify and document the objective of the assessment in terms of purpose, scale and depth.
2. Project context	Consider: <ul style="list-style-type: none"> • What is the reason for the project? • What is the function of the road? • What is the speed environment? • What road users are present? • What is the vehicle composition?
3. Safe System Matrix	In order to ensure that Safe System elements are considered, or to measure how well a given project (e.g. an intersection, road length, area, treatment type etc.) aligns with Safe System principles, the Framework provides a Safe System matrix. The matrix helps the assessment of different major crash types against the exposure to that crash risk, the likelihood of it occurring and the severity of the crash should it occur.
4. Treatment hierarchy	Finally the Framework outlines a Safe System-based hierarchy of solutions for common high severity crash types: <ul style="list-style-type: none"> • run-off-road • head-on • intersection • pedestrian • bicyclist • motorcyclist • other. The guidance on Safe System treatment hierarchy can inform decisions regarding the appropriate treatments that might be used to address crash risks identified by the assessment matrix.

Table 2.3: Intersection treatment hierarchy and selection

Hierarchy	Treatment	Indication on how safety is influenced by each treatment
Safe System options ('primary' or 'transformational' treatments)	<ul style="list-style-type: none"> • Grade separation • Close intersection • Low speed environment/speed limit • Roundabout • Raised platform. 	<ul style="list-style-type: none"> • Likelihood, Severity • Exposure • Likelihood, Severity • Likelihood, Severity • Likelihood, Severity
Supporting treatments (compatible with future implementation of Safe System options)	<ul style="list-style-type: none"> • LILO, with protected acceleration and deceleration lanes where required • Ban selected movements • Reduce speed environment/speed limit, including the use of speed related vehicle activated signs similar to those used in the New Zealand Rural Intersection Active Warning System (Commentary 21). <p style="text-align: right;">[see Commentary 21]</p>	<ul style="list-style-type: none"> • Likelihood, Severity • Exposure • Likelihood, Severity
Supporting treatments (does not affect future implementation of Safe System options)	<ul style="list-style-type: none"> • Redirect traffic to higher quality intersection • Turning lanes • Vehicle activated signs • Improved intersection conspicuity • Advanced direction signage and warning • Improved sight distance • Traffic signals with fully controlled right turns • Skid resistance improvement • Improved street lighting. 	<ul style="list-style-type: none"> • Exposure • Likelihood • Likelihood⁽¹⁾ • Likelihood • Likelihood • Likelihood • Likelihood • Likelihood • Likelihood
Other considerations	<ul style="list-style-type: none"> • Speed cameras combined with red light cameras. 	<ul style="list-style-type: none"> • Likelihood, Severity

¹ Speed related vehicle activated signs will influence likelihood and severity.

Source: Adapted from Safe System Assessment Framework (Austroads 2016a).

An example illustrating the application of the *Safe System Assessment Framework* is provided in Appendix B.

Modelling

In large urban areas and for bypasses of towns, it may be necessary to use transport modelling software to produce traffic forecasts. The traffic volumes derived from traffic modelling should be reviewed to develop estimated traffic volumes for future years for design purposes. For further guidance, refer to the *Guide to Road Transport Planning* (Austroads 2009b).

Road user volumes and movements

In addition to cars, the volumes and movement of other road users (public transport, heavy vehicles, motorcyclists, pedestrians – including people who have a vision, mobility or hearing impairment – and cyclists) must also be determined as their requirements can influence the type of intersection adopted and its operational plan (refer to the *Guide to Traffic Management Part 3: Traffic Studies and Analysis*, Austroads 2013).

Preliminary analysis and feasible types

A preliminary analysis of traffic volumes, including turning movements, and all other relevant factors should be undertaken to establish the feasible intersection types – those that can accommodate the estimated traffic demand and that meet strategic objectives and other specific requirements (refer to the *Guide to Traffic Management Part 3: Traffic Studies and Analysis*, Austroads 2013).

Operational options

Various operational options will then be considered to assess the best overall outcome for a particular intersection. This is particularly relevant where the feasible intersection layouts require good traffic control in order to accommodate the current or future demands by motor vehicles and specific users. An iterative process may be required whereby the performance of a feasible treatment is assessed and the results are used to re-examine the network and road user implications of adopting the treatment.

Detailed analysis of options

A final and detailed analysis of options should be based on accurate functional layouts and firm operational plans that preferably have the support of stakeholders. This leads to a recommended conceptual layout and operational plan for the particular intersection or interchange. This should then be checked back against the network performance objectives identified at the beginning of the selection process to ensure that their satisfaction is being achieved as desired.

2.3.3 Assessment of Intersection Control Options

Primary traffic control options

The suitability of types of traffic control to different intersection layouts is presented in Table 2.4, while the primary intersection control options and the key traffic and safety factors considered in their selection are summarised in Table 2.5.

Traffic control selection should optimise safety and operational performance, i.e. the minimisation of conflict points or angles where site and economic considerations allow. In rural environments and on the local road network, although it is common to initially provide the lowest level of traffic management at intersections, subject to traffic and site conditions, often the level of control will need to be increased from a signed priority control to a roundabout or traffic signal control as problems with traffic safety or traffic congestion begin to arise. In terms of operational performance, the choice of intersection type should be based on a Whole of Life Cycle Cost basis rather than just initial construction costs. A number of recent studies (Austroads 2015i; Austroads 2016a, Austroads in press, NZTA 2013a) suggest that:

- roundabouts more consistently perform closer to Safe System than conventional signalised and unsignalised intersections. There is emerging evidence that signalised roundabouts can also provide strong Safe System performance.
- signalised intersections tend to perform better than unsignalised intersections but worse than roundabouts.
- unsignalised intersections tend to experience the highest severe (fatal and serious injury) crash risk.

In view of the above, the Safe System intersection hierarchy of control is:

1. roundabouts
2. signalised intersections
3. unsignalised (*stop* or *give way* preferred to road rules only).

It should be noted that there is a large degree of variation in intersection safety performance depending on design, environment and road user interactions.

Table 2.4: Suitability of types of traffic control to different intersection layouts

Intersection layout	Roundabout	Signals	Stop or give way	Road rules only
T-intersections	All forms of control generally work well.			
Four-way intersection	Generally work well.	Generally work well.	A staggered T-intersection is preferred(1).	
Y-junction	Generally work well.	Generally work well.	Not recommended due to poor observation angle on the minor road.	Not recommended due to poor observation angle on the minor road. Also confusion regarding who has right-of-way.
Multileg intersection (more than four legs)	Single lane roundabouts generally work well. Multileg, multilane roundabouts cause significant driver confusion in terms of the appropriate lane choice for the intended movement.	Can experience high crash rates. Can result in inadequate sighting of lanterns. Can produce a high proportion of inter-green time.	Can cause confusion as to who has right-of-way.	

1 Staggered T-intersections are deemed to be safer than four-way unsignalised intersections with aligned minor legs (see Commentary 5).

Source: Based on Queensland Department of Transport and Main Roads (TMR) (2015a).

Table 2.5: Intersection control options and considerations

Type of control	Key traffic and safety considerations	References
Roundabout	<ul style="list-style-type: none"> Can be used at a wide range of sites and improve safety by simplifying conflicts, reducing speeds and providing clear indication of priority. Are useful where there is a high proportion of right-turning traffic. Perform best when traffic flows are balanced. Cyclists (especially when turning right) and pedestrians find it more difficult to negotiate multilane roundabouts. An off-road facility may be required for cyclists in some cases. Signalisation may be considered to improve safety of vulnerable road users or help manage dominant flows on one approach, which otherwise may lead to excessive delay on other approaches. 	See Parts 4 and 10 of the <i>Guide to Traffic Management</i> ⁽¹⁾⁽³⁾ and AS 1742.2.
Traffic signals	<ul style="list-style-type: none"> Used where an unsignalised intersection has a poor crash record, there are excessive delays for traffic using minor roads, or a roundabout is unsuitable. Are suitable for high pedestrian movement including people who have a vision, mobility or hearing impairment. Numerical warrants may apply (see signalised intersections in Table 2.9). 	See Section 4 and Parts 9 and 10 of the <i>Guide to Traffic Management</i> ⁽²⁾⁽³⁾ .
Stop signs and give way signs	<ul style="list-style-type: none"> Used at intersections other than those controlled by roundabouts or traffic signals. Used to reinforce road rules or to assign priority. Stop signs must only be used when warrant is met. Advance warning signs may be necessary where there is a high approach speed or where approach sight distance is limited. 	See Part 10 of the <i>Guide to Traffic Management</i> ⁽³⁾ and AS 1742.2.
Give way lines only	<ul style="list-style-type: none"> May be used at local street T-intersections to reinforce priority although an appropriate sign (stop or give way) may be required in these circumstances. Not common practice. 	See Australian Road Rules and Parts 4 and 10 of the <i>Guide to Traffic Management</i> ⁽¹⁾⁽³⁾ and AS 1742.2.

Type of control	Key traffic and safety considerations	References
Road rules only	<ul style="list-style-type: none"> • Applied in the absence of intersection traffic control devices. • Is common practice at T-intersections between local streets where traffic control devices may not be provided. • Cross-roads generally have traffic control devices, however, they need not be provided on very low-volume roads in remote areas where a major/minor road hierarchy does not exist (note that New Zealand requires all cross-roads to be controlled). 	See Australian Road Rules and New Zealand Land Transport Rules.

Sources:

- 1 *Guide to Traffic Management Part 4 (Austroads 2016b).*
- 2 *Guide to Traffic Management Part 9 (Austroads 2016c).*
- 3 *Guide to Traffic Management Part 10 (Austroads 2016d).*

Other traffic control options

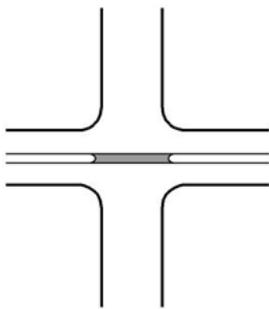
At some intersections it may be desirable that the primary traffic control options are supplemented by traffic control devices (e.g. signs or islands) to require all or some traffic to move in a particular direction or to ban particular movements. These devices are used to prevent:

- unsafe traffic movements
- traffic movement that would be detrimental to the operation of major movements within the intersection
- traffic from using sensitive areas adjacent to an arterial road.

Where a right-turn lane cannot be provided, and safety and/or capacity problems exist, then consideration should be given to banning the turn. For example, a filter right-turn which opposes a lagging right-turn during normal phase sequence operation at traffic signals should be banned for safety reasons as it is confusing². Before any right-turn is banned, convenient alternative access should be available or provided. Various methods of banning right-turns are shown in Figure 2.25. Further options to restrict right-turns using channelisation are discussed in Section 2.2.10.

² Note that a filter right-turn which opposes a lagging right-turn during normal phase sequence operation at traffic signals can be used where special all red is used to manage the phase transition.

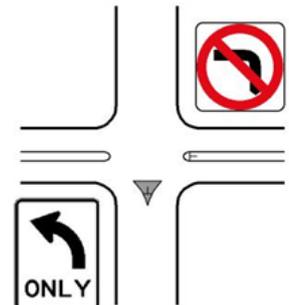
Figure 2.25: Methods of banning right-turns



(a) Close Median
Prevents opposing right turn and cross movements



(b) Close Local Street
Prevents all movements to and from local street



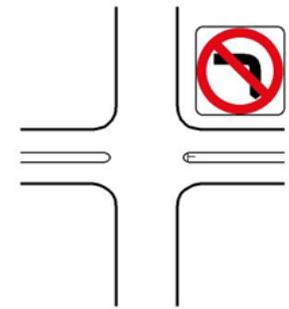
(c) Splitter Island
Allows left turn only in/out of local street



(d) Half road closure (exit)
Allows left turn only out of local street



(e) Half road closure (entry)
Allows left turn only into local street



(f) No Right Turn Sign
(Total or specific times)
Legal prevention of right turn

Note: See the TCD Manual (NZTA 2008c³) for signs that apply in New Zealand

Source: Adapted from Queensland Department of Main Roads (2006).

Traffic control and road classification

Table 2.6 provides a broad guide to the suitability of the type of traffic control in relation to the functional classification of roads. It is based on a general appreciation of the need to provide a satisfactory level of safety and mobility on arterial roads. In some cases the suitability is obvious whilst in other cases traffic analysis and examination of other factors is required to determine the most appropriate form of control at a site. Needs of all roads users should be taken into account when selecting traffic control. For example, as noted in Section 3.4.2 and 3.4.3, while roundabouts are generally safer than other types of at-grade intersection for motor vehicle occupants, they do not offer the same extent of benefits for cyclists and motorcyclists (Austroads 2015d).

3 Note the relevant part of the TCD Manual may be unpublished, in which case refer to the Manual of Traffic Signs and Markings (MOTSAM) (NZ Transport Agency (NZTA) 2010a, 2010b). MOTSAM is being progressively replaced by the TCD Manual (in press).

Table 2.6: Suitability of types of traffic control to different road types based on operational and Safe System objectives

Road type	Primary arterial	Secondary arterial	Collector and local crossing road	Local street
Roundabouts				
Primary arterial	A	A	X	X
Secondary arterial	A	A	A	X
Collector & local crossing road	X	A	A	O
Local street	X	X	O	O
Traffic signals				
Primary arterial	O	O	O	X
Secondary arterial	O	O	O	X
Collector & local crossing road	O	O	X	X
Local street	X	X	X	X
Stop signs or give way signs				
Primary arterial urban/(rural)	X/(X)	X/(O)	A	A
Secondary arterial urban/(rural)	X/(O)	X/(O)	A	A
Collector & local crossing road	A	A	A	A
Local street	A	A	A	A

A = Most likely to be an appropriate treatment
 O = May be an appropriate treatment
 X = Usually an inappropriate treatment.

2.3.4 Intersection Type Selection – Key Traffic Management Considerations

The following Tables summarise the key traffic management considerations that must be taken into account, in association with the costs of the various options, in selecting the type of intersection to be used in any given situation:

- unsignalised at-grade intersections (Table 2.7)
- roundabouts (including signalised roundabouts) (Table 2.8)
- conventional signalised intersections (Table 2.9)
- interchanges (Table 2.10).

Note that there may be relevant jurisdictional guidance to supplement the following considerations. Practitioners should consider local practice and all relevant issues as part of selecting the relevant intersection type.

Table 2.7: Key traffic management considerations in the selection of unsignalised at-grade intersections

	Key traffic management selection considerations ⁽¹⁾
Basic	<ul style="list-style-type: none"> • Used at urban locations where low-volumes and low-speeds occur and at rural sites with low cross and turning volumes. • Designed to be compact and low cost; can be used with any road surface. • Offers no protection to turning traffic and causes through traffic to slow when such movements occur. • Skewed T-intersection (Figure 5.1) layouts may have safety problems • Consider the needs of other road users including pedestrians, cyclists, motorcyclists and heavy vehicles (Section 2.4).

	Key traffic management selection considerations ⁽¹⁾
Capacity	<ul style="list-style-type: none"> • Unsignalised intersections rely on gap selection for the entry of minor road traffic into or across the major road and for right-turn movements from the major road. • Higher conflicting volumes result in increased delays and higher risk of crashes. <p>Intersection analysis can be undertaken to determine absorption capacity, delays and queue lengths (<i>Guide to Traffic Management Part 3, Austroads 2013</i>).</p>
Auxiliary lanes	<ul style="list-style-type: none"> • Auxiliary lanes may be added to the basic intersection to improve safety (Sections 2.3.5 and 2.3.6). • Typically used in rural areas where high-speed, low-volume traffic occurs and the volume and slow manoeuvring of turning traffic is sufficient to create a conflict with following traffic. • Generally intended to provide separation for the manoeuvring of a single vehicle. • Left passing lane allows traffic to bypass a vehicle waiting to turn right; it is not intended for locations with regular queuing. • Left-turning lane allows traffic to decelerate and turn without affecting through traffic. • Lanes should be installed on a needs basis and may not be required on all approaches. • Right-turn auxiliary lanes without channelisation are not used in some jurisdictions. • Consider the need for bicycle lanes.
Channelised	<ul style="list-style-type: none"> • See Sections 2.3.5 and 2.3.6. • When channelisation is being considered, the capacity of the intersection in the unsignalised state should be analysed to determine suitability. • Used where there is a need to define vehicle paths where there would otherwise be a large area of pavement; also used where conflicting vehicle travel paths need to be separated and where approaches are at odd angles or multileg. • Applicable where turning traffic movements are heavy with frequent queuing. • Necessary where refuges are required for pedestrians and cyclists or to provide separation between street furniture and vehicle paths. • Used to cater for unusual manoeuvres or where unwanted movements are to be eliminated. • Provide islands that can safely accommodate pedestrians (types and numbers).
Staggered T-intersection	<ul style="list-style-type: none"> • Generally used to treat right-angle crashes at existing low-volume rural cross-intersections. Staggered T-intersections can experience higher crash rates than cross-intersections, particularly in rural environments (See Section 2.2.7). • Right-left configuration on two-lane, two-way roads may develop safety problems at high traffic volumes. • Two configurations may be used: <ul style="list-style-type: none"> - left-right (L-R) configuration (i.e. left-turn followed by right-turn crossing from minor road) <ul style="list-style-type: none"> - is preferred, due to lower crash risk, compared to a R-L configuration - is used to improve cross movements from the minor road where major route volumes are high - has right-turn lanes on major road, thus benefitting major road right-turn movements - allows minor road crossing traffic to select gaps in each direction of flow independently - provides reduced delay, higher capacity and safer manoeuvres for minor road traffic than R-L configuration - requires stagger distance that is significantly greater than R-L configuration as right-turn lanes for deceleration and storage are required between the minor roads (this leads to increased land acquisition and higher costs). - right-left (R-L) configuration (i.e. right-turn followed by left-turn crossing from minor road) <ul style="list-style-type: none"> - is used to stop traffic on the minor road crossing an arterial or sub-arterial at high-speed - requires crossing traffic to select gap in two-way traffic stream (major road undivided) - is suited to lower-volume locations, particularly on the major road - avoids the possibility of minor road cross traffic queuing in the major road - creates longer delays on minor roads where traffic must select gaps in two-way undivided major road stream - uses opposing right-turning movements that do not overlap, enabling a short stagger distance and resulting in little land acquisition - is an option where the costs preclude the provision of a L-R configuration. • R-L and L-R configurations may be used on divided roads provided that the stagger distance is large enough to satisfactorily accommodate turn lanes on the major road.

	Key traffic management selection considerations ⁽¹⁾
Seagull	<ul style="list-style-type: none"> • See traffic management considerations (Section 2.2.8). • Generally used only at T-intersections. • Appropriate at locations where right-turns from the terminating leg experience delays due to lack of gaps. • Only requires gap selection to nearside approach direction. • Requires additional pavement width on major road to accommodate turning movements and merge taper for through movement. • Provides storage for right-turn movements from the non-terminating road. • May not be suitable where a significant traffic generator exists at the top of the T-intersection, as some drivers may attempt wrong-way movements to access the minor road opposite the development. • Issues may exist where road geometry or islands mask the road surface. • Roundabouts are generally preferred to seagulls.
Wide median treatment (WMT)	<ul style="list-style-type: none"> • See traffic management considerations (Section 2.2.9). • Typically used at high-speed rural divided roads where a crossroad must be retained and it is necessary to manage the speed of crossing traffic. • Similar in design to a roundabout, but priority is given to the major road drivers. • Necessary to consider WMTs and roundabouts in same area – to minimise driver confusion, they should not be alternated along the same route nor used in close proximity to each other.
Two-staged crossing	<ul style="list-style-type: none"> • Suitable on roadways with wide medians where the volume of right-turning traffic is low and through volumes are high. • May not be appropriate where a substantial number of heavy vehicles turn into the minor road.
Offset right-turn lanes	<ul style="list-style-type: none"> • Suitable where there are wide medians. • Improve sight lines for a right-turning driver to see past a vehicle waiting to turn right from opposite direction. • May be advantageous to older drivers in order to accommodate their slower decision times and declining motion perception abilities.
Intersections with service roads	<ul style="list-style-type: none"> • Service roads generally operate as one-way carriageways due to operational problems at intersections and headlight glare to the left of drivers on the major carriageway. • Two-way service roads may be used where the outer separator is wide enough to prevent operational or glare problems or they form short sections immediately prior to or beyond an intersection that functions as property access.

¹ For further guidance on unsignalised intersection modifications, refer to Part 4 of the Guide to Road Design (Austroads 2017a).

Table 2.8: Key traffic management considerations in the selection of roundabouts

	Key traffic management selection considerations ⁽¹⁾
General	<ul style="list-style-type: none"> • Generally much safer than traffic signals in terms of crash severity. • Usually less delay than traffic signals during the off-peak periods, leading to less overall delay to traffic throughout the day. • Readily caters for heavy right-turns. • Can be used in local streets. • Controls vehicle speeds as a traffic calming measure (e.g. at the extremities of high pedestrian activity area). • May not be suitable where strong coordination of movement required along a route. • May not be able to provide sufficient capacity for high-volume sites. • May not be appropriate for high-speed divided rural roads in terms of efficiency, although it can assist in providing access for important minor roads. • Dominant flows on one approach may lead to excessive delay on the subsequent approach (although metering can assist). • Where multilane approaches and circulating lanes are needed to manage traffic flows, consideration of the use of traffic management on approaches, or a turbo roundabout design (see Commentary 6) can assist lane selection, and improve lane discipline and safety performance. <p style="text-align: right;">[see Commentary 6]</p> <ul style="list-style-type: none"> • Does not allow positive regulation of particular movements (e.g. access to local street from a busy road). • Safety concerns for on-road cyclists, particularly at multilane roundabouts (see Section 3.4.2). • Consider needs of motorcyclists (See Section 2.4). • Need to consider pedestrians of all types and cyclist movement and numbers. • Pedestrian facilities should be placed one or two car lengths from the holding line (6 or 12 m) together with sufficient width and storage area within the splitter island. • Placement of pedestrian facilities should also consider roundabout exit conditions. • Traffic signals would be preferred instead of multilane roundabouts in high activity areas for pedestrians and cyclist safety and accessibility. • Need to consider bus and long-vehicle requirements without overdesigning for vehicle movements. Consider use of encroachment areas to reduce excessive circulating widths (see Commentary 7). <p style="text-align: right;">[see Commentary 7]</p> <ul style="list-style-type: none"> • Need to consider footprint and therefore possible land acquisition.

¹ For more detail on appropriate and inappropriate sites for roundabouts, see Section 3.2, Part 3 of the Guide to Traffic Management (Austroads 2013) and Part 4B of the Guide to Road Design (Austroads 2015c).

Table 2.9: Key traffic management considerations in the selection of signalised intersections

	Key traffic management selection considerations ⁽¹⁾
General	<ul style="list-style-type: none"> • Provides the most suitable treatment for very high-volume sites. • Enables efficient coordination along traffic routes. • Can readily accommodate priority measures for public transport. • May provide controlled crossings for pedestrians and cyclists. • Are safer for cyclists than multilane roundabouts that don't include a separated path. • May be preferred for sites with high pedestrian and cyclist activity where a design that is friendly for them is not feasible. • Generally preferred to roundabouts for intersections along freight routes. • Are not generally as safe as roundabouts. • Are generally not desirable from a safety perspective in high-speed environments but, if used, vehicle detection technology, speed limit reductions or electronic interactive warning devices are required.

Key traffic management selection considerations ⁽¹⁾	
	<p>The following guidelines indicate those circumstances where signals could be of significant benefit. The terms ‘major’ and ‘minor’ are used respectively to indicate the roads carrying the larger and smaller traffic volume:</p> <ol style="list-style-type: none"> Traffic volume: Where the volume of traffic is the principal reason for providing a control device, traffic signals may be considered, subject to detailed analysis when the major road carries at least 600 veh/hour (two-way) and the minor road concurrently carries at least 200 veh/hour (highest approach volume) on one approach over any four hours of an average day⁽³⁾⁽⁴⁾. Continuous traffic: Where traffic on the major road is sufficient to cause undue delay or hazard for traffic on a minor road, traffic signals may be considered when the major road carries at least 900 veh/hour (two-way) and the minor road concurrently carries at least 100 veh/hour (highest approach volume) on one approach, over any four hours of an average day. This warrant applies provided that the installation would not disrupt progressive traffic flow, and that no alternative and reasonably accessible signalised intersection is present on the major road⁽¹⁾⁽²⁾. Pedestrian safety: To help pedestrians cross a road in safety, signals should be considered when over any four hours of an average day, the major road carries 600 veh/hour (two-way), or where there is a central pedestrian refuge at least 1.2 m wide, the major road flow exceeds 1000 veh/hour, and 150 pedestrians per hour or more cross the major road⁽³⁾⁽⁴⁾⁽⁵⁾. Crashes: Where the intersection has an average of three or more reported casualty crashes per year over a three-year period where the crashes could have been prevented by traffic signals, and traffic flows are at least 80% of the volume warrants given in (1) and (2). <ul style="list-style-type: none"> Combined factors: In exceptional cases, where no single guideline is satisfied but where two or more of the warrants given in (1) and (2) are satisfied to the extent of 80% or more of the stated criteria. <p>Other site-specific considerations may need to be taken into consideration. Intersection analysis can be undertaken to calculate capacity and assess various measures for intersection performance (Part 3 of the <i>Guide to Traffic Management</i>, Austroads 2013). Further information on standards associated with traffic signals is given in AS 1742.2.</p>
Channelised	<ul style="list-style-type: none"> See Sections 2.3.5 and 2.3.6. Preferred where traffic volumes justify auxiliary lanes and separation of traffic streams. Desirable where signal aspects would otherwise be poorly located for approaching traffic. <p>Necessary to provide islands that can safely accommodate pedestrian demands.</p>
Staggered T-intersection	<ul style="list-style-type: none"> Refer to unsignalised intersections. Issues relating to queuing or other operational issues meant this configuration often not desired for signals (Commentary 8). <p style="text-align: right;">[see Commentary 8]</p> Special considerations are needed for signal design.
Seagull	<ul style="list-style-type: none"> Refer to considerations noted for unsignalised seagull intersections (Table 2.7). Purpose is to avoid stopping the major road through traffic that approaches from the left side of the T-junction stem. Are not suitable where substantial pedestrian and cyclist flows must cross the major road.
Offset right-turn lanes	<ul style="list-style-type: none"> Refer to considerations noted for unsignalised offset right-turn lane intersections (Table 2.7).

1 For further guidance on signalised intersections, refer to Section 4 and the *Guide to Road Design Part 4* (Austroads 2017a).

2 For more detail on appropriate and inappropriate sites for roundabouts, see Section 3.23.2, Part 3 of the *Guide to Traffic Management* (Austroads 2013) and Part 4B of the *Guide to Road Design* (Austroads 2015c).

3 Two-way volumes are defined as the sum of both directions approaching the intersection for a road, e.g. major road.

4 Differences exist between warrants used in different jurisdictions. Please refer to your relevant jurisdictional supplement.

5 The *Pedestrian Crossing Facility Selection Tool* (available from Austroads 2016f) also provides guidance on selection of pedestrian treatments.

Table 2.10: Key traffic management considerations in the selection of interchanges

Intersection type	Key traffic management selection considerations ⁽¹⁾
Motorway/motorway	<ul style="list-style-type: none"> • Grade separation is essential at all motorway/motorway intersections. • Appropriate form is dependent on detailed traffic analysis and land constraints. • No local access is provided for vehicles, pedestrians or cyclists.
Motorway/arterial	<ul style="list-style-type: none"> • Are essential to provide interchanges on urban freeways and motorways. • It is desirable to provide interchanges on rural freeways and motorways. • The provision at minor side roads on rural freeways or motorways may be dependent on National Highway rules or committed major development served by the minor road. • The decision not to provide an interchange at very low-volume side roads on rural freeways or motorways may be dependent on a detailed economic analysis. • Pedestrian and cyclist facilities may need to be accommodated at the arterial level.
Arterial/arterial	<ul style="list-style-type: none"> • Are provided where operational or safety performance of an at-grade intersection is unsatisfactory. • Must result in network benefits (e.g. not shift traffic delay to downstream intersections). • May involve grade separation of only one traffic movement within an intersection. • May need to accommodate pedestrian (including people having a vision, mobility or hearing impairment) and cyclist movements on and between both roads.

¹ For further guidance on interchanges, refer to Section 6 and Part 4C of the Guide to Road Design (Austroads 2015b).

2.3.5 Determining the Need for Auxiliary Lanes

Deceleration turn lanes

The layouts of many intersections include turning lanes to ensure that deceleration and storage of turning vehicles occur clear of the through traffic lanes. The need for deceleration turn lanes cannot be stated definitively in all instances because of the many factors to be considered, such as speeds, traffic volumes, capacity, type of road, service provided, traffic control and crash history.

However, the need is usually established on the basis of ensuring that turning traffic does not impede through traffic to the extent that:

- the operational efficiency of an intersection or intersection approach is compromised
- an unacceptable level of safety would result due to turning traffic slowing or stopping in a through lane.

The need for auxiliary lanes and the type of treatment should consider:

- the function of the road and its strategic significance
- the volume of heavy vehicles using the road
- operating speeds at the intersection
- available sight distance to drivers of turning vehicles
- consistency of treatment along a corridor to meet driver expectations
- traffic volumes.

Auxiliary lanes to accommodate right-turn or left-turn movements, or to improve the capacity of a through movement, may be provided across the range of available intersection types. Warrants for the provision of auxiliary lanes for AU and CH treatments are provided in Section 2.3.6.

Where volumes are substantial a need is usually established through traffic analysis (*Part 3 of the Guide to Traffic Management*, Austroads 2013). At major signalised urban intersections it is common for two, and in some cases three, turn lanes to be required for right-turning or left-turning movements based on operational efficiency.

Acceleration lanes

There are no simple numerical warrants for the provision of acceleration lanes. However, an auxiliary lane may be added on the departure side of a left-turn or right-turn lane if traffic is unable to join safely and/or efficiently with the adjacent through traffic flow by selecting a gap in the traffic stream.

Acceleration lanes may be provided at major intersections depending on traffic analysis. However, they are usually provided only where:

- insufficient gaps exist for vehicles to enter a traffic stream
- turning volumes are high (e.g. 300 to 500 veh/hour)
- the observation angle falls below the requirements of the minimum gap sight distance model (for example, inside of horizontal curves)
- heavy vehicles pulling into the traffic stream would cause excessive slowing of major road vehicles.

Acceleration lanes should only be used where there is no demand for the turning drivers to weave over a relatively short distance across the carriageway once they leave the acceleration lane.

Auxiliary through lanes

At rural intersections an auxiliary through lane will be associated with the need to provide an overtaking lane or a climbing lane (*Guide to Road Design Part 3: Geometric Design*, Austroads 2016e).

At urban intersections the need for an auxiliary through lane will relate to the need to increase the capacity or improve the level of service on an approach (*Guide to Traffic Management Part 3*, Austroads 2013).

2.3.6 Warrants for BA, AU and CH Turn Treatments

These warrants apply to major road turn treatments for the basic, auxiliary lane and channelised layouts discussed in Section 2.2.2, 2.2.3 and 2.2.4. The warrants shown in Figure 2.26 provide guidance on preferred minimum turn treatments for major roads. It should be noted that CHR or CHL turn treatments are preferred (to ensure a clear line of sight for vehicles at the intersection), although it is recognised that many existing intersections (particularly those on low-volume lower-order roads) are of a lower standard (e.g. without any shoulder and/or lane widening). They may not meet minimum design layout requirements to accommodate BA, AU or CH turn treatments. Figure 2.26 contains three graphs for the selection of turn treatments on roads with a design speed:

- ≥ 100 km/h; Figure 2.26(a) is appropriate for high-speed rural roads
- between 70 and 100 km/h; Figure 2.26(b) is appropriate for higher-speed urban roads, including those on the urban fringe and lower speed rural roads
- < 70 km/h; Figure 2.26(c) is appropriate for urban roads.

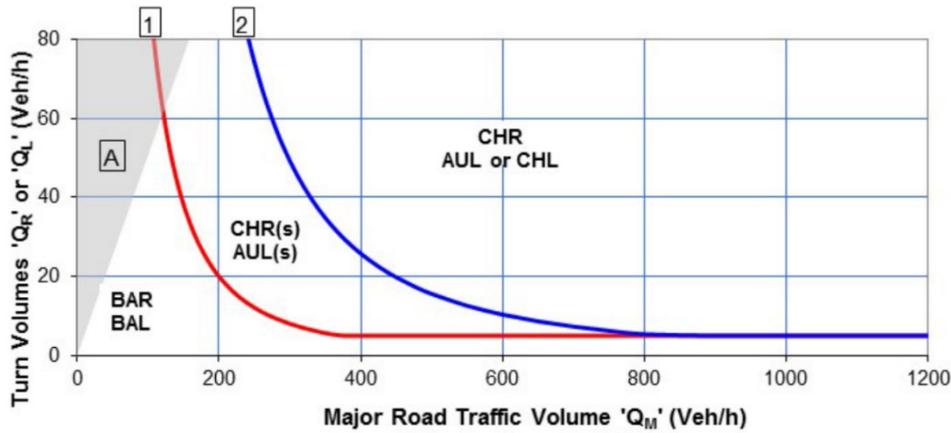
The warrants focus on safety performance outcomes. Evaluation of operational performance may indicate that a higher level treatment or alternative intersection control be adopted than those recommended in Figure 2.26. Where practicable a CH treatment should be used in preference to non-channelised turn treatments. It should be noted that in some circumstances, while adding auxiliary turn lanes will reduce the risk of rear end crashes, the risk of other high severity crash types may increase (such as right-angle crashes). Consideration of this issue should be taken into account when selecting appropriate turn treatments.

If a particular turn from a major road is associated with some geometric minima (for example, limited sight distance, steep grade), then consideration should be given to the adoption of a turn treatment of a higher order than that indicated by the warrants. For example, if the warrants indicate that a BAR turn treatment is acceptable for the relevant traffic volumes, but limited visibility to the right-turning vehicle is available, then consideration should be given to the adoption of a CHR(S) or CHR turn treatment instead. Another example is a major road on a short steep downgrade where numerous heavy vehicles travel quickly down the grade. In this case it would not be appropriate to adopt a BAL turn treatment; a CHL would be a preferred treatment.

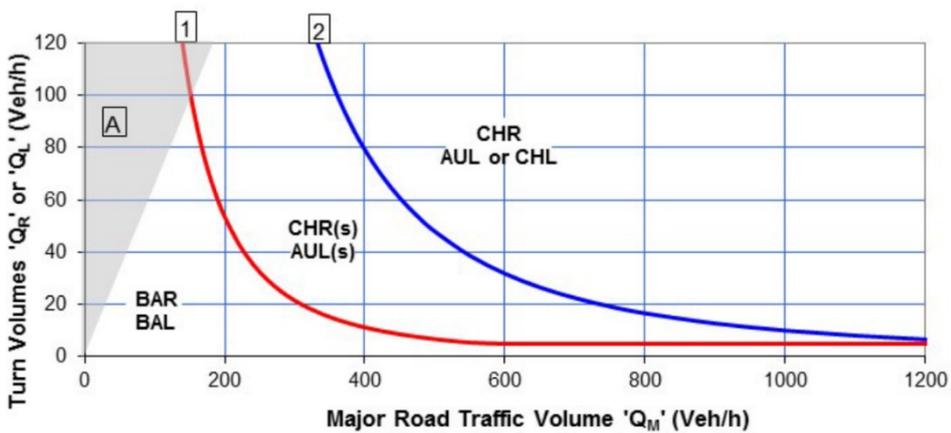
The development of the warrants in this section is detailed in Arndt and Troutbeck (2006) and TMR (2016a). It is also briefly discussed in Commentary 9. The *Safe System Assessment Framework* (Austroads 2016a) may also be a useful reference when considering road turn treatments (see Table 2.2).

[\[see Commentary 9\]](#)

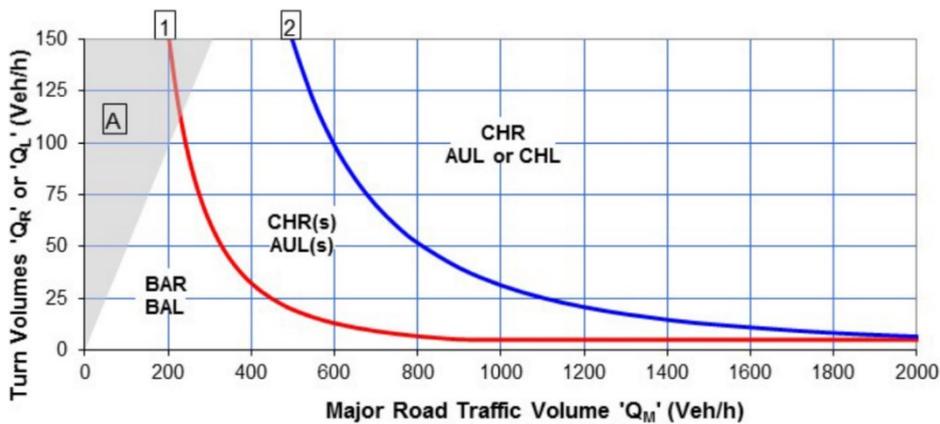
Figure 2.26: Warrants for turn treatments on major roads at unsignalled intersections



(a) Design Speed ≥ 100 km/h



(b) 70 km/h < Design Speed < 100 km/h



(c) Design Speed ≤ 70 km/h

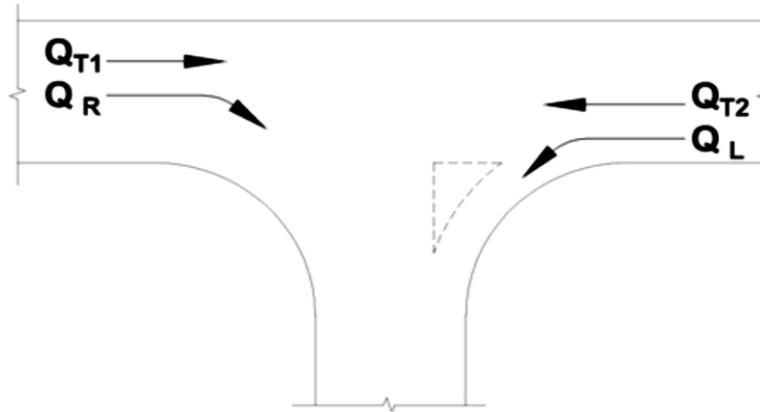
Note: the minimum right-turn treatment for multilane roads is a CHR(s).

Source: TMR (2016a).

In applying the warrants in Figure 2.26 designers should note that:

- Curve 1 represents:
 - on two-lane two-way roads: the boundary between a BAR and a CHR(S) turn treatment and between a BAL and an AUL(S) turn treatment
 - on four or six-lane two-way roads: the boundary between a BAL and an AUL(S) turn treatment. Note that on these roads, the minimum right-turn treatment is a CHR(S).
- Curve 2 represents the boundary between a CHR(S) and a CHR turn treatment and between an AUL(S) and an AUL or CHL turn treatment. The choice of CHL over an AUL will depend on factors such as the need to change the give way rule in favour of other manoeuvres at the intersection and the need to define more appropriately the driving path by reducing the area of bitumen surfacing.
- The warrants apply to turning movements from the major road only (the road with priority). Turn treatments for the minor road should be determined through an operational performance evaluation.
- Figure 2.27 is to be used to calculate the value of the major road traffic volume parameter (Q_M):
 - on two-lane two-way roads: the value of the major road traffic volume parameter (Q_M) is the total through traffic flow in both directions ($QT_1 + QT_2$).
 - on four- or six-lane two-way roads: the major road traffic volume parameter (Q_M) for right turns uses the full opposing flow QT_2 and only the traffic flow in the nearest lane of the following flow QT_1 . For left turns, the major road traffic volume parameter (Q_M) uses only the traffic flow in the leftmost through lane of the following flow QT_2 .
- Traffic flows applicable to the warrants are peak-hour flows, with each vehicle counted as one unit (i.e. do not use equivalent passenger car units [pcus]). Where peak hour volumes or peak hour percentages are not available, assume that the design peak hour volume equals 8 to 10% of the AADT for urban situations and that the design hour volume equals 11 to 16% of AADT for rural situations.
- If more than 50% of the traffic approaching on a major road leg turns left or right, consideration needs to be given to possible realignment of the intersection to suit the major traffic movement. However, route continuity issues must also be considered (for example, realigning a highway to suit the major traffic movement into and out of a minor road would be unlikely to meet driver expectation).
- If a turn is associated with other geometric minima, consideration should be given to the adoption of a turn treatment of a higher order than that indicated by the warrants.
- Some road agencies may consider that the CHR(S) treatment is not a suitable arrangement in all instances. Where this occurs, the Main Roads Western Australia (MRWA) AUR treatment may be used as an alternative (*Part 4A of the Guide to Road Design, Austroads 2017b*). However the CHR(S) treatment is considered to be preferable for general use on major roads.

Figure 2.27: Calculation of the major road traffic volume Q_M



Road type	Turn type	Splitter island	Q_M (veh/h)
Two-lane two-way	Right	No	$= Q_{T1} + Q_{T2} + Q_L$
		Yes	$= Q_{T1} + Q_{T2}$
	Left	Yes or no	$= Q_{T2}$
Four-lane two-way	Right	No	$= 50\% \times Q_{T1} + Q_{T2} + Q_L$
		Yes	$= 50\% \times Q_{T1} + Q_{T2}$
	Left	Yes or no	$= 50\% \times Q_{T2}$
Six-lane two-way	Right	No	$= 33\% \times Q_{T1} + Q_{T2} + Q_L$
		Yes	$= 33\% \times Q_{T1} + Q_{T2}$
	Left	Yes or no	$= 33\% \times Q_{T2}$

Source: TMR (2016a).

2.3.7 Wide Median Treatment – Traffic Management Considerations

The WMT is outlined in Section 2.2.9. The treatment was developed and designed to reduce the crossing and entering speed of minor road traffic to a safe value on divided major roads in rural areas.

Research conducted by VicRoads has shown that there is a level of exposure beyond which WMTs develop safety issues and that they should only be considered for use at intersections (Equation 1) where:

- for T-intersections, the entering minor road volume is not greater than 1000 veh/day
- for cross-intersections, the sum of the entering volumes on the two minor roads is not greater than 1000 veh/day
- the exposure, given by the following formula, does not exceed 6000 veh/day.

$$2\sqrt{V_{minor} \times V_{major}} \leq 6000 \tag{1}$$

where

V_{minor} = Total volume of traffic entering from the minor roads

V_{major} = Total volume of traffic entering from the major roads

Equation 1 can be used to determine the year in which a WMT will no longer be appropriate, and beyond which an alternative treatment will be required.

2.4 Road User Considerations

Common issues faced by pedestrians, cyclists, motorcyclists, trucks and public transport users and possible treatments are summarised in the following sections.

2.4.1 Pedestrians

Consideration should be given to ensure that appropriate pedestrian facilities are provided at intersections, taking into account the types of pedestrians (in terms of age and ability), particularly where there is a high percentage of school children, elderly pedestrians or pedestrians who have a vision, mobility or hearing impairment.

Primary (or transformational) Safe System treatment options for pedestrians include separation of pedestrian facilities or the provision of very low motorised vehicle speed environment, particularly at intersections or crossing points. Supporting treatments include reducing the speed environment, providing at-grade crossing facilities, and improving sight distance and lighting (Austroads 2016a *Safe System Assessment Framework*).

For further guidance on pedestrian treatments, refer to Australian and New Zealand Standards, the cited references specific to issues noted in Table 2.11, and *Parts 4* and *6A* of the *Guide to Road Design* and *Part 10* of the *Guide to Traffic Management* (Austroads 2017a, 2017c, 2016d respectively). The *Pedestrian Crossing Facility Selection Tool* (available from Austroads 2016f) also provides guidance on the selection of pedestrian treatments.

Table 2.11: Issues for pedestrians

Issue	Characteristics	Treatments
<ul style="list-style-type: none"> Excessive pedestrian delay. Severance of communities. 	<ul style="list-style-type: none"> Minimal gaps in the traffic stream. No safe crossing facility. 	<ul style="list-style-type: none"> Signalised pedestrian crossing. Pedestrian crossing. Refuge islands and medians. Kerb extensions. Grade separation.
<ul style="list-style-type: none"> Squeeze points for wheel chairs and pedestrians with prams. 	<ul style="list-style-type: none"> Location of street furniture and other obstacles. 	<ul style="list-style-type: none"> Relocate furniture to provide clear path. Control use of footpaths through local municipal laws (e.g. advertising signs, alfresco eating areas).
<ul style="list-style-type: none"> Accessibility for persons who have a vision, mobility or hearing impairment to facilities such as road crossings and public transport stops. 	<ul style="list-style-type: none"> No kerb ramps. Steep footpath gradients or crossfalls. Steep ramp grades or steps. Inadequate public transport stops. 	<ul style="list-style-type: none"> Provide raised pedestrian facility. Provide suitable ramps. Provide flatter ramps. Provide compliant bus/tram stops. Provide tactile paving to guide vision impaired pedestrians to appropriate crossing locations and to warn them of hazards.
<ul style="list-style-type: none"> Poor driver visibility to pedestrians. 	<ul style="list-style-type: none"> Poor lighting. Structure, road furniture or vegetation blocking sight lines. Inadequate sight lines due to road geometry (grades, vertical curves and horizontal curves). 	<ul style="list-style-type: none"> Provide suitable lighting. Redirect and control pedestrians to a safer crossing point – pedestrian fencing. Relocate structure/furniture if possible to achieve suitable sight distances. Adjust location of traffic lane and/or add kerb extension to improve sight distance. Realign road (refer to <i>Part 3</i> of the <i>Guide to Road Design</i>, Austroads 2016e).
<ul style="list-style-type: none"> Inadequate pedestrian storage areas. Long unprotected crossing distances. 	<ul style="list-style-type: none"> Narrow verges and footpaths. No storage islands. Storage not suitable for people with disability or mobility difficulty. 	<ul style="list-style-type: none"> Widen verge/path. Provide kerb extensions. Provide median or refuge island. Provide access facilities for impaired persons.

Issue	Characteristics	Treatments
<ul style="list-style-type: none"> High-speed turning traffic. 	<ul style="list-style-type: none"> Intersection layout enables excessive speed for turning movement. 	<ul style="list-style-type: none"> Provide a sign warning of pedestrians ahead (e.g. AS 1742.1 sign W6-1). Redesign turning path to achieve smaller radius. Provide channelisation (e.g. traffic island to prevent 'corner cutting').
<ul style="list-style-type: none"> Driver distraction despite adequate road rules for pedestrian safety. 	<ul style="list-style-type: none"> Attention of left turning drivers at uncontrolled slip lanes and unsignalised intersections is to the traffic coming from their right. Pedestrians on the driver's left may not be seen (cognitive and physical). Attention of right turning drivers at signalised (no arrows) and unsignalised intersections is focussed on the oncoming traffic. The driver may not 'see' (cognitive and physical) pedestrians crossing the road the driver wants to turn into. 	<ul style="list-style-type: none"> High entry angle ($\geq 70^\circ$) slip lanes (predominantly to reduce consequence and may reduce likelihood). Reduce vehicle speeds through intersection using physical device, e.g. road hump or wombat crossing on slip lanes that don't have high entry angle (predominantly to reduce consequence and may reduce likelihood). Move footpath and kerb ramp further away from intersection corner (without making it an inconvenient detour for pedestrians), and use landscaping, etc. to prevent pedestrians from crossing elsewhere. Use flashing yellow arrow where two aspect left turn arrows (red and yellow) are used with no pedestrian lights at slip lanes. Fully controlled (pedestrians and drivers) slip lanes. Fully controlled right turns (no filtering).

Note: See AS 1742.10 Pedestrian Control and Protection, New Zealand Transport Agency Pedestrian Planning and Design Guide (NZTA 2009) and the Pedestrian Crossing Facility Selection Tool (available from Austroads 2016f).

2.4.2 Cyclists

Cyclists differ from drivers in that they have a broader range of age and ability. They have to be able to balance the vehicle whilst negotiating the road and traffic situations (Commentary 10). The needs of different cyclist types and their abilities should be taken into account in all intersection type and design decisions. In addition to the range in age and skill (from novices to experts), some cyclists may be competent but risk adverse. Cyclists also travel for a variety of reasons, such as for a specific purpose (i.e. commuting) or recreation. The type of cyclist to be catered for, and the level of service to be provided will influence the type of bicycle facility as well as safety and design considerations⁴.

Bicycle facilities may be:

- bicycle path, separated path or shared path – facilities separated from motorised traffic although they generally do not have priority at intersections.
- cycle track – bicycle facilities separated from motorised traffic within the road corridor with the cyclist having priority at intersections (for more information refer to Commentary 11)
- bicycle lane – has priority at intersections; however, the facility is not generally physically separated from motorised traffic.

[\[see Commentary 10 and Commentary 11\]](#)

⁴ Cyclists may also travel on footpaths (note, age restrictions apply in some jurisdictions).

Cyclists may use off-road paths where a high-quality convenient route is available. However, commuter cyclists in particular may use the road network because:

- off-road paths may be indirect and not located to satisfactorily serve the trip route
- the path’s surface may not be as smooth as arterial roads
- 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, etc.).

Primary (or transformational) Safe System treatment options for cyclists include separation of cyclist facilities or the provision of very low motorised vehicle speed environment, particularly at intersections or crossing points. Supporting treatments include shared pedestrian/cyclist paths, on-road cyclist lanes, cyclist boxes or separation at intersections (Austroads 2016a).

Further guidance can be found in Australian and New Zealand Standards, the cited references specific to issues noted in Table 2.12, and *Parts 4 and 6A of the Guide to Road Design* and *Part 10 of the Guide to Traffic Management* (Austroads 2017a, 2017c, 2016d respectively).

Table 2.12: Issues for cyclists

Issue	Characteristics	Treatments
<ul style="list-style-type: none"> • Safely cross or join conflicting flows. 	<ul style="list-style-type: none"> • Insufficient gaps in the traffic stream being crossed or joined. 	<ul style="list-style-type: none"> • Provide a signalised cyclist crossing. • Provide a refuge island. • Develop a well-designed transition from bicycle path, separated path or shared path to an on-road bicycle lane i.e. physical protection for cyclist through the alignment of the left-side kerb (refer to the <i>Guide to Road Design Part 4</i>, Austroads 2017a). • Consider suitability and practicability of the provision of a cycle track (Commentary 11).
<ul style="list-style-type: none"> • Squeeze points. 	<ul style="list-style-type: none"> • Road narrows and the separation between cyclists and motor vehicles reduces. • Non-flush service pit covers and sumps (New Zealand) that reduce the available width for cyclists. 	<ul style="list-style-type: none"> • Install local widening or remark traffic lanes to achieve a wide kerbside lane (where insufficient width is available for a bicycle lane). • Provide a bicycle lane. • Provide a bicycle/car parking lane. • Provide a shared path (provide where an on-road facility is impracticable and for use by young and inexperienced cyclists). • Provide a bicycle path or separated path (see shared path above). • Add watch for bicycles sign (AS 1742.9 sign G9-57). • Provide a bicycle symbol and short continuity line in a wide kerbside lane to increase motorist awareness of the presence of cyclists and to improve cyclist comfort (Daff and Barton 2005). • Ensure that service covers and drainage assets do not reduce the road width available for safe use by cyclists.

Issue	Characteristics	Treatments
<ul style="list-style-type: none"> Lack of continuity and connectivity. 	<ul style="list-style-type: none"> Cyclists continually have to re-join motor vehicle lanes because bicycle lane is terminated at squeeze points, resulting in hazardous movements. 	<ul style="list-style-type: none"> Use continuous bicycle lanes through unsignalised intersections where feasible. Provide green surfacing for bicycle lanes through hazardous areas or complex situations. If practicable, re-allocate road space used by other road users or for other purposes to achieve bicycle lane continuity. Consider suitability and practicability of provision of a cycle track (Commentary 11). Erect watch for bicycles signs at bicycle lane terminations (AS 1742.9 sign G9-57).
<ul style="list-style-type: none"> Gaining position to turn right. 	<ul style="list-style-type: none"> Unsafe weaving manoeuvres on approach to major intersection. Space to wait and undertake right-turning manoeuvre. Difficult conditions turning right. 	<ul style="list-style-type: none"> Provide a bicycle lane on the left side of the intersection approach and space for cyclists to store whilst making a 'hooked turn'. Locate a right-turn bicycle lane between the right-turn lane and through lane for motor vehicles (does not assist with weaving on the approach but provides some refuge). Provide adequate swept paths for cyclists to turn right with other vehicles, especially heavy vehicles including buses. Provide off-road path on periphery of intersection.
<ul style="list-style-type: none"> Cyclist not seen by motorists (potentially due to driver distraction), or cyclists speed misjudged. 	<ul style="list-style-type: none"> Cyclist likely to be involved in a crash. Attention of left turning drivers at uncontrolled slip lanes and unsignalised intersections is to the traffic coming from their right. Cyclists on the driver's left may not be seen (cognitive and physical). Attention of right turning drivers at signalised (no arrows) and unsignalised intersections is focussed on the oncoming traffic. The driver may not 'see' (cognitive and physical) cyclists crossing the road the driver wants to turn into. 	<ul style="list-style-type: none"> Provide bicycle lanes and logos to increase motorist awareness of the likely presence of cyclists. Erect 'Watch for Bicycles' signs (AS 1742.9 sign G9-57). High entry angle ($\geq 70^\circ$) slip lanes (predominantly to reduce consequence and may reduce likelihood). Reduce vehicle speeds through intersection using physical device, e.g. road hump or wombat crossing on slip lanes that don't have high entry angle (predominantly to reduce consequence and may reduce likelihood). Move footpath and kerb ramp further away from intersection corner (without making it an inconvenient detour for cyclists), and use landscaping, etc. to prevent cyclists from crossing elsewhere. Use flashing yellow arrow where two aspect left turn arrows (red and yellow) are used with no pedestrian lights at slip lanes. Fully controlled slip lanes. Fully controlled right turns (no filtering).
<ul style="list-style-type: none"> Loss of access. 	<ul style="list-style-type: none"> Road closure or provision of one-way streets could result in loss of access for cyclists. 	<ul style="list-style-type: none"> Provide access for cyclists to pass through local road terminations and pedestrian malls. Provide contra-flow for cyclists on one-way streets in low-speed environments.

Note: See Part 4 of the Guide to Road Design (Austroads 2017a); AS 1742.9 Bicycle Facilities; Austroads (2005 and 2017d); NZTA (2010c).

2.4.3 Motorcyclists

The report *Infrastructure Improvements to Reduce Motorcycle Casualties* (Austroads 2016i) noted that ‘motorcyclists have unique needs and as a result have a higher reliance on the design and standard of road infrastructure to make safe decisions and maintain stability’. The report observed that motorcyclists are ‘susceptible to crashes at intersections’ due to issues such as obstructed visibility and low conspicuity of the motorcycle and intersection features.

Primary (or transformational) Safe System treatment options for motorcyclists include separate motorcyclist lane (e.g. on freeways/motorways). Supporting treatments include shared lanes (with bus/taxi), motorcycle-friendly barrier systems, consistent design and delineation or skid resistance improvements (Austroads 2016a).

Table 2.13: Issues for motorcyclists

Issue	Characteristics	Treatments
<ul style="list-style-type: none"> Drivers failing to see/give way to motorcyclists, particularly when drivers are turning right or when angles between intersection legs result in reduced observation angle. Motorcyclists struck while queuing, particularly at urban intersections. 	<ul style="list-style-type: none"> Motorcyclists hit travelling through intersection. Motorcyclists may feel pressured to move through the intersection to avoid being struck from the rear or side-swipe crashes. 	<ul style="list-style-type: none"> Separate through and turning traffic, particularly at signalised intersections. Provide channelised right and auxiliary left turn lanes at signalised and unsignalised intersections. Improve intersection sight distance and ensure clear sight lines. Consider the provision of motorcycle lanes at intersections, or lanes sufficiently wide to allow motorcyclists to filter to the front of the queue.
<ul style="list-style-type: none"> Drivers failing to see/give way to motorcyclists (and other drivers) due to inconspicuous intersections. 	<ul style="list-style-type: none"> Intersections located on a crest or curve may not be seen by drivers Intersections may be inconspicuous in rural areas due to restricted sight lines (e.g. cuttings or vegetation) and in cluttered urban environments. 	<ul style="list-style-type: none"> Improve intersection sight distance and supplement with warning signage when required. Where this is not possible consider intersection ahead pavement markings or vehicle-activated signs.
<ul style="list-style-type: none"> Judgement of motorcycle approach speed by motor vehicle drivers. 	<ul style="list-style-type: none"> Overall visibility: single headlight can make driver judgement difficult. Motorcycles can unexpectedly accelerate at a high rate. 	<ul style="list-style-type: none"> Provide clear sight lines. Install lighting on intersection approaches.
<ul style="list-style-type: none"> Headlight effectiveness on curved intersection approaches (including roundabouts) reduced due to lean of motorcycle. 	<ul style="list-style-type: none"> Motorcycle headlights typically provide a dimmer and narrower light spread than a passenger vehicle. This is compounded by available light reducing as the motorcycle leans; this can result in only a narrow section of the road being illuminated in front of a turning motorcycle. Signs and road markings less effective. Differentiation between kerb and road pavement difficult. 	<ul style="list-style-type: none"> Improve street lighting. Use higher-quality markings on curved intersection approaches. Install larger brighter intersection warning signs.
<ul style="list-style-type: none"> Nature and location of roadside hazards. 	<ul style="list-style-type: none"> Hazards within the clear zone. Motorcycle leaning on curves can place part of motorcyclist’s body beyond the edge of the road. 	<ul style="list-style-type: none"> Hazard-free clear zone and remaining hazards frangible (for motorcyclists) if possible. For necessary items, use appropriate setbacks for road furniture, signage and utility poles. Define safe position for pedestrians to wait.

Note: For more information, see *Infrastructure Improvements to Reduce Motorcycle Casualties* (Austroads 2016i) and *Safer Journeys for motorcycling on New Zealand Roads* (NZTA 2016b).

2.4.4 Trucks

Heavy vehicle needs must be taken into account. As noted in Section 3.1, the design vehicle for roads in residential and commercial areas will often be either a single unit truck/bus, a shorter service vehicle or an ultra low-floor bus.

The vehicles should generally be able to negotiate intersections with adequate clearance to the face of kerbs (exceptions may be made for roundabouts as noted in Section 3.1).

Table 2.14: Issues for trucks

Issue	Characteristics	Treatments
<ul style="list-style-type: none"> Sight distance. 	<ul style="list-style-type: none"> Truck drivers have a higher driver eye height compared to car drivers. This must be taken into account at intersections. 	<ul style="list-style-type: none"> Ensure adequate sight distances are available (refer to <i>Part 3</i> of the <i>Guide to Road Design</i>, Austroads 2016e). Locate signs, vegetation and other structures so that safe intersection sight distance line-of-sight is not impeded at the truck driver eye height. Ensure that overhead structures and sign gantries do not impede the approach sight distance (can be an issue where a sag vertical curve exists on the intersection approach).
<ul style="list-style-type: none"> Acceleration. 	<ul style="list-style-type: none"> Trucks, particularly when fully loaded, require larger gaps to safely enter or cross opposing traffic flow. 	<ul style="list-style-type: none"> Provide suitable acceleration lanes following left and right-turns onto the major road. Consider use of <i>trucks (entering or crossing)</i> warning sign AS 1742.1 sign W5-22.
<ul style="list-style-type: none"> Deceleration. 	<ul style="list-style-type: none"> Trucks, particularly when fully loaded, require a longer distance in which to stop. 	<ul style="list-style-type: none"> Ensure adequate sight distances are available. Consider the provision of longer deceleration lanes for turning trucks to reduce the impact of decelerating trucks on following vehicles Increase left-turn radius if feasible.
<ul style="list-style-type: none"> Length. 	<ul style="list-style-type: none"> Trucks, in particular articulated vehicles, occupy more space when queued. 	<ul style="list-style-type: none"> Ensure the length of storage lanes is sufficient to accommodate the expected number of trucks.
<ul style="list-style-type: none"> Turning paths. 	<ul style="list-style-type: none"> Trucks require a greater area in which to turn. 	<ul style="list-style-type: none"> Check the intersection design with turning path templates or software package. Mark turning paths. Relocate kerb-side furniture (signs, etc). Use mountable kerbs where appropriate.
<ul style="list-style-type: none"> Environmental effects. 	<ul style="list-style-type: none"> Noise, vibration and emissions. 	<ul style="list-style-type: none"> See Table 2.18.

2.4.5 Public transport

Public transport vehicles needs must be taken into account. Public transport stops also need to accommodate public transport users, who are often pedestrians (see Section 2.4.1).

Table 2.15: Issues for public transport

Issue	Characteristics	Treatments
Public transport – buses		
<ul style="list-style-type: none"> Delays to buses. 	<ul style="list-style-type: none"> Buses incur similar excessive delays to other traffic on the same approach. 	<ul style="list-style-type: none"> Examine the feasibility of a <i>bus only</i> lane. Consider the use of buses excepted supplementary signs (e.g. left lane must turn left, buses excepted).
<ul style="list-style-type: none"> Bus stop location. 	<ul style="list-style-type: none"> Can affect passenger accessibility, traffic and bus delays, sight distances and safety. 	<ul style="list-style-type: none"> Bus stops located on the departure side are normally preferred except where not appropriate due to: <ul style="list-style-type: none"> passenger accessibility requirements accumulation of buses at the stop could extend back to block the intersection. Bus stops should be located well upstream on the approach side in situations where buses using the stop subsequently turn right at the intersection. Need to consider sight distance restrictions (for other drivers and pedestrians) caused by a bus stationary at the stop, particularly where the bus stop is located on the approach. Need to consider visibility of traffic signs while the bus is stopped. Bus stop shelters should be located having regard to their effect on sight distances. Pedestrian facilities at the intersection should enable safe crossing of the roads and safe access to the bus stop. They should also take account of the needs of waiting and disembarking passengers: adequate storage areas are required for passengers waiting to cross a road and/or board a bus.
<ul style="list-style-type: none"> Bus dimensions. 	<ul style="list-style-type: none"> Includes space occupied at bus stops and in queues. Turning paths are wider than for most other vehicles. 	<ul style="list-style-type: none"> Ensure bus stops and turn storage lanes are long enough to accommodate the maximum likely number and size of buses. Check intersection design against bus turning path templates. Mark turning paths. Relocate kerbside furniture (signs, etc.) if necessary.
Public transport – trams⁽¹⁾		
<ul style="list-style-type: none"> Delays to trams. 	<ul style="list-style-type: none"> Trams usually have priority at unsignalised intersections along tram routes. However, where trams share road space with cars trams may be delayed by vehicles turning right from the tram tracks. Trams are often accommodated in the medians of divided roads. Where they exist, unsignalised cross and T-intersections may experience queuing within the median opening that causes delay to trams. 	<ul style="list-style-type: none"> Implement regulations and an enforcement regime to penalise motorists who delay trams. Install full-time or part-time tram lanes. Modify the intersection to eliminate crossing movements. Signalise the intersection to eliminate queuing. Provide signs and markings to encourage motor traffic to keep the tram tracks clear.

Issue	Characteristics	Treatments
<ul style="list-style-type: none"> Tram stop location. 	<ul style="list-style-type: none"> Can affect passenger accessibility, traffic and tram delays, sight distances and safety. Tram passengers have the same basic requirements as bus passengers with respect to safe, equitable and efficient access to public transport. In addition, the principles that apply to the spacing and general location of bus stops also apply to tram stops. 	<ul style="list-style-type: none"> Similar location principles as are applied to bus stops. Have traditionally been located near side streets that serve a passenger catchment area. Locate and design the tram stop to enhance visibility of tram passengers when boarding and alighting trams. Pedestrian facilities at the intersection should enable safe crossing of the roads and safe access to the stop. They should also take account of the needs of waiting and disembarking passengers: adequate storage areas are required for passengers waiting to cross a road and/or board a tram. Coordinate with pedestrian crossings to assist safe access. May comprise kerbside stops, or platform stops that provide access for people who depend on wheelchairs or other mobility devices.
<ul style="list-style-type: none"> Tram dimensions. 	<ul style="list-style-type: none"> Space occupied at tram stops and in queues Turning paths are wide and may encroach on the space used by other vehicles. 	<ul style="list-style-type: none"> Ensure tram stops and platforms are long enough to accommodate the maximum likely number and size of trams. Check implications of tram swept width (i.e. turning path including overhang of front and rear) on intersection design or operation. Delineate, preferably in contrasting surfacing (e.g. concrete) tram turning paths. Relocate kerbside furniture (signs, etc.) if necessary.

¹ See *VicRoads* (2016).

2.5 Intersection Performance

2.5.1 Safety

Safe intersection performance is based on the following principles:

- ensuring adequate visibility
- minimising potential for conflict
- managing priority movements
- managing speeds
- clear and easy to understand design and layout.

Ensuring adequate visibility

Adequate visibility of the intersection, of any traffic control devices on the approach and within the intersection, and of other vehicles approaching or standing at the intersection must be available to permit drivers to undertake reasonable actions to ensure safe progress through the intersection. There are four sight distance criteria applicable to intersections (*Part 3 of the Guide to Road Design, Austroads 2016e*):

- approach sight distance (ASD)
- entering sight distance (ESD)
- safe intersection sight distance (SISD)
- minimum gap sight distance (MGSD).

ASD and SISD should be achieved for all intersections, ESD where possible and MGSD where appropriate. It is particularly important that sight distance considerations be examined in situations where a new intersection with an existing road is being proposed or where there is likely to be a significant increase in traffic volumes at an existing intersection.

Heavy vehicles accelerate and decelerate much slower than cars and it is important that this be considered when assessing the adequacy of sight distances, noting however that the truck drivers' eye height is significantly higher than that for car drivers.

Trials of reducing sight distance on the approach to intersections have been undertaken, in order to encourage drivers to slow on the approach to the intersection (Commentary 20).

[\[see Commentary 20\]](#)

For further guidance on sight distances, refer to *Part 3* and *Part 4* of the *Guide to Road Design* (Austroads 2016e and Austroads 2017a).

Minimising potential for conflict

The potential for conflict within an intersection should be minimised through reduction of the number of points of conflict, their spatial separation and/or minimising the area of conflict.

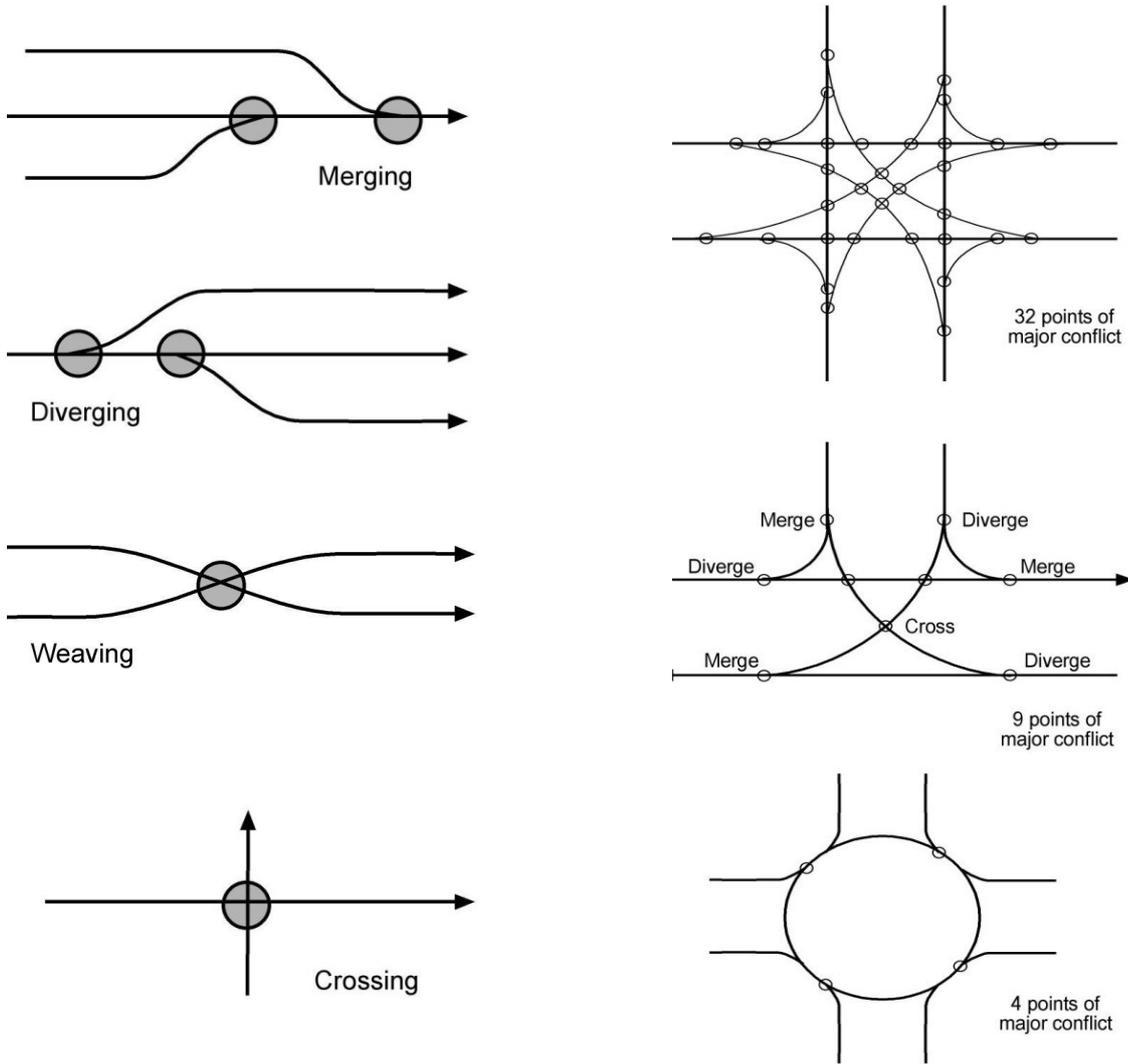
Points of conflict can be separated or reduced by the addition of deceleration lanes, realignment of the intersection, turn bans, etc. The basic forms of conflict are shown in Figure 2.28(a). The analysis of typical intersections to identify the points of conflict is illustrated in Figure 2.28(b). For example, it can be seen that the number of conflict points at cross-intersections is much greater than for T-intersections or roundabouts. It can also be seen that the impact angle is more favourable for a roundabout design than for the angles associated with some of the conflict points at cross-intersections and T-intersections.

Intersection manoeuvres involving conflicts are:

- merging
- diverging in which the vehicle following is forced to slow
- weaving
- crossing.

Figure 2.29 shows examples of ways in which existing points of conflict can be localised by channelisation and the area of conflict reduced by realignment. It should be noted that realignment of an intersection may impact sight distance and/or the impact angle for vehicles involved in collisions at the intersection.

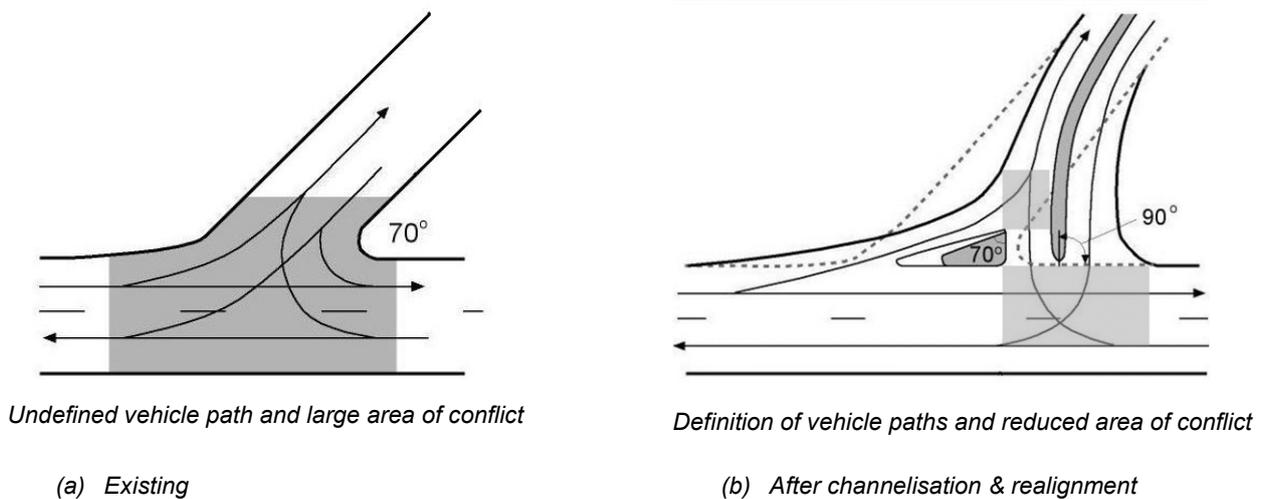
Figure 2.28: Points of conflict



(a) Basic forms

(b) For typical intersections

Figure 2.29: Examples of reduction of number of points of conflict and area of conflict



(a) Existing

(b) After channelisation & realignment

Managing priority movements

Consideration should be given to managing priority movements at intersections in line with driver expectations. In general, preference should be given to major movements. There is high driver expectation that major rural routes will have a free-flowing alignment and priority and drivers who have travelled for long, uninterrupted distances at high-speed will be slow to react to a sudden change in alignment or to the entry of a high-speed vehicle from a minor road.

Minor movements should be clearly subordinated to major or high-speed movements by design, signing and/or speed control. Adequate warning should be provided:

- on major priority approaches through provision of adequate ASD and SISD
- on minor approaches by providing adequate ASD, and ESD where practicable or MGSD where appropriate.

Managing speeds

Vehicle speeds through an intersection should be managed safely. Low relative speed provides a safer environment for conflicting manoeuvres and enables drivers to accept smaller gaps thus reducing delays and increasing capacity. The relative speed between two vehicles approaching each other from various angles can be determined by the construction of a vector diagram.

Crossing manoeuvres that produce high potential relative speeds should be made preferably at right-angles, although 70° to 110°/120° is acceptable (*Part 4 of the Guide to Road Design, Austroads 2017a*) to minimise driver estimation errors. In such cases, it is usually necessary to reduce approach speeds by altering approach alignment and channelisation (e.g. converting a skewed intersection to a T-intersection) or the installation of traffic control devices. It should be noted that a 70° skew can present difficulties for truck drivers, and therefore provision of an auxiliary left turn lane may be considered rather than an island. Finally, the direction of skew makes a difference in terms of safe operation of the intersection, particularly in relation to the ability for drivers to clearly see intersection, and traffic on intersecting road, in advance.

Approximate Safe System critical impact speeds for five major crash types were determined in *Improving the Performance of Safe System Infrastructure (Austroads 2015d)*. These speeds, which represent a 10% severe (FSI) injury risk, are presented in Table 2.16 and Commentary 1. The authors note that 'due to many assumptions in the preparation of the relationships, the threshold speeds should not be taken as precise values'. The authors also undertook further analysis to determine critical entry speeds for different roundabout design characteristics (Table 2.17). Again, these speeds represent a 10% severe injury risk.

Table 2.16: Approximate Safe System critical impact speeds for common crash types

Crash type	Critical impact speed (km/h) ⁽¹⁾
Pedestrian-vehicle	20
Head-on	30
Adjacent direction	30
Opposing-turning	30 ⁽²⁾
Rear-end	55

¹ Suggested solutions are outlined in *Austroads (2015d)*, Sections 6.3.

² Critical impact speeds for targeted crashes suggested in *Austroads (2015d)*, Section 4.2.

Source: *Austroads (2015d)*.

Table 2.17: Approximate critical entry speeds for roundabouts

Entry and impact angle	Circulating speed	Critical entry speed (km/h)
70	40	30
70	30	40
30	40	60

Source: Austroads (2015d).

Clear and easy to understand design and layout

Ensure that the layout is easily recognised and that legal priorities are clear. Clear definition of queuing locations and turn paths to be followed.

Complicated intersections have poor accident records. A fundamental check is to imagine what a driver using the intersection for the first time would do. Two requirements are paramount:

- No driver should need special knowledge of how to negotiate the intersection.
- There should be a clear order of priority within the intersection. (TMR 2015a).

The provision of median islands on an intersection approach can raise drivers' alertness of an intersection, assist in identifying the intersection location and assist in the selection of the travel path through the intersection. When a turning lane is provided, median islands also provide some protection for road users by allowing them to travel out of the through lane when turning (*Road Geometry Study for Improved Rural Safety*, Austroads 2015i).

New Zealand have developed a Rural Intersection Active Warning System (RIAWS) which aims to reduce fatal and serious casualties at rural intersections through speed and traffic management and improving conspicuity of the intersection. Commentary 21 includes a summary of the system.

A road safety audit should be used to assess the safety of all intersections. Detailed information on road crashes, countermeasure development, road safety audits and general road safety developments is found in the *Guide to Road Safety* (Austroads 2006–2015). In particular, *Part 6* of the *Guide to Road Safety* (Austroads 2009a) provides guidance on the road safety audit process. The *High Risk Intersection Guide* (NZTA 2013a) provides 'guidance how to identify, prioritise and treat key road safety issues at high-risk intersections'. Guidance for road safety audit procedures in New Zealand are found in *Road Safety Audit Procedures for Projects: Guidelines* (NZTA 2013b).

2.5.2 Improving Traffic Flow Performance

In general, the first step towards improving capacity performance is to identify capacity constraints and eliminate or alleviate them as far as practicable so that road users can undertake their desired movements safely and efficiently. This requires:

- a review of the existing geometric layout and traffic control devices
- an analysis of traffic movements
- comparison of these with standard or preferred arrangements detailed in the *Guide to Road Design Part 4* and *Part 4A* (Austroads 2017a, 2017b).

Options that may be considered to improve capacity include:

- the addition of regulatory signs to define movement priorities
- introduction of turn bans
- relocation of pedestrian crossing facilities away from the intersection
- channelisation and auxiliary lanes to separate movements on an approach and provide storage space or remove conflicting flows and to raise capacity by eliminating constraints on the priority flow.

Warrants for the use of auxiliary turn lanes cannot be stated definitively because of the many factors to be considered, such as speeds, traffic volumes, capacity, type of road, service provided, traffic controls and crash history. Turning treatment warrants are discussed in Section 2.3.6. For design details refer to the *Part 4* and *Part 4A* of the *Guide to Road Design* (Austroads 2017a, 2017b). The need for an auxiliary turn lane should be established using the basic design data considering the factors mentioned above. For example, auxiliary lanes (type AU or CH) may be favoured on high-speed highways or freight routes, and a sheltered right-turn treatment (type CH) should be preferred where horizontal or vertical sight distance is restricted (*Part 3* of the *Guide to Road Design*, Austroads 2016e).

2.5.3 Environmental Considerations

Environmental factors relevant to intersections are generally the same as those relevant to other parts of a road network and are normally taken into consideration during the road/intersection design process.

For further guidance, refer to reports on *Environmental Impact Assessment of Major Roads in Australia* (Austroads 1993), reports on a *Strategy for Ecologically Sustainable Development: Progress and Directions* (Austroads 2000), and to the NZTA (2008a).

The principal environmental factors involved with respect to intersections are:

- noise/vibration (e.g. exhaust, engine, air-brakes or tyres)
- vehicle emissions (e.g. carbon monoxide, nitrous oxides or smoke)
- amenity (e.g. traffic volume considered excessive for nature of the abutting land development).

The environmental effects of the above factors are directly related to one or more of the following:

- traffic volumes
- traffic speeds
- traffic composition (e.g. proportion of heavy vehicles)
- operational efficiency (e.g. number of stops and minimising delays).

Traffic noise may also be influenced by acceleration and deceleration due to horizontal and vertical alignment on intersection approaches (*Part 3* of the *Guide to Road Design*, Austroads 2016e).

So far as it is possible to alleviate specific environmental impacts by traffic management measures at an intersection, it will be by methods that reduce either traffic volumes, speeds or the proportion of heavy vehicles on one or more arms of the intersection. The traffic management measures described in Table 2.18 are therefore aimed at controlling one or more of these, and could be considered to alleviate specific environmental impacts, either during the initial traffic engineering design process or subsequently.

Table 2.18: Traffic control at intersections to alleviate environmental effects

Objective	Possible treatments	Comments
Reduce traffic volumes on one or more legs	Regulatory sign(s) or physical devices to prevent vehicles moving to and/or from the minor road: <ul style="list-style-type: none"> • turn prohibition sign(s); full-time or part-time • no entry sign(s); full-time or part-time • islands, channelisation or median gap closure. 	<ul style="list-style-type: none"> • Need to consider likely effects of the diverted traffic on other parts of the road network. • For further guidance, refer to <i>Methods for Reducing Speeds on Rural Roads: Compendium of Good Practice</i> (Austroads 2014a), which identifies treatments for reducing traffic speed on intersection approaches in rural areas.
Reduce traffic speeds on one or more legs	<ul style="list-style-type: none"> • Decrease left-turn kerb radius. 	<ul style="list-style-type: none"> • Check turning paths for large vehicles. • To extend the length over which speed is restricted, it would be necessary to adopt other speed control measures along the road(s) leading to/from the intersection (e.g. alignment, roundabouts).
Reduce proportion of heavy vehicles on one or more approaches	<ul style="list-style-type: none"> • Sign(s) to prohibit entry of heavy vehicles into one or more arms; full-time or part-time. 	<ul style="list-style-type: none"> • The provision of suitable signs could present problems depending on jurisdiction however some options are: • truck prohibition (AS 1742.1 sign R6–10); refer to ARR 104 (National Transport Commission 2012); note that ‘truck’ is defined in the ARRs as a motor vehicle with GVM over 4.5 tonnes except a bus, tram or tractor • <i>gross load limit sign</i> (AS 742.1 sign R6–4); note that an <i>end load limit sign</i> should be used at the end of the road section subject to the limit • need to consider the likely effects of the diverted vehicles on other parts of the road network, and also the consequences of prohibiting certain types of trucks such as waste collection trucks and trucks associated with construction works.
Improved operational efficiency	<ul style="list-style-type: none"> • Provide turn lanes (bays). • Install <i>give way</i> signs instead of <i>stop</i> signs. 	<ul style="list-style-type: none"> • Warrants exist for the installation of a <i>stop</i> sign rather than a <i>give way</i> sign (Figure 5.2).
Assist road users	<ul style="list-style-type: none"> • Include guide signs, warning signs and regulatory signs. 	<ul style="list-style-type: none"> • Guide and protect road users approaching and travelling through intersections and associated traffic facilities.

2.5.4 Road Lighting

Intersections are locations where the driving task is generally more complex than elsewhere along a route. In urban areas they are the source of most crashes, and lighting of urban intersections to appropriate standards is usually justified even with low traffic volumes.

In urban areas the need for other road users (such as pedestrians and cyclists) to see and be seen should be taken into account, as well as the lighting of physical devices (e.g. channelisation, roundabouts, local area traffic management (LATM) treatments).

In rural areas it is common not to illuminate a route, but intersection lighting may be used to indicate the presence of an intersection or to illuminate vehicle paths through a channelised treatment. This is particularly important if signage (directional, regulatory, or warning) or delineation is insufficient to provide cues to enable deceleration to a safe manoeuvring speed. At isolated rural intersections that have raised medians on the through route it is desirable to illuminate the nose of the median island on the external approaches. At these locations, care needs to be taken to control glare and to avoid providing excessive light, which can lead to driver difficulty in adapting to darkness on the road immediately beyond the intersection.

Lighting can have other positive and negative effects such as improving the safety and personal security of people (including pedestrians and cyclists) and creating light-spill and glare that can be annoying to abutting residents.

There are two basic lighting situations at intersections:

- flag-lit – used at minor rural intersections that are remote and do not have channelisation and comprises one or two luminaires specifically to indicate the presence of the intersection
- normal – used at intersections where one or more of the following apply:
 - high conflicting traffic volumes
 - channelisation/islands at the intersection
 - it would be difficult for drivers to readily identify in advance the general layout of the intersection or their desired route through the intersection
 - significant crossing movements, especially by pedestrians or cyclists (significant pedestrian movement across a road requires floodlighting of the facility).

Australian and New Zealand Lighting Standards are contained in AS/NZS 1158 and design details are covered in the *Guide to Road Design Part 6B* (Austroads 2015f).

2.6 Evaluation of Options

Evaluation is the process of undertaking a comparison of various intersection layouts and possible forms of control. Its function is to demonstrate that there are a number of suitable solutions, which then allows other factors to determine the preferred scheme. Evaluation:

- is required at both existing sites (where improvements are planned) and where new intersections are proposed
- should consider or state all options, even those that may be inappropriate or offer a marginal solution
- can highlight elements of a particular solution which cause that scheme to perform poorly; this allows refinement of that option for further consideration.

In general, the evaluation process should, as a minimum, address:

- safety (e.g. conduct a safety audit of feasibility concept or initial design and ultimately the detailed design)
- delay
- site suitability
- financial analysis
- environmental issues.

Evaluation is a key step within the Network Operation Planning process (outlined in *Part 4* of the *Guide to Traffic Management*, Austroads 2016b) when assessing treatment options. An evaluation may consider network-fit assessment (i.e. assessing the impacts of treatment options through an assessment of performance gaps) and benefit-cost analysis. Post-implementation evaluation is also recommended, in order to assess how effectively the treatment(s) have reduced the performance gaps.

Austroads (2004) discusses a form of multi-criteria analysis which involves a direct comparison between a base case and each option using selected performance criteria. For additional guidance on the evaluation process, refer to the *Guide to Project Evaluation* (Austroads 2005–12) and *Economic Evaluation Manual: Volume 1* (NZTA 2016a).

Crash costs for intersections are usually determined by applying a crash rate (casualty crashes/100 million entering vehicles) for each type of treatment and average crash costs which are likely to be available from the relevant local jurisdiction. However, it should be noted that crash rates for similar treatments (e.g. roundabouts) can vary substantially depending on a number of factors such as volume, operating speed and the scale of treatment.

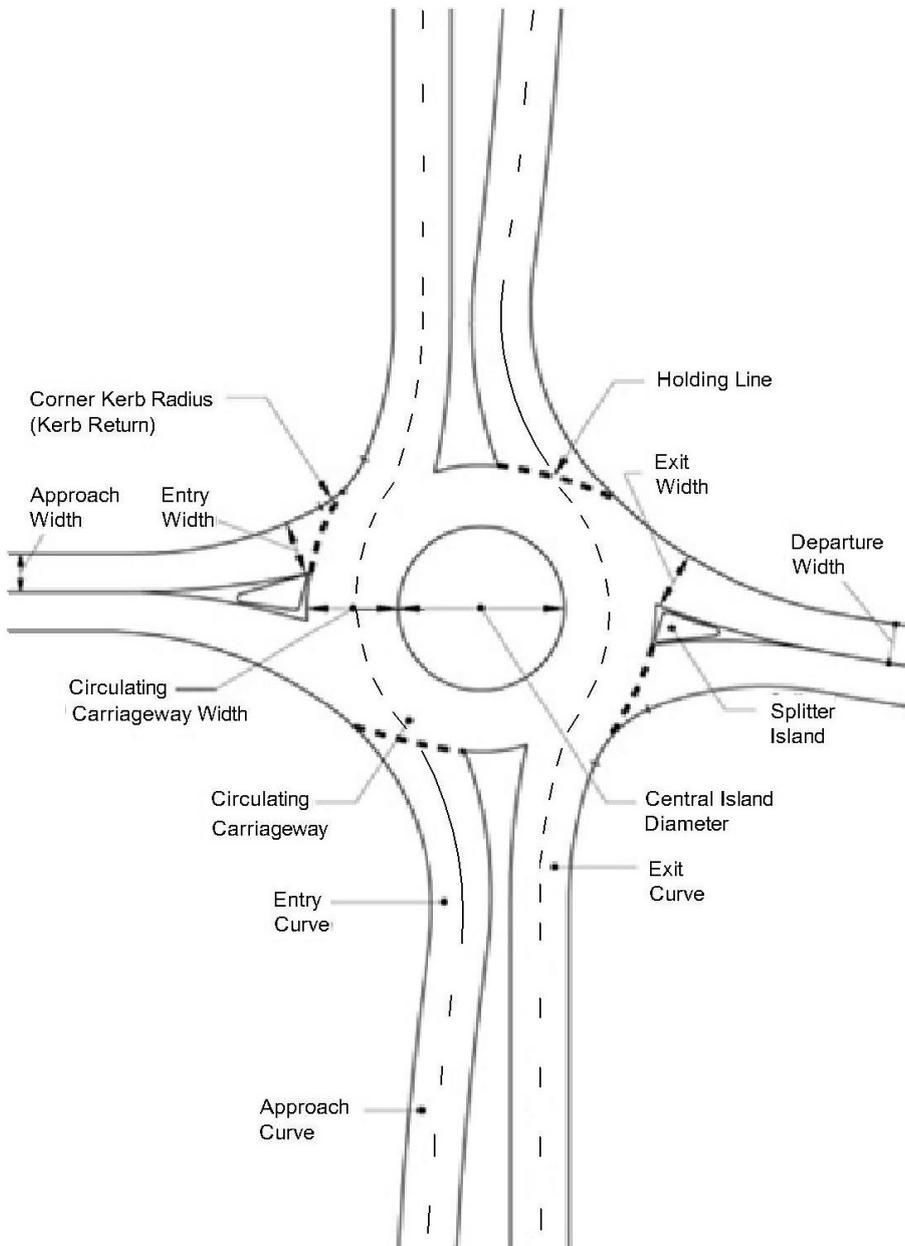
While consideration of traffic management aspects and evaluation is very important, the type of intersection adopted at a particular site may also be influenced by road design considerations, refer to *Part 4* of the *Guide to Road Design* (Austroads 2017a). Other more general road design considerations are discussed in the *Guide to Road Design Part 2: Design Considerations* (Austroads 2015e).

3. Roundabouts

3.1 General

A roundabout is a form of intersection channelisation in which traffic circulates clockwise around a central island (usually circular) and all entering traffic is required to give way to traffic on the circulating roadway. They are sometimes referred to as rotary controlled intersections (e.g. in NZ). Properly designed roundabouts physically control the speeds of all vehicles entering and travelling through the intersection, as well as the angle at which traffic enters the intersection. As a consequence, it can be safer than other forms of at-grade intersection where traffic can pass through at high-speeds. The main geometric elements of a roundabout are presented in Figure 3.1.

Figure 3.1: Geometric elements of a roundabout



All traffic entering roundabouts undertakes the same relatively simple task of giving way to traffic from the right, ensuring that traffic conflict is only from one direction. The reduction in speed, fewer conflict points and the relatively low angle of conflict between entering and circulating traffic reduces the number and severity of crashes for motor vehicle occupants. However, studies have shown that multilane roundabouts are less safe for cyclists due to possible lane changes, 'complexity of negotiation, cyclist visibility to drivers and the relatively high speed of entering vehicles' (Austroads 2015d).

When used in appropriate circumstances, a roundabout provides efficient operating conditions, often resulting in less overall delay to drivers than signalised intersections.

It is essential that all urban roundabouts, and rural roundabouts where appropriate, have pedestrian and cyclist facilities that are well designed and suited to the particular site. Such facilities include all necessary paths, crossings, lanes and traffic control devices (e.g. signs and markings). The information in this guide focus on specific aspects of design and does not necessarily illustrate pedestrian and cyclist facilities. This is not to be taken to suggest that these facilities are less important than any other aspect of roundabout design. Detailed guidance on the design of pedestrian and cyclist facilities is available in *Austroads Guide to Road Design Part 4B* (Austroads 2015c).

Roundabouts on all types of road must provide for the safe and convenient passage of an appropriate design vehicle. Readers are referred to *Part 4* of the *Guide to Road Design* (Austroads 2017a) for information on the selection of design vehicles in New Zealand and Australia. This requirement also includes collector and local roads that often have local area traffic management schemes in place to improve safety and amenity. It is particularly important that these roads are designed to enable the safe and convenient passage of scheduled route buses and emergency vehicles (e.g. fire trucks).

Depending on the type of vehicle to be accommodated, generally the design vehicle in residential and commercial areas will be either:

- a single unit truck/bus
- a shorter service vehicle such as garbage collection vehicles and emergency fire trucks
- an ultra low-floor bus.

The vehicles should generally be able to negotiate the roundabouts with adequate clearance to the face of kerbs. Where necessary on collector and local roads, it may be required for the vehicle to mount a slightly raised apron around the periphery of the central island when turning right. In cases where it is unavoidable that the body of the design vehicle (e.g. ultra-low floor bus) must overhang a verge or island, the roundabout should be designed to ensure that it will not collide with the ground surface, island, traffic control device or any other object.

This section of the Guide provides guidance on roundabouts with respect to traffic management. In terms of traffic safety the key aspects are to physically control the speed at which a vehicle can enter and pass through the roundabout, and to provide adequate sight distance for drivers both approaching the roundabout and drivers waiting to enter them. With respect to sight distance it is most important to consider the combined effects of vertical and horizontal geometry (refer to the *Guide to Road Design Part 4B*, Austroads 2015c).

3.2 Use of Roundabouts

Roundabouts can be used satisfactorily at a wide range of intersection sites, including:

- urban local and collector roads
- arterial roads in urban areas
- rural roads
- freeway/motorway ramp terminals
- as a grade separated treatment at an interchange (Section 6.5.3).

Given that so many factors need to be considered, it is not possible to specify that roundabouts should or should not be installed in various general situations. However, the information in Table 2.6 may be used as a guide to the general applicability of a roundabout treatment according to various functional road classifications. The information in Table 2.6 should not be used as the only assessment; it is more appropriate to consider each case in detail, and to evaluate the operational, safety, environmental and financial advantages and disadvantages of alternative treatments.

Table 2.8 summarises the key traffic management considerations in selection of intersection type, including roundabouts. A detailed guide to site characteristics that may result in a roundabout either being appropriate or inappropriate in a particular situation is provided in Commentary 12.

Roundabouts can be effectively used in pairs, and in some instances three roundabouts have been used in close proximity. However, this situation is not common and it should be implemented only where satisfactory performance can be demonstrated through traffic analysis (Commentary 13).

Roundabouts may also be used for traffic calming in local areas or on the approaches to areas of high pedestrian activity to control the speed of traffic entering those areas. (e.g. low-speed roundabouts at both ends of a shopping strip). However, at intersections where there is a high level of pedestrian activity a roundabout may not be the most appropriate type of intersection. This is particularly the case where vehicle speeds are relatively high or where traffic volumes are high.

Roundabouts may be favoured in urban areas for aesthetic reasons, as the central island provides an opportunity to beautify an intersection by providing vegetation and landscaping in the central island. However, any fixed objects or vegetation to be located in the central island of a roundabout should be offset from the circulating roadway by an appropriate distance to ensure safety.

[\[see Commentary 12 and Commentary 13\]](#)

3.3 Performance

3.3.1 Safety

From the Safe System perspective roundabouts act predominantly by reducing severity of impacts because:

- entry and circulating speeds of traffic are moderated by horizontal deflections
- impact angles in adjacent-direction crashes are lower than at other intersection forms ($\leq 70^\circ$)
- of the reduction in the number of conflict points
- of the relative simplicity of decision-making at the point of entry
- on undivided roads, in high-speed areas, long curved splitter islands can provide good 'advance warning' of the presence of the intersection and type of intersection
- an expectation that entering drivers may have to stop to give way to vehicles within the roundabout may also contribute to lower speeds and increased driver alertness.

These factors not only reduce the number of crashes but also ensure that crashes are less severe than those that occur at other types of intersection.

When replacing priority intersections, roundabouts can achieve strong crash reductions (Austroads 2015d):

- 63–100% for fatal crashes
- 37–84% for severe (FSI) crashes
- 45–87% for casualty crashes.

A further 60–78% casualty crash reduction was observed when converting from a signalised intersection to a roundabout. Roundabouts also provided strong reductions in pedestrian crashes (up to 90% compared with priority control) based on limited studies. Austroads (2013) analysis of urban data from Melbourne showed that the severe crash rate per entering vehicle for a roundabout was half of that for a signalised intersection. (Austroads 2015d).

However, evidence exists to show that there are safety concerns for motorcyclists and cyclists at roundabouts 'due to issues such as complexity of negotiation, visibility to drivers and the relatively high speed of entering vehicles' (Austroads 2015d).

The size and layout of roundabouts are factors for cyclists. In general, small roundabouts with relatively slow traffic speeds, and with a circulating roadway narrow enough to prevent motor vehicles overtaking cyclists, present no special risks (Balsiger 1992, Bruede & Larsson 1996, Van Minnen 1996). Studies also confirm that the majority of crashes at roundabouts involving cyclists were associated with entering motor vehicle drivers who had not noticed the cyclist on the circulating roadway (Commentary 14).

Roundabouts tend to be associated with fewer pedestrian crashes compared to priority control intersections. However, when pedestrian crashes do occur they are more frequently of high severity (Austroads 2015d). The reduced crash occurrence may be due to pedestrians being able to cross one direction of traffic at a time by staging on the splitter islands. However, it is acknowledged that some pedestrians are concerned about their safety because roundabouts do not give positive priority to pedestrians over through and turning traffic movements (e.g. Australian Road Rule No 114, National Transport Commission 2012). Exits are problematic, particularly for elderly pedestrians and children who may consider that traffic signals provide greater security for them to cross the road.

Sections 3.4.2 and 3.4.3 describe treatment options to improve the safety at roundabouts of cyclists and pedestrians respectively. 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 and pedestrians use or are expected to use a site, and if a low-speed roundabout suitable for pedestrians and cyclist 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.

The safety performance of a particular existing roundabout or roundabout design is dependent on geometry, speed environment and traffic flow data (Commentary 15). The ARNDT computer program (available from TMR website, TMR 2016b) may assist practitioners to assess the likely safety performance of existing roundabouts or design options leading to safer designs. In addition, TMR (2015c) has provided models relating to cyclists at roundabouts.

[\[see Commentary 14 and Commentary 15\]](#)

3.3.2 Traffic performance

In Australia and New Zealand, assessment of the capacity of roundabouts and the delays to traffic using them is based on gap acceptance theory. Guidance on analysis procedures for roundabouts is provided in *Part 3 of the Guide to Traffic Management* (Austroads 2013). Analysis is usually undertaken using an appropriate software package such as SIDRA INTERSECTION (Akcelik & Associates 2011). The effects of other traffic control devices in close proximity to the roundabout, and of all road users, should be taken into account when assessing the performance of roundabouts.

3.4 Road Space Allocation and Lane Management

3.4.1 General

Road space on the approaches to and within multilane arterial road roundabouts may be allocated to particular turning movements. Exclusive left and/or right-turn lanes may be marked on approaches, usually in urban areas or approaches on the non-continuing road of a T-intersection.

A NOP can be used to guide the suitable allocation of road space and lanes to and within roundabouts. It can also help balance the needs of various road user groups.

Figure 3.2 shows a pavement marking arrangement for a roundabout at the intersection of a divided six-lane arterial road with roads that have narrower cross-sections. It can be seen that an exclusive right-turn and a combined through and right-turn lane are provided from one of the minor legs to ensure an adequate level of service on that approach. This results in a three-lane circulating roadway being required opposite this entry. While a spiral line marking is shown within the circulating roadway to delineate the path for the exclusive right-turn lane, it should be noted that some jurisdictions do not support this practice or may limit its use to manage particular situations at existing roundabouts.

Where traffic demand is high, a left-turn auxiliary lane, with or without a left-turn roadway, may be provided. Figure 3.3 illustrates a treatment where left-turning traffic diverges into a left-turn roadway that operates under give way control.

Figure 3.4 illustrates a treatment that is designed to provide downstream merging where left-turning traffic decelerates in an auxiliary lane, turns at a moderate speed and then accelerates to the operating speed of the intersecting road. Lane markings and other pavement markings should be in accordance with AS 1742.2, the New Zealand *TCD Manual* (NZTA 2008c⁵) and the *Guide to Traffic Management Part 10* (Austroads 2016d).

Where left-turn slip lanes are to be provided (e.g. as illustrated in Figure 3.3) pedestrian and cyclist needs should be taken into account. Where pedestrian and cyclists are expected to cross a slip lane, low vehicle speeds should be encouraged at the crossing point. Priority at crossings should be clear for all road users (i.e. whether motorists, pedestrians or cyclists have priority).

Where special-use lanes (e.g. bus lanes) exist on the approaches to multilane roundabouts it may be appropriate for them to continue to the holding line and through the roundabout. For treatment of bicycle lanes at multilane roundabouts refer to Section 3.4.2.

It is important to ensure that adequate space is provided to store pedestrians within the splitter islands of roundabouts and for crossing points and crossing facilities to be conveniently located and correctly constructed.

5 Note the relevant part of the TCD Manual may be unpublished, in which case refer to the Manual of Traffic Signs and Markings (MOTSAM) (NZ Transport Agency (NZTA) 2010a, 2010b). MOTSAM is being progressively replaced by the TCD Manual (in press).

Figure 3.2: Pavement marking on major urban roundabout approaches

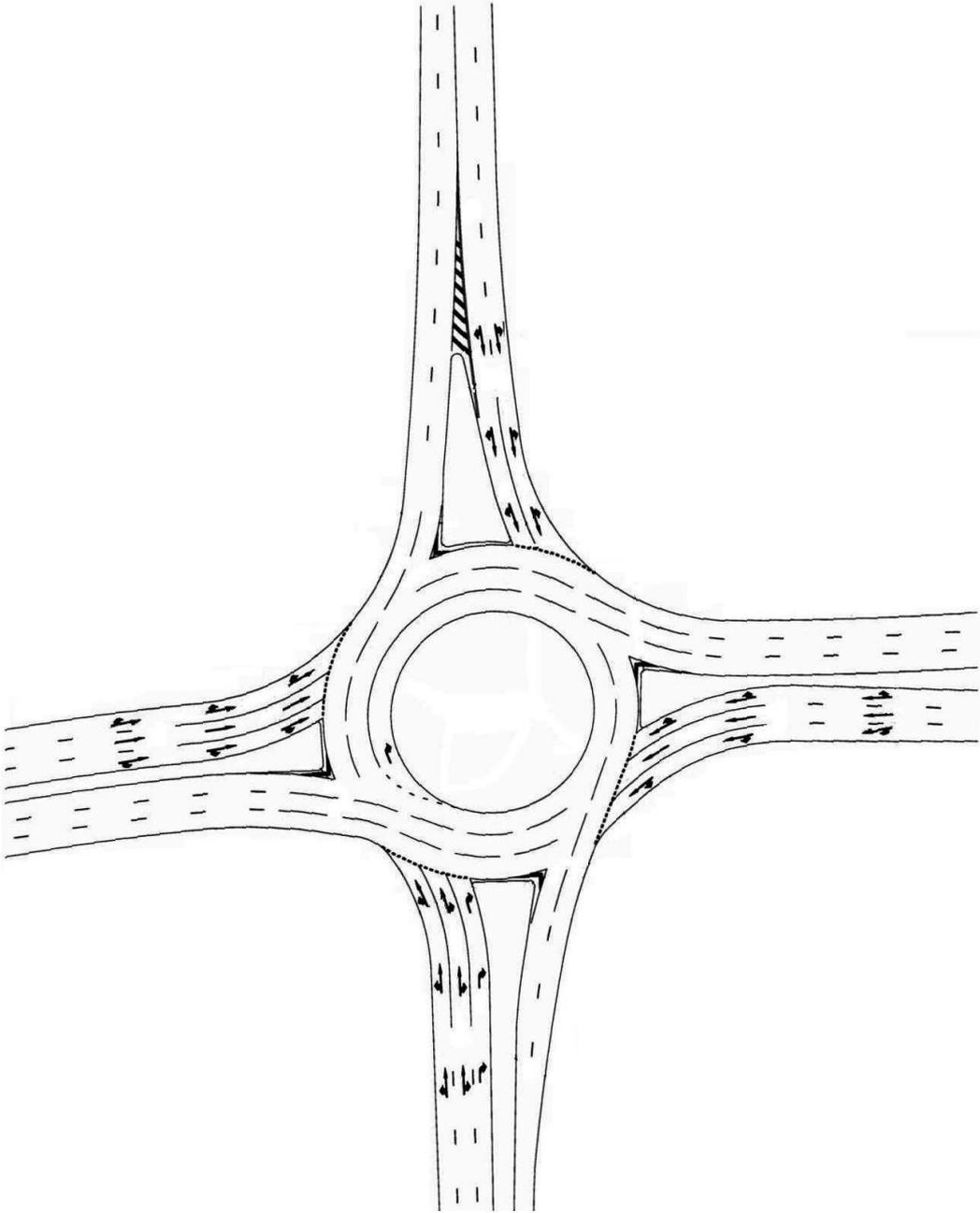


Figure 3.3: Left-turn slip lane with a high entry angle give way arrangement

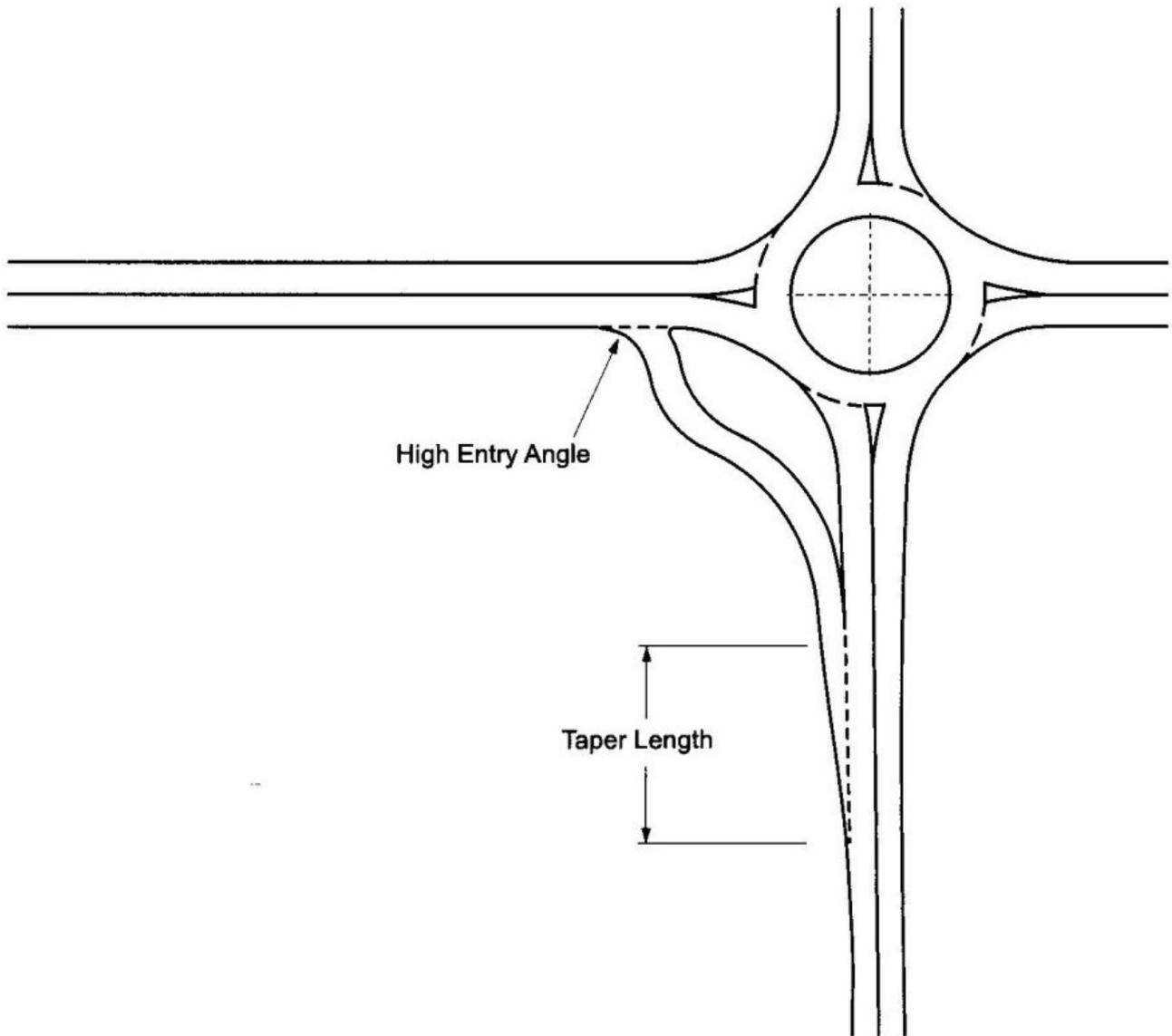
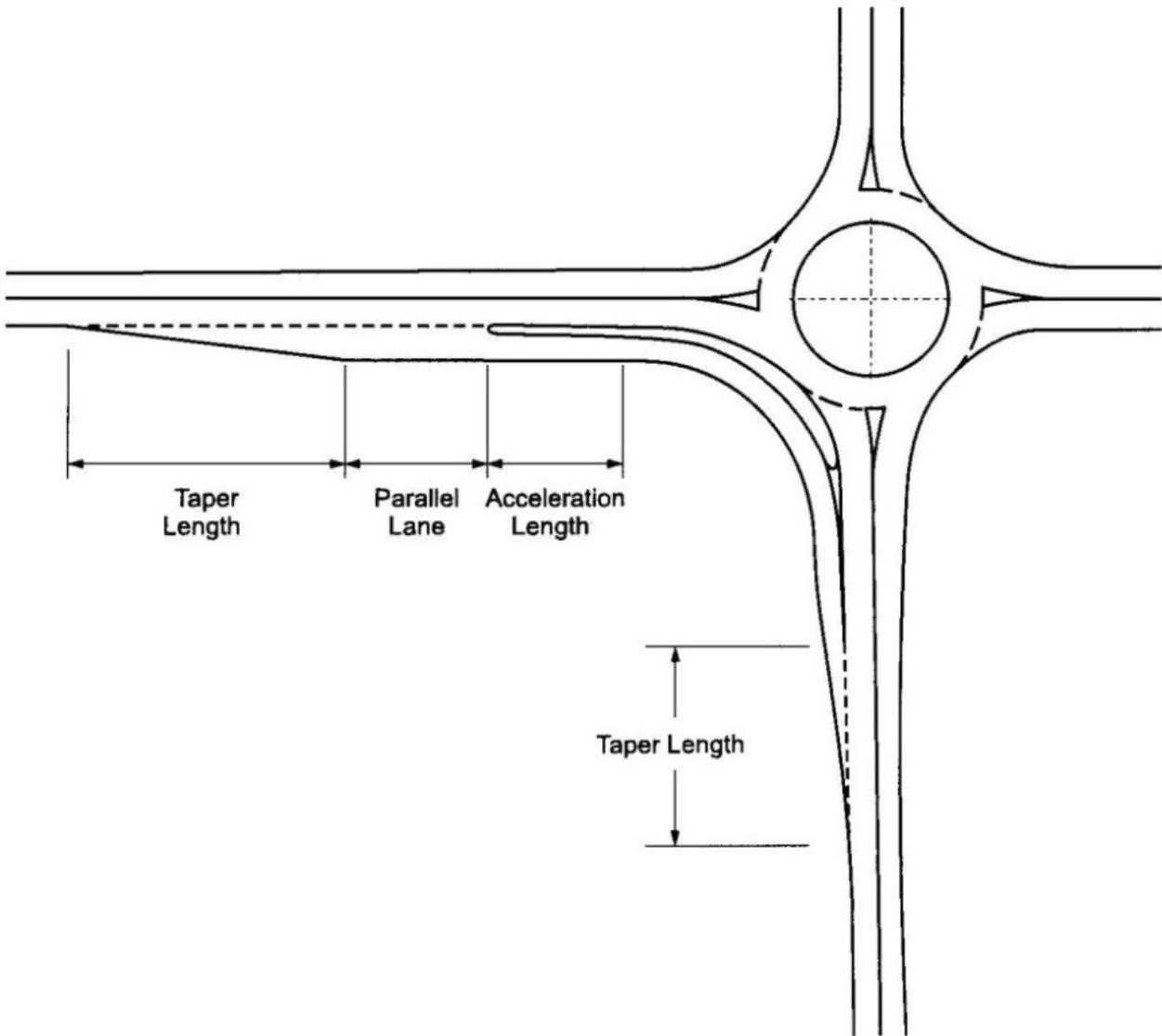


Figure 3.4: Left-turn slip lane with downstream merging



Note: Parallel section allows a driver in the acceleration lane to observe the traffic stream leaving the roundabout for a suitable gap prior to merging.

3.4.2 Cyclists

General issues relating to cyclists are summarised in Table 2.12. Some of them relate to roundabouts. 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 2015d).

Studies have shown that a large proportion of cyclist crashes 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 (Commentary 14, Commentary 15).

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 3000 – 5000 veh/day, two-way flow), although a separated cycle path may be safest where there are large vehicle flows (Commentary 16).

[\[see Commentary 16\]](#)

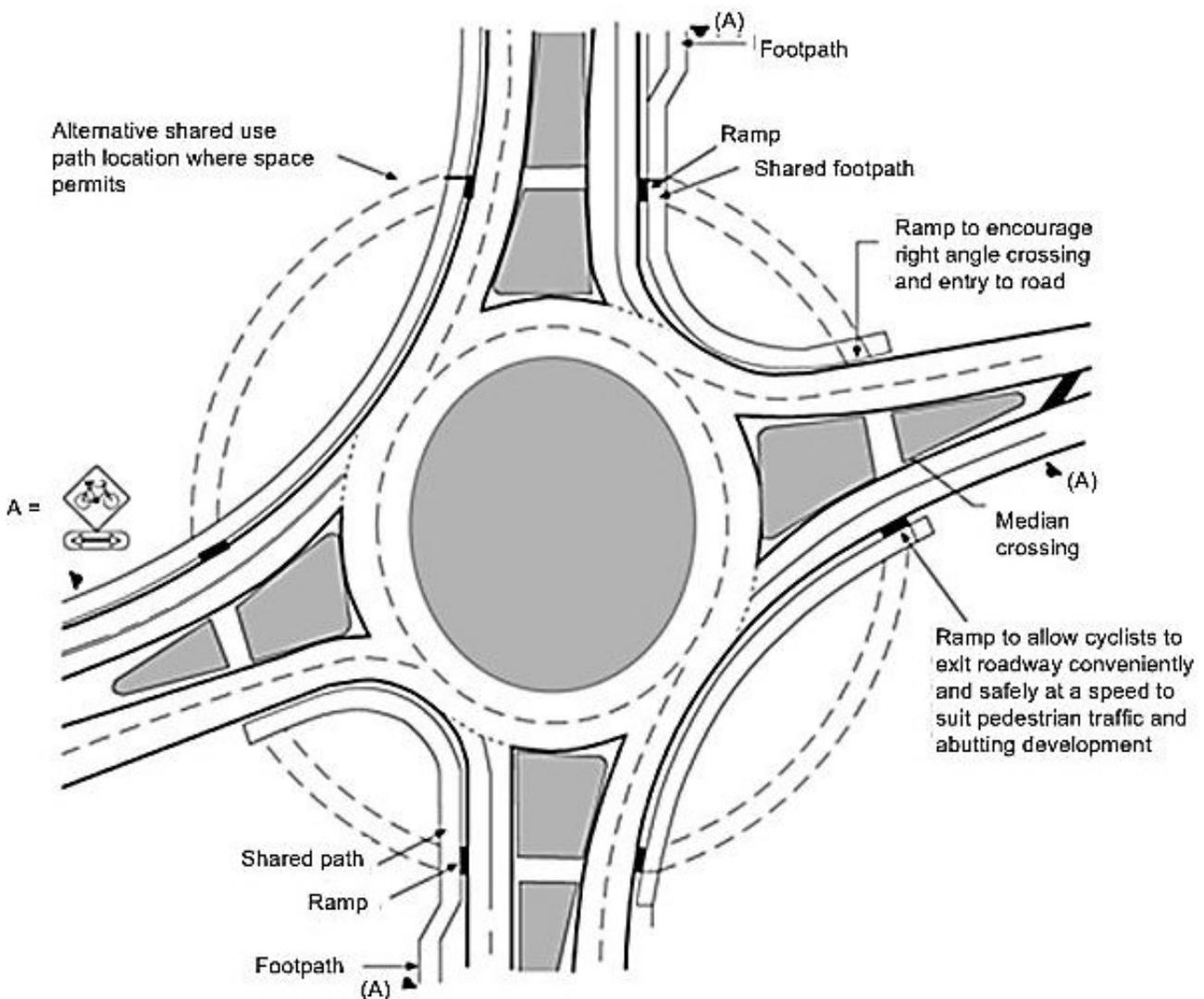
The following options may be considered with respect to cyclists' use of larger single-lane or multilane roundabouts:

- grade separation of bicycle paths at road crossings
- an off-road bicycle path around the roundabout (Figure 3.5) with uncontrolled cyclist/pedestrian movement across each approach leg (evidence suggests that this is the safest design, at least where traffic flows are high)
- no specific cycle facility (may be acceptable under some circumstances).

Conventional right-turning manoeuvres at multilane roundabouts are a problem for cyclists because of the nature of their interaction with motorised traffic. However, under the Australian Road Rules cyclists may undertake a hooked right-turn. This requires cyclists to give way to traffic exiting the roundabout. The provision of a storage area (i.e. refuge) may be considered on the left side of exits where cyclists can wait for a gap in the exiting traffic.

Many commuter cyclists would consider the use of an off-road path around a roundabout 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 intersections, including roundabouts.

Figure 3.5: Paths for cyclists at roundabouts



The extent to which special geometric treatments and/or traffic control measures should be applied to a roundabout to achieve an adequate level of cyclist safety may depend on:

- the proportion of cyclists and other 'non-motorised' road users expected to use the intersection
- the type of cyclist and skill level expected to use the intersection (Commentary 10)
- the functional classification of the roads involved
- the overall traffic management strategy adopted for the site and surrounding network.

Where circumstances require that a significant number of cyclists use a roundabout, the approaches should be designed to cater for the lowest practicable approach speed. Consideration may also be given to adopting a European compact radial alignment which is considered to be a safer option than a tangential design for cyclists (and all road users) as they can 'achieve equitable negotiation speeds between motor vehicles and people cycling' (Fowler 2016) (Commentary 17). The European compact radial design features an approach angle that is approximately perpendicular to the central island (i.e. minimal flare).

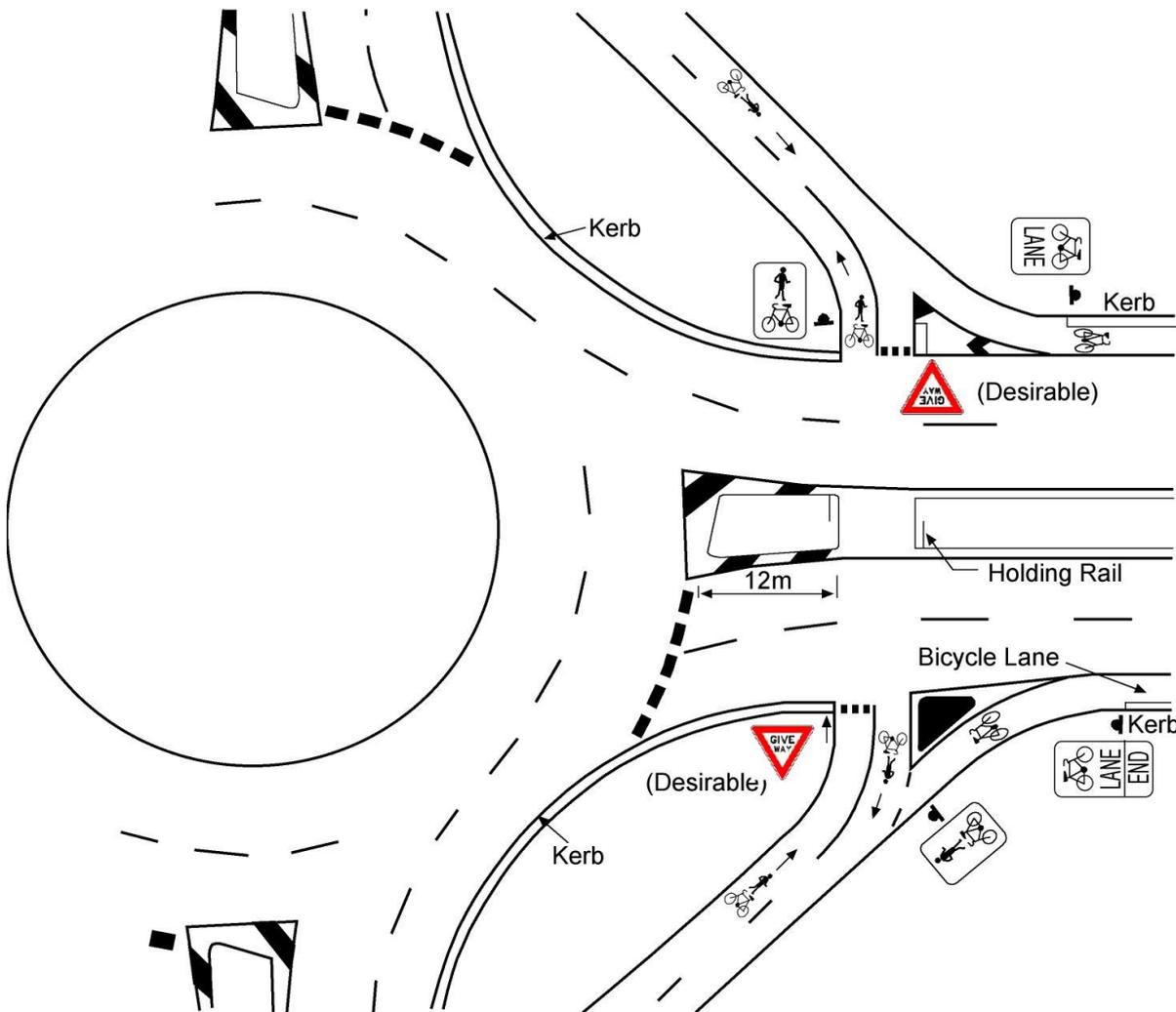
[\[see Commentary 17\]](#)

Other situations where special consideration of cyclists and treatments is required to assist access and safety include:

- 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 for and give way to cyclists moving around the roundabout
- provision of a by-pass of three-legged roundabouts for cyclists travelling across 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 (e.g. a marked bicycle lane may be required)
- where a major motor vehicle movement is able to by-pass the 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 any bicycle lanes that may exist on the roundabout approaches and departures (Figure 3.6). The central median should also be of sufficient width to accommodate cyclists.

Figure 3.6: Details of shared path intersection on roundabout legs



Note: Channelised connection to bicycle lane. Where a significant number of commuter cyclist's travel straight through the roundabout the bicycle lane should extend to the give way line and the connection to the shared path should be designed for ease of entry by less experienced cyclists.

3.4.3 Motorcyclists

General issues relating to motorcyclists are summarised in Table 2.13 and some of them relate to roundabouts. As noted previously, while roundabouts are generally safer than other at-grade intersection types for motor vehicle occupants, research indicates that motorcyclists experience higher crash likelihood and severity outcomes at roundabouts (Austroads 2016i, Austroads 2015d).

Infrastructure Improvements to Reduce Motorcycle Casualties (Austroads 2016i) notes that 'it is important that a motorcyclist can identify the presence of a roundabout, be able to correctly perceive the speed of circulating vehicles and to appropriately judge how fast to negotiate the roundabout'. Elements that may affect the likelihood of a motorcyclist crash at a roundabout include (Austroads 2016i and NZTA 2016b):

- Adverse crossfall on curves and/or inadequate surface texture – As motorcyclists need to accelerate through curves, there is a high risk of destabilisation if surface grip is insufficient, particularly where there is adverse crossfall. Pavement markings can also reduce surface grip.
- Entry and exit design speeds – These are generally designed for cars and other motor vehicles and are unlikely to reduce motorcycles speeds.

- Sight distance – Planting within a roundabout island may obscure motorcyclists from other drivers.
- Roundabout layout and curve radius – If these are not clear to an approaching motorcyclist, then inappropriate speed selection may result. A compound curve is effectively created when the radius of the circulating carriageway is not constant. The resulting change in riding path can increase the risk of destabilisation.
- Kerb profiles – For motorcyclists, a mountable kerb is preferable, followed by semi-mountable kerb, as redirection and opportunity for recovery is more likely. A 'barrier kerb is likely to abruptly alter the direction of the motorcycle resulting in loss of control', or may potentially snag a motorcyclist's foot or foot peg.
- Horizontal geometry – 'Due to the braking and handling characteristics of a motorcycle an intersection conflict point located on a curve (through road, slip lane or roundabout) is more difficult for a motorcycle to undertake evasive action without becoming destabilised'.

3.4.4 Pedestrians

Pedestrian delays at roundabouts are generally similar to other forms of non-signalised intersection control and usually less than at signalised alternatives.

Where space allows for a staged crossing, it should be arranged so that pedestrians moving along the splitter island or median walk towards the conflicting traffic stream and therefore have a clear view of approaching traffic, and that adequate manoeuvring space is provided for pedestrians with prams and also for cyclists. Where space does not allow for a staged crossing, it is usually preferable to provide a straight crossing of the road as it is more direct and convenient for pedestrians in general, and facilitates a well-directed and designed crossing for vision-impaired pedestrians. Direct unsignalised crossings should generally be located one or two car lengths (6 or 12 m) back from the holding line at the entrances of roundabouts. It is desirable that splitter islands are large enough to ensure that all types of pedestrians (e.g. people pushing prams) can use them as a refuge.

Where a pedestrian crossing is signalised or it is desirable to provide a staged crossing, the crossing should be located further from the roundabout. At exits, a distance from the roundabout of at least two to four car lengths (12–24 m) is preferable because it provides exiting drivers with more time to observe and respond to pedestrians and reduces the probability of vehicles queuing back into the roundabout and blocking its operation.

Design features that improve the level of service and safety for pedestrians at roundabouts include:

- smaller radius entry and exit curves that minimise the entry and exit speeds
- splitter islands that are large enough to comfortably accommodate pedestrians and enable drivers to anticipate their movement onto the road
- prohibition of parking on approaches to provide clear visibility
- pram crossings that are designed for people with a disability and/or mobility difficulty
- street lighting
- signs and vegetation located so as not to obscure 'smaller' pedestrians
- conformance to the Australian Commonwealth *Disability Discrimination Act 1992* or the equivalent NZ Act as appropriate, also AS 1428 *Design for Access and Mobility* and NZS 4121:2001.

Consideration may be given to providing priority crossings (e.g. zebra crossings) for pedestrians where a jurisdictional warrant is met (Section 8). Considerations may include:

- high pedestrian volumes
- a high proportion of young, elderly or people with disability or mobility difficulty want to cross the road
- pedestrians experiencing particular difficulty in crossing and being excessively delayed.

Priority crossings are generally only suitable for single-lane roundabouts in low-speed environments – not recommended for multilane approaches to roundabouts⁶.

Further information is available in Transportation Research Board (2010) which provides information and guidance on roundabouts, for designs suitable for a variety of typical conditions in the United States. It provides general information, planning techniques, evaluation procedures for assessing operational and safety performance, design guidelines, and principles to be considered for selecting and designing roundabouts.

Transportation Research Board (2011) provides practitioners with specific guidance on establishing safe crossings at roundabouts for pedestrians with vision impairment. It identifies the conditions under which pedestrians with vision impairment may experience problems with crossing performance, and suggests specific treatment solutions. It also includes advice on conducting pedestrian/vehicle studies related to these problems, and on quantifying pedestrian accessibility at crossings.

The ability of drivers to enter a roundabout can be severely affected by a pedestrian crossing. These crossings can decrease the rate that drivers can both enter and leave the roundabout and this must be considered in an analysis of capacity.

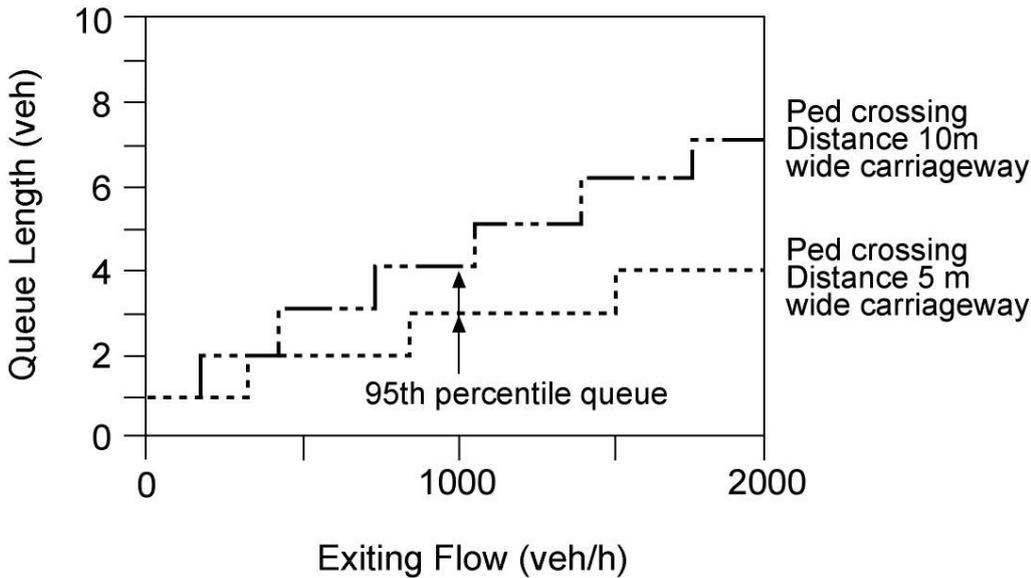
The distance required between the exit from the roundabout and a pedestrian crossing may be determined from Figure 3.7. This gives the 95th percentile queue length of waiting vehicles while a pedestrian crosses an exit that is 5 or 10 m wide. The graph is based on the assumptions of low pedestrian flow, an average able-bodied person's walking speed of 1.5 m/s, random vehicle arrivals, sufficient time available between pedestrian movements for queued vehicles to clear and, for two lanes, vehicles being queued in both lanes. If there is considerable pedestrian activity, the queue lengths will be longer and a signalised pedestrian crossing may be required. The walking speed of 1.5 m/s used for this graph relates to able and agile pedestrians and many sites would have a lower average walking speed.

The pedestrian walking speed for determining pedestrian walk time and clearance time is usually 1.2 m/s. A clearance speed of 1.0 m/s may be appropriate for sites with relatively high populations of slower pedestrians. The walking speeds of 1.0 m/s and 1.2 m/s represent the 5th and 15th percentile walking speed respectively (i.e. 5 and 15% of pedestrians walk at a slower speed).

Bennett et al. (2001) and Akcelik and Associates (2001) provide additional guidance on speeds appropriate for signalised crossing calculations. For more detailed analysis regarding the effect of zebra and signalised pedestrian crossings on roundabout legs, refer to Akcelik and Associates (2011).

6 Zebra crossings are not appropriate for crossings of multilane roundabout approaches or exits (Section 8.2).

Figure 3.7: 95th percentile queue length for vehicles waiting at pedestrian crossings near roundabout exits



A signalised pedestrian crossing near a roundabout may assist its operation by metering a heavy entering flow that enables drivers to enter from low-volume side roads (Section 3.6.2).

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

3.5 Functional Design

3.5.1 General

The functional design of roundabouts is concerned with:

- the safety of all users
- traffic performance.

The principles of roundabout design are similar for urban and rural intersections. Because of the high traffic speeds in rural areas and on some higher-speed urban arterials, it is very important that designs control the speed of traffic entering roundabouts in these environments. While it is sometimes difficult to achieve the criteria for the control of speed at multilane inner urban roundabouts, the consequences of not doing so are less critical.

Local street roundabouts are primarily concerned with safety and amenity and therefore have a much lower design speed, as well as reduced superelevation and road gradient requirements than that adopted for arterial and collector roads.

Like all types of intersection, the requirements of all road users should be taken into account in the design of roundabouts. This includes consideration of pedestrian desire lines and provision of space for pedestrians and cyclists (where applicable) to store on footpaths and traffic islands. These aspects may have an influence on the road design and layout of the roundabout.

3.5.2 Number of Legs

Limiting the number of legs of a roundabout to four and aligning them at approximately 90° is the most preferable treatment because drivers are more easily able to comprehend the layout. However, the provision of a greater number of legs (maximum of six) on a single-lane roundabout, which would require a large central island, may be acceptable for practical and economic reasons.

Multilane roundabouts should have no more than four legs, aligned at approximately 90°, as this enables motorists to determine the appropriate choice of lanes for their path through the roundabout. Multilane roundabouts with legs aligned at different angles, or that have more than four legs, can create conflict at exits and drivers can experience difficulty in anticipating the appropriate lane choice required for left, through and right-turns on some of the approaches multilane roundabouts with more than four legs can also complicate direction signage and render it less effective (Commentary 18).

[\[see Commentary 18\]](#)

3.5.3 Key Design Elements

The key elements that relate to the safety and traffic performance of roundabouts are illustrated in Figure 3.1. They comprise:

- the entry and approach curves
- the numbers of entry, circulating and exit lanes
- the widths of the entries, circulating roadway and exits
- the central island (including diameter)
- the approach traffic islands
- the exit curves.

These elements combine to control the speed that drivers can enter and pass through a roundabout and enable the deflection criteria to be achieved.

3.5.4 Entry Curvature and Deflection

Adequate deflection of the paths of vehicles entering a roundabout is a very important factor influencing their safe operation. Roundabouts should be designed so that the speed of all vehicles is restricted to:

- less than 50 km/h within the roundabout where there are no cyclists and pedestrians have adequate provision
- less than 30 km/h within the roundabout where cyclists and pedestrians will be interacting at the intersection (see Commentary 1).

This is achieved by adjusting the geometry of the approach road (especially the entry curvature) and by ensuring that 'through' vehicle paths are significantly deflected by one or more of the following means:

- the alignment of the approach road and the shape, size and position of approach splitter islands
- provision of a central island of suitable size and in an effective position
- introduction of a staggered or non-parallel alignment between any entry and exit.

The most important consideration in controlling speed is the geometry of the entry. Lower total crash rates occur by slowing drivers prior to the circulating road using entry curvature rather than on the roundabout using deflection alone. Design layouts should not enable drivers to enter at a speed greater than the speed that can be safely accommodated within the roundabout (i.e. circulating roadway and exit). Incompatible entry speeds often lead to higher crash rates.

In high-speed environments, such as on rural roads, an entry may comprise a single left hand curve on the immediate approach to a roundabout, or two or three curve reversals to progressively slow drivers from 100 km/h in advance of the roundabout to 50 km/h on the immediate approach (*Guide to Road Design Part 4B*, Austroads 2015c). Roundabouts on local streets and collector roads are usually designed to restrict the entry speed of vehicles to 20–30 km/h. The needs pedestrians and cyclists should also be considered on higher-order urban roads.

Whilst speed reduction should be achieved through appropriate design of the roundabout approach, problematic sites where drivers approach at excessive speeds may necessitate employing traffic management measures to assist in reducing speed. A number of potential treatments included in Table 3.1 provide additional guidance on many of these countermeasures. Care should be taken in the design of such treatments to ensure that drivers are safely guided through the intersection. For example, designs where drivers may select a line through the intersection that limits the intended speed reduction (refer to *Guide to Road Design Part 4B*, Austroads 2015c). It should be noted that the effectiveness of some of these treatments, including the provision of reverse curves, is not completely known.

Table 3.1: Potential speed reduction treatments for roundabout approaches

Treatment	Effectiveness
Large advance direction and warning signs	<ul style="list-style-type: none"> Unknown speed reduction, estimated crash reduction of 30%⁽²⁾
Lane narrowing	<ul style="list-style-type: none"> Estimated speed reduction of 5 km/h, estimated fatal and injury crash reduction of 20%⁽²⁾
Perceptual countermeasures ⁽¹⁾ e.g. perceptual narrowing or perceptual speed reduction treatments (including herringbone, peripheral and lane width transverse lines)	<ul style="list-style-type: none"> Estimated speed reduction of 4 km/h from perceptual narrowing Estimated speed reduction of 8 km/h from markings that give the appearance of travelling faster on the approach to an intersection⁽²⁾
Speed limits	<ul style="list-style-type: none"> Uncertain as an intersection treatment (reductions typically 15-20% crash reduction)⁽³⁾
Guide posts at decreasing spacing towards the roundabout	<ul style="list-style-type: none"> Uncertain
Rumble strips	<ul style="list-style-type: none"> Estimated speed reduction of 5 km/h⁽²⁾
Flashing lights	<ul style="list-style-type: none"> Uncertain
Appropriate run-out areas.	<ul style="list-style-type: none"> Uncertain
Horizontal deflections on approaches Vertical deflections on approaches	<ul style="list-style-type: none"> Low entry and circulating speeds (< 30 km/h) may provide a high level of Safe System alignment for vehicle occupants and vulnerable road users⁽⁴⁾.

1 Perceptual countermeasures create a lower desired speed by creating an environment that suggest a lower speed is appropriate.
 2 Reference: *Methods for Reducing Speeds on Rural Roads: Compendium of Good Practice* (Austroads 2014a).
 3 Reference: *Effectiveness of Road Safety Engineering Treatments* (Austroads 2012).
 4 Reference: *Improving the Performance of Safe System Infrastructure* (Austroads 2015d).

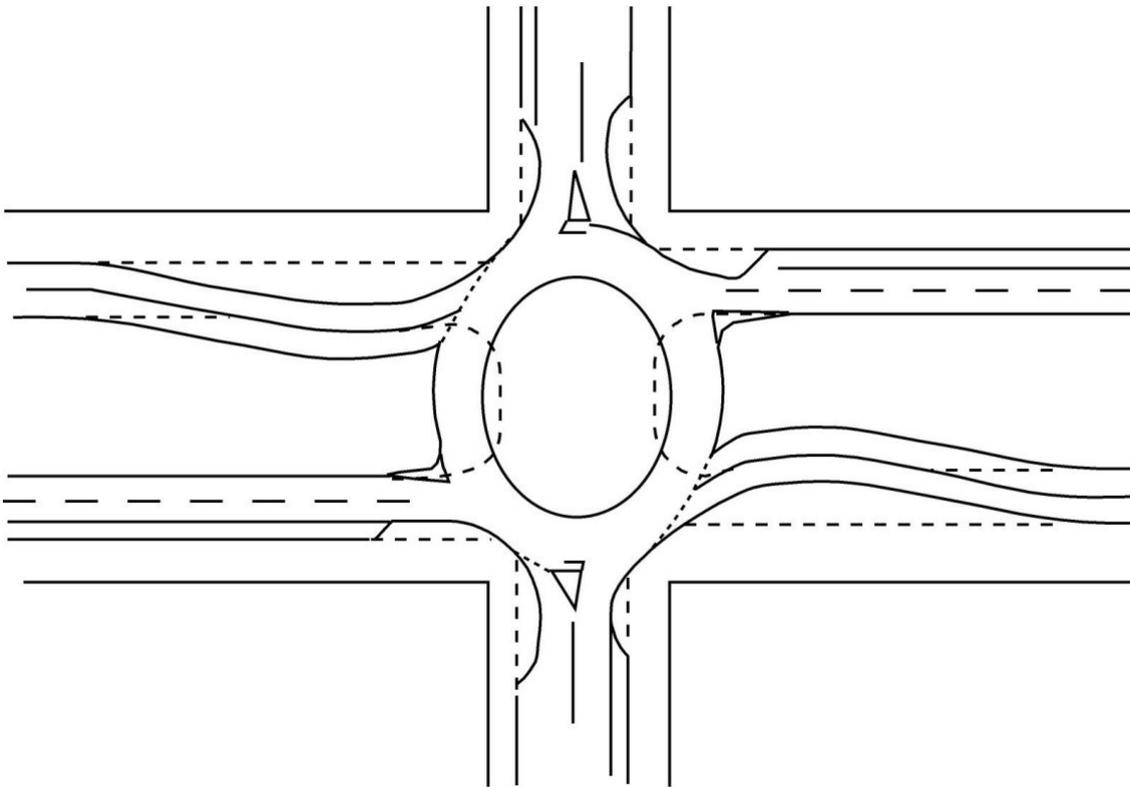
3.5.5 Wide streets and T-intersections

Particular problems in roundabout design occur at locations where one intersecting street is considerably wider than the other and/or where a wide median exists. This situation can occur with local, collector or arterial roads, or where the intersecting streets are not of the same functional classification.

The provision of appropriate entry curvature and deflection for through traffic entering the roundabout may require widening into the median and the use of an oblong central island (Figure 3.8). In these situations, the central island will involve different circulating speeds for different sections of the circulating roadway. Right-turning drivers entering from the narrow road will find that the radius of their turning path decreases and becomes more difficult. A circular roundabout at this location, although quite large, would provide a safer treatment if space permits.

Where kerb lines are built out on approaches to roundabouts, special care should be taken to ensure that adequate delineation is provided, particularly in instances where there may be no parked vehicles on the approach. A suitable treatment involves using line marking, raised reflective pavement markers and semi-mountable kerbs.

Figure 3.8: Roundabout on a road with a very wide median



Where roundabouts are installed at existing T-intersections it can be difficult to achieve adequate deflection on the continuing road approaches, because there is usually limited space available within the road reservation. Similar issues can arise at skewed T-intersections.

3.5.6 Sight Distance

As for other types of intersection, roundabouts must be designed with adequate sight distance for drivers approaching the roundabout and standing at the holding lines. Three sight distance criteria must be met for the safe operation of roundabouts, these being:

1. The alignment of the approach should be such that the driver has a good view of the splitter island, the central island and desirably the circulating roadway (approach sight distance).
2. The driver, stationary at the give way line, should have a clear line of sight to approaching traffic entering the roundabout from an approach immediately to the right, and to turning traffic approaching on the circulating roadway, for at least a distance representing the travel time equal to the critical acceptance gap (MGSD).
3. It is desirable that drivers approaching the roundabout are able to see the other entering vehicles well before they reach the give way line (provision of a sight triangle to the right).

These three criteria are described in detail in *Part 3* of the *Guide to Road Design* (Austroads 2016e). The first two criteria are essential whilst the third is desirable. It is most important that horizontal and vertical geometry, including their combined effects, be taken into account. Additional guidance on sight distance criteria at roundabouts is provided in the *Guide to Road Design Part 4B* (Austroads 2015c). In some circumstances, consideration may be given to limiting the sight triangle in order to encourage drivers to slow on the approach to a roundabout (Commentary 20).

Designers and maintenance personnel must ensure that vegetation, landscaping and road furniture do not impede sight distance at roundabouts, with respect to both entering and circulating traffic. Pedestrians crossing the road or waiting to cross the road should be clearly visible to drivers approaching, travelling through and departing from roundabouts.

3.5.7 Signs and Line Marking

Appropriate signs and line markings are fundamental to the effective operation of roundabouts. For further guidance, refer to *Part 10* of the *Guide to Traffic Management* (Austroads 2016d), New Zealand *TCD Manual* (NZTA 2008c⁷) and *Guidelines for Marking Multilane Roundabouts* (NZTA 2010c).

3.5.8 Landscaping and Road Furniture

The safety and effectiveness of roundabouts can be affected by details of the design, landscaping and the type and location of road furniture.

It is important to ensure that the landscape design does not create a danger to road users or obscure the view of other drivers or the layout of the roundabout. It is particularly important that drivers have a clear view of pedestrians waiting to cross the road and crossing the road at roundabouts.

Planned landscaping can enhance safety and environmental benefits by making the intersection a focal point and by reducing the perception of a high-speed through traffic movement.

Structures associated with roundabouts such as kerbs, signs, lighting and utility poles, should be selected or designed to minimise their adverse effect on an impacting vehicle.

The grading and landscaping on arterial road roundabouts must be designed to ensure the achievement of the sight distance requirements and to avoid obstructing the visibility of signs.

For roundabouts on local roads where the approach and negotiation speeds are lower, achieving appropriate sight distances should not be difficult and roadside hazard concerns will also be less critical.

For additional guidance, refer to *Part 4B* of the *Guide to Road Design*, *Part 10* of the *Guide to Traffic Management*, *Part 9* of the *Guide to Road Safety* (Austroads 2015c, 2016d, 2008) and New Zealand *TCD Manual* (NZTA 2008c⁷).

3.5.9 Lighting

The satisfactory operation of a roundabout relies on drivers being able to enter into and separate from the circulating traffic stream in a safe and efficient manner. This requires drivers to be able to perceive the general layout of the intersection and the position and movement of vehicles within the roundabout. This task is more difficult at night and therefore it is recommended that some form of lighting be provided at all roundabouts on all classes of roads.

General principles and guidance on lighting of traffic routes is covered in the *Guide to Road Design Part 6B: Roadside Environment* (Austroads 2015f) and AS/NZS 1158.1.1:2005, and AS/NZS 1158.1.1:2010.

⁷ Note the relevant part of the TCD Manual may be unpublished, in which case refer to the Manual of Traffic Signs and Markings (MOTSAM) (NZ Transport Agency (NZTA) 2010a, 2010b). MOTSAM is being progressively replaced by the TCD Manual (in press).

3.6 Signalised Roundabouts

3.6.1 General

Research (*Improving the Performance of Safe System Infrastructure*, Austroads 2015d) has found that, for signalised intersections, signalised roundabouts are best aligned with achieving Safe System objectives (Commentary 19). Signalisation may also be considered if an existing roundabout is performing poorly in terms of delay on several approaches the benefits that might be derived from signalisation should be investigated through traffic analysis.

[\[see Commentary 19\]](#)

Options that may be considered include:

- metering in advance of a roundabout entry
- full or partial signalisation at the junction of roundabout entries and the circulating carriageway.

3.6.2 Metering in Advance of Roundabouts

An entry to a roundabout will not function efficiently if there are insufficient acceptable gaps in the circulating traffic stream. This may be caused by a very heavy through or right-turn flow from one approach not being sufficiently interrupted by the circulating flow. In such cases, the entry can be metered by installing traffic signals to interrupt the heavy traffic flow when the queue on another entry exceeds a pre-determined length. Where permitted, purpose built (two aspect red and yellow) signals or standard pedestrian operated signals may be used. Metering can be applied to more than one entry at a roundabout.

Figure 3.9 illustrates metered roundabouts using purpose built signals and 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.

Where purpose built signals are used it is important that:

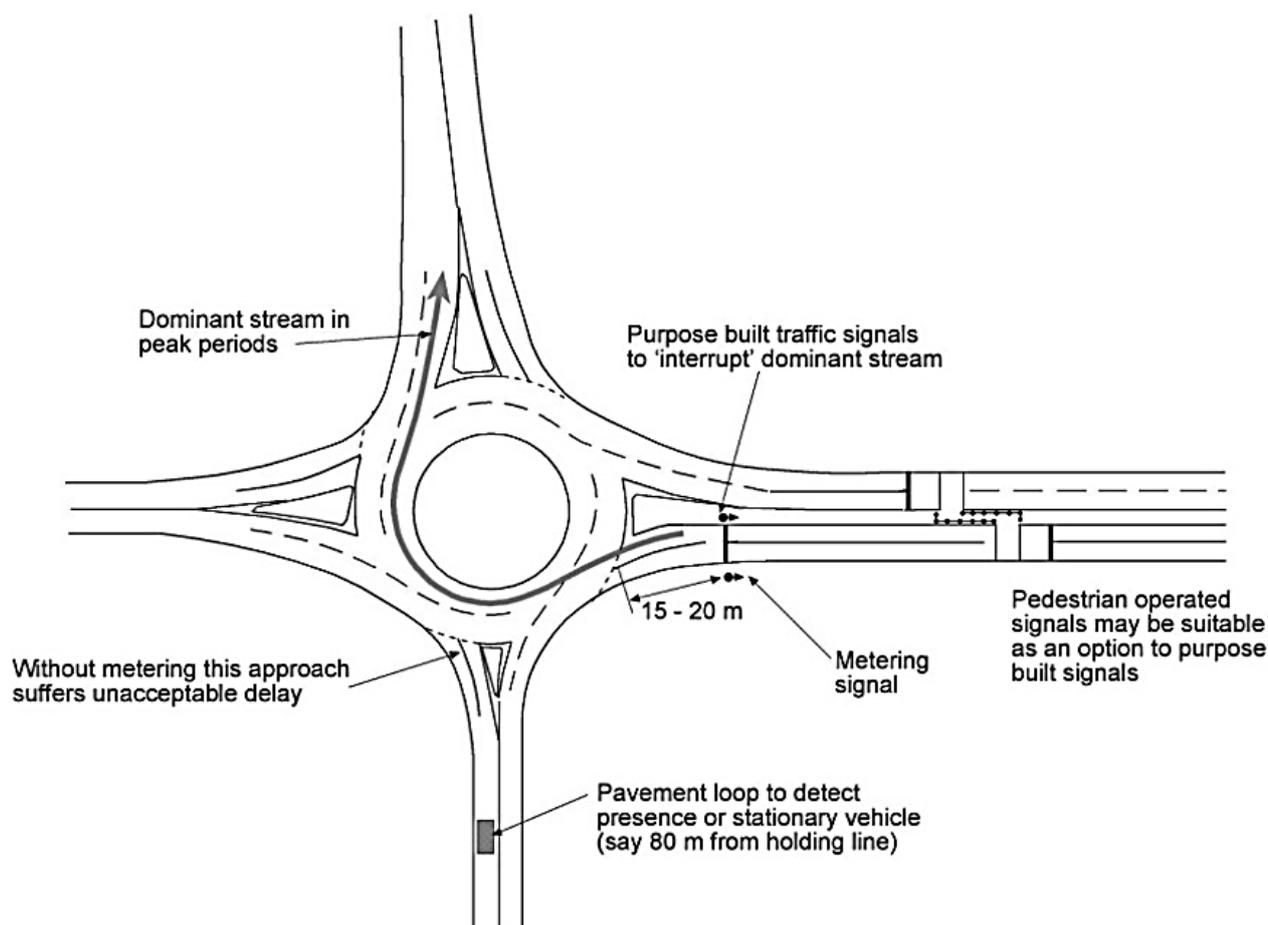
- they are located at least 15 to 20 m in advance of the roundabout holding line to provide adequate separation between the roundabout regulatory signs and the traffic signals so that possible driver confusion is avoided
- signs are provided at the signals to advise drivers that the flow is being metered
- provision of *stop here on red signal* signs is considered.

Where pedestrian operated signals are used for metering:

- the crossing must be located a sufficient distance from the exit, and on divided roads pedestrian movement 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).

For further guidance on the signal displays and signs used in conjunction with roundabout metering, refer to *Part 10* of the *Guide to Traffic Management* (Austroads 2016d).

Figure 3.9: Metering of roundabout approaches



3.6.3 Signalisation at Junction of Roundabout Entry and Circulating Carriageway

Signalising the junction of roundabout entries and the circulating carriageway may be considered for similar reasons to those noted for metering of roundabouts. However, this type of signalisation provides a more direct method of controlling the entry of traffic and may be applied to all arms of a roundabout to fully control traffic entry to and internal movements on a roundabout.

Signalisation may assist in improving the capacity of a roundabout and in balancing approach queues. Additionally, in some instances, signalising roundabouts may improve the safety of a roundabout or may provide options for accommodating pedestrians and cyclists (Commentary 19).

If signalisation is implemented, signals:

- must control both entering and circulating traffic at each entry
- should not be used to control traffic that is exiting from the circulating roadway.

For 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.

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

- 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.

Partial signalisation of roundabout entries

It may not be necessary to signalise all entries to a roundabout, particularly if there is a low-volume minor approach. Using give way priority for one leg may merit consideration if:

- the approach volume is low
- there is an upstream signal for which control inefficiencies (e.g. signal start up and loss times) may provide sufficient gaps for traffic to enter via give way priority
- there is adequate storage space downstream from the give way entry point and prior to the next traffic signal stop line on the circulating carriageway to accommodate queuing.

This type of control may be advantageous as it can reduce the number of phases thereby enabling a shorter cycle time at the signalised roundabout.

Other considerations

Other considerations at fully or partially signalised roundabouts are shown in Table 3.2. For further guidance on the analysis and design of roundabouts, refer to Department of Transport (2009). Several roundabouts have been converted to signalised roundabouts in New Zealand (refer to Chard, Thomson & Bargh 2009 and Dryland & Chong 2008). For guidance on the operation of traffic signals, refer to Section 4.5 and Part 9 of the *Guide to Traffic Management* (Austroads 2016c).

Table 3.2: Other considerations at fully or partially signalised roundabouts

Issue	Considerations
Roundabout size	<ul style="list-style-type: none"> • Signalisation is generally more suitable for larger roundabouts as more storage space is available for traffic stopped on the circulating carriageway.
Lane configuration	<ul style="list-style-type: none"> • Signalised roundabouts may require modifications to maximise storage capacity or optimise operation. Considerations may include: <ul style="list-style-type: none"> • flaring roundabout approaches at the roundabout entry • reducing the deflection normally provided at unsignalised roundabouts in order to improve visibility to the right for drivers entering a roundabout • providing additional lanes on sections of the circulating carriageway • considering movements that pass through the central island.
Lane marking	<ul style="list-style-type: none"> • Spiral lane markings (Section 3.4.1) may merit consideration to minimise weaving and guide drivers through the signalised roundabout without requiring lane changes. However, some jurisdictions do not support this practice or may limit its use to manage particular situations at existing roundabouts (for further guidance, see <i>Guide to Road Design Part 4B</i>, Austroads 2015c).
Full-time vs part-time signal control	<ul style="list-style-type: none"> • Signalised roundabouts may be considered during all times of day or be restricted to certain poorly performing peak periods. • Where signalising a roundabout entry, part-time control may compromise the optimal roundabout configuration, as it needs to consider both signalised and give way priority control (Department for Transport 2009). For example, the optimal lane configuration may not be the same for full-time and part-time control. • Signing or motorist information requires special care with part-time control to avoid driver confusion regarding the type of control in operation.
Traffic signal operation	<ul style="list-style-type: none"> • Shorter cycle times are preferred to minimise queuing and storage issues on the circulating carriageway. • Signalised roundabouts may require different forms of traffic control than standard signalised intersections (e.g. SCATS Masterlink mode may not be compatible, requiring a roundabout to be operated in Flexilink, isolated mode). For further guidance on traffic signal control settings, refer to Part 9 of the <i>Guide to Traffic Management</i> (Austroads 2016c).

4. Signalised Intersections

4.1 Introduction

Traffic signals are used when the selection process described in Section 2.3 indicates that a signalised intersection would provide the most appropriate form of traffic control. Traffic signals are provided either to:

- rectify a safety or operational problem at existing intersections (i.e. reduce crashes, traffic conflicts or delays), or
- ensure an appropriate level of safety and mobility at new intersections.

The *Level of Service Metrics (for Network Operations Planning)* (Austroads 2015g) provides a series of measures that can support assessment of options for each road user and their needs. Table 4.1 outlines the contribution of signal management to road user needs within the LOS framework.

Table 4.1: Contribution of signal management to meeting road user needs

Road user need	Contribution of signal management
Mobility	<ul style="list-style-type: none"> • Adjust signal timings and phasing to reduce delay at individual intersections, for priority road users/movements at certain times of the day. • Improve coordination of signals along a corridor to maximise throughput and progress priority uses/movements at certain times of the day. • Implement network-wide congestion management strategies (e.g. pre-emption/gating of general traffic to address recurrent congestion problems in an area. • Support control of access to the network and dissipation of traffic to assist incident management in reducing non-recurrent congestion. • Actively discourage vehicle movements in locations with good level of service for other modes, to encourage modal shift and reduce traffic on the network. • Support public transport and freight movements where intended.
Safety	<ul style="list-style-type: none"> • Prevent unsafe conflict of movements. • Provide protection to vulnerable road users such as pedestrians and cyclists.
Access	<ul style="list-style-type: none"> • Improve level of service for all road users. • Assist in improving equity for side/local road access to key arterials during off-peak periods. • Provide priority for emergency vehicles where possible.

Source: Adapted from Austroads (2015h), *Signal Management Techniques to Support Network Operations*.

Issues related to pedestrians and cyclists may also influence a decision to signalise an intersection. Treatments may range from the installation of signals at an existing site with minimal or no change to the layout, to the provision of complex signalised arrangements in conjunction with major road projects. The *Safe System Assessment Framework* (Austroads 2016a) can help prompt safety considerations for all road users including motorists, pedestrians and cyclists at the intersection.

The provision of a safe and efficient signalised intersection may be dependent on the:

- functional layout and geometry
- signal phasing
- signal timings, including cycle time, phase times, and inter-green times
- coordination with adjacent intersections and level crossings.

The design of the intersection and the traffic signal control system (including signals, signs and line marking) should be such that it can be easily seen and identified by road users.

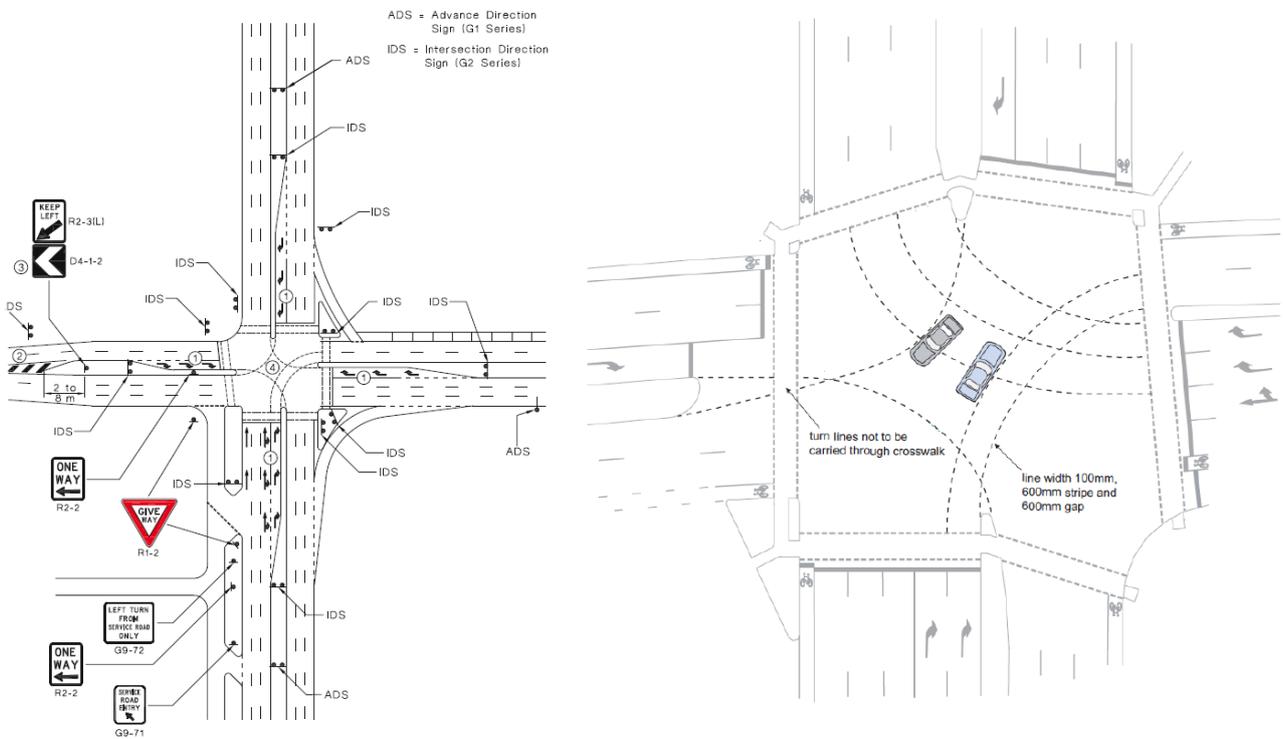
This section provides considerations on traffic management aspects of signalised intersections including layout, road space allocation and lane management. Additionally, other traffic management considerations noted in this section are more fully described in other parts of the Guide including:

- traffic signal phasing, timings and coordination which are described in detail in the *Guide to Traffic Management Part 9: Traffic Operations* (Austroads 2016c)
- traffic signal displays, associated signs and road markings which are described in detail in the *Guide to Traffic Management Part 10: Traffic Control and Communication Devices* (Austroads 2016d).

Part 4 of the *Guide to Road Design* (Austroads 2017a) addresses the road design of signalised intersections including design considerations pertaining to sight distances, intersection layouts and traffic lanes and is of particular relevance to this section. For other key sections of the *Guide to Traffic Management* and *Guide to Road Design* relating to aspects of signalised intersections, refer to Appendix A.

An example of a signalised intersection between two arterial roads is illustrated in Figure 4.1.

Figure 4.1: An example of a signalised intersection between two arterial roads



Source: AS 1742.2

Source: Department of Planning, Transport and Infrastructure (2015).

Note: Signalised intersections must also include adequate provision for all pedestrian, cyclist and public transport facilities that are determined to be necessary.

4.2 Functional Layout

The functional layout of an intersection reflects its use and the way in which road users are to be managed. It can be produced as a conceptual layout at the planning and feasibility stages of projects or as a larger-scale plan to present the combination of traffic control devices used to manage an intersection. The general form and the details of a layout can affect both the capacity and safety of a signalised intersection. Traffic management through the use of traffic signals at intersections is therefore dependent to a large extent on the layout.

The functional design and the operation of a signalised intersection are dependent on the allocation of road space and time to various road user groups and the way in which lanes are managed:

- allocation of road space and lane management are discussed in Sections 4.3 and Section 4.4 respectively
- allocation of time is summarised in Section 4.5 and is described in greater depth in the *Guide to Traffic Management Part 9* (Austroads 2016c).

Road user issues relating to pedestrians and cyclists are summarised in Table 2.11 and Table 2.12, some of which relate to signalised intersections. Specific issues related to:

- road space allocation are summarised in Table 4.3
- lane management are discussed in Table 4.5
- traffic signal operation (i.e. signal phasing and timing) are discussed in *Part 9* of the *Guide to Traffic Management* (Austroads 2016c).

In considering a functional layout plan, traffic engineers and road designers should also be mindful of the effect of horizontal and vertical geometry on traffic management and road safety (e.g. visibility of signals and other traffic control devices). Table 4.2 presents geometric factors that may affect the capacity or safety of a signalised intersection. For further guidance on these factors, refer to the *Guide to Road Design Part 4* (Austroads 2017a).

It is possible to signalise any type of intersection (Section 2.2). As noted in Section 3.6.1 and Commentary 19, signalised roundabouts are well aligned with achieving Safe System objectives. Signalisation of roundabouts may also be considered to address delay issues, although this is not typically necessary for efficient operation (Section 3.6).

Table 4.2: Factors affecting signalised intersection capacity and safety

Factors	Issues	Comment
Mid-block cross-section	<ul style="list-style-type: none"> • Compatibility of mid-block capacity with intersection approach capacity. 	<ul style="list-style-type: none"> • Intersections usually control capacity of urban road networks. • It is usually not possible to match mid-block capacity with intersection approach capacities.
Lane alignment	<ul style="list-style-type: none"> • Approach roads not aligned to enable through lanes to be on straight alignment, leading to poor lane discipline and possibly crashes. • Traffic inadvertently led into auxiliary lanes. 	<ul style="list-style-type: none"> • An instantaneous change of direction or short curve within the intersection is undesirable. If a curve is necessary it should extend through the intersection from the approach to the departure. • Where lane misalignments cannot be avoided, turning lines or raised pavement markers should be used for delineation within the intersection (<i>Part 10</i> of the <i>Guide to Traffic Management</i>, Austroads 2016d). • Provide short auxiliary lane tapers to better define alignment of through lanes. • Where possible, avoid lanes that appear to be through lanes but require drivers to turn after they have entered them (sometimes referred to as 'trap' lanes).

Factors	Issues	Comment
Approach vertical alignment	<ul style="list-style-type: none"> Limited sight distance to rear of traffic queue. Limited sight distance between right-turners and opposing through traffic. 	<ul style="list-style-type: none"> Design for appropriate sight distance (<i>Part 3 of the Guide to Road Design, Austroads 2016e</i>). Where it is not possible to meet approach sight distance guidelines, provide interactive devices to warn approaching traffic of a queue (<i>Part 10 of the Guide to Traffic Management, Austroads 2016d</i>). Consider provision of fully controlled right-turn phase or right-turn ban (<i>Parts 9 and 10 of the Guide to Traffic Management, Austroads 2016c, 2016d</i>).
Number of lanes	<ul style="list-style-type: none"> Adequate capacity of intersection or particular movements or particular road user groups. Traffic intrusion into sensitive areas. 	<ul style="list-style-type: none"> Provide sufficient lanes to meet design objectives in relation to allocation of space and lane management. Depending on traffic management strategy for area, some traffic movements may be prohibited or limited.
Desire lines	<ul style="list-style-type: none"> Pedestrians and cyclists will attempt to use the shortest path and this can lead to the use of unsafe crossing locations or constructed paths being redundant. 	<ul style="list-style-type: none"> Where possible construct paths along pedestrian and cyclist desire lines. Use landscaping, fences or other barriers to encourage pedestrians to use safe road crossing locations.
Turning paths	<ul style="list-style-type: none"> Adequate space for design vehicles to turn within intersections without the risk of conflict with other road users. Adequate clearance between opposing right-turns that operate concurrently. 	<ul style="list-style-type: none"> Design for the swept width of an appropriate design vehicle (may also include trams for some movements). Consider conflict with pedestrians, including front overhang of ultra-low-floor ('kneeling') buses. Inadequate clearance between opposing concurrent turns may require each right-turn to operate in different phases. See <i>Part 4 of the Guide to Road Design (Austroads 2017a)</i>.
Length of crossing	<ul style="list-style-type: none"> Unnecessarily wide intersections. Excessive crossing distances; inconvenient staging and delays for pedestrians. Increased clearance time for vehicles. Inefficiency due to increased lost time, inter-green time and hence traffic signal cycle times (longer cycle times generally increase delays). 	<ul style="list-style-type: none"> Design intersections to be as compact as possible whilst meeting road space requirements of users.
Phase and cycle times	<ul style="list-style-type: none"> Phase and hence cycle times influence the overall delay experienced by road users at signalised intersections. Coordination of signals may require longer cycle times leading to longer delays for pedestrians crossing the major road and vehicles entering from minor road approaches. Providing priority for certain road user groups (where required). 	<ul style="list-style-type: none"> Signal systems should be responsive to traffic demands so that efficient phase and cycle times can be applied at different times of the day and week, considering the function of the traffic route and intersection. Shorter cycle times during the day, in situations where vehicle demands are lower and pedestrian demands higher than in peak periods, can lead to improved pedestrian compliance with traffic signals.

Factors	Issues	Comment
Differential speeds	<ul style="list-style-type: none"> Road users traverse intersections at different speeds that may result in some users not having sufficient time to clear the intersection. Laden trucks consume considerable time on intersection approaches that rise steeply. Cyclists have insufficient time to clear intersections during the inter-green time on rising gradients. 	<ul style="list-style-type: none"> Provide additional time where a significant number of aged, disabled or mobility impaired pedestrians use signalised crossings. Consider use of detectors to monitor progress of slow moving pedestrians. Road geometry (gradient, horizontal alignment) can influence speeds of vehicles. Consider time required for slow moving vehicles, particularly on rising grades.
Speed of approaching vehicles	<ul style="list-style-type: none"> Drivers difficulty at estimating the speed of approaching vehicle (perception distance). Contribution to impact speed. 	<ul style="list-style-type: none"> At rural sites, consider use of warning signs (advance or vehicle activated), enhanced line marking, perceptual countermeasures, lane-narrowing, reduced speed limits on approach and through intersections, variable speed limits, high friction coloured surfacing, speed and red light cameras. At urban sites, consider use of speed discrimination equipment, provide separate right-turn phase, align opposing right turns, speed and red light camera. Refer to <i>High Risk Intersection Guide</i> (NZTA 2013a) and <i>Methods for Reducing Speeds on Rural Roads: Compendium of Good Practice</i> (Austroads 2014a).

4.3 Road Space Allocation

4.3.1 Introduction

The principles of road space allocation for mid-block situations are addressed in *Part 5* of the *Guide to Traffic Management* (Austroads 2014b). It is described in terms of road space allocation for motor vehicles and also the allocation of space between various road users. The same principles apply to the allocation of road space at intersections. A NOP can help to balance the competing demands of various road user groups for limited road space and time (refer to *Guide to Traffic Management Part 4* for further information).

Signalised intersections are further complicated because, in addition to allocating space to various traffic movements and road uses, it is also necessary to allocate times to conflicting movements (Section 4.5). *Signal Management Techniques to Support Network Operations* (Austroads 2015h) outlines techniques for prioritising road space and signal phasing for different road user groups, i.e. public transport, freight or emergency vehicles, pedestrians or cyclists.

Some less conventional intersection designs have been developed in other parts of the world separating conflicts in space to alleviate right-turn movements. These types of designs are discussed in Commentary 6.

4.3.2 Urban Arterial Road Signalised Intersection Approaches

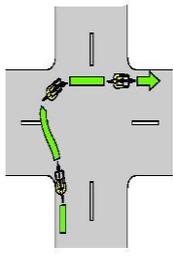
At arterial road intersection sites where there is no constraint on road space (e.g. new road corridors in outer urban areas), it may be possible to provide facilities to meet the requirements of all road user groups. However, in urban areas road space is often limited and may have to be allocated in accordance with transportation or traffic management objectives for the corridor or area (*Part 5* of the *Guide to Traffic Management*, Austroads 2014b). Table 4.3 provides guidance on the traffic management considerations that apply to the allocation of space on arterial road approaches to signalised intersections.

Table 4.3: Road user requirements for arterial road signalised approaches

User group	Context	Guidelines
Motor vehicle drivers	Through lanes	<p>The capacity of the through movement of a signalised intersection approach is determined by the number of through lanes on the approach and the time that can be allocated to the movement.</p> <p>Generally, the number of through lanes at the intersection (or the number of turning lanes on the stem of a T-intersection) should not be less than the number of mid-block through traffic lanes servicing the approach. Exceptions are:</p> <ul style="list-style-type: none"> • very wide arterial roads where capacity at the intersection is not an issue. In such cases the space available may be used for other purposes such as a parking lane, mid-block bicycle lanes, a median or to improve amenity • cases where a road agency has a strategy to reduce the capacity of a route in order to encourage use of an alternative route. <p>As intersections control the capacity of urban routes, the number of through lanes at the stop line should desirably exceed the number of mid-block traffic lanes at an isolated intersection.</p> <p>An auxiliary lane may be provided to enhance the capacity of a through traffic movement. Auxiliary lanes:</p> <ul style="list-style-type: none"> • may be needed to compensate for a loss of capacity resulting from full signal control of the opposing right-turn movement • should be long enough on the intersection approach to accommodate a queue length that corresponds to the maximum green time so that the lane is well utilised • should be long enough on the departure side of the intersection to ensure that potential lane capacity is realised • are not beneficial within coordinated signal systems where signals are preferred for progression of the through movement, except at critical intersections on the boundary of sub-systems.
	Turn lanes	<p>Space required for turning lanes at intersections should be based on capacity analysis to determine the:</p> <ul style="list-style-type: none"> • number of lanes required for each movement • length of lane necessary to accommodate safe deceleration at times of low demand, and sufficient storage clear of the through lanes during peak periods • length of turn lane required to enable access to turn lanes and leading right-turn phases when through traffic is queued. <p>Slip lanes may be provided for heavy left-turn movements at signalised intersections in urban areas and at rural intersections to provide an improved level of service. They are often preceded by a sufficient length of auxiliary lane to ensure access to the slip lane (in urban areas) and to provide for deceleration and storage of left-turning vehicles. Acceleration lanes are not normally provided after left-turn slip lanes (i.e. free-flow arrangement) – rather, high entry angles are used to ensure that left-turns occur at low-speed, with drivers having a clear view of conflicting traffic, including any pedestrians on a zebra crossing located on the left slip lane.</p> <p>High entry angle left-turn slip lanes are preferred because of the lower vehicle speeds where pedestrians have to cross the lane. Where it is necessary to provide a free-flow left-turn lane, and pedestrians are expected to be present, an appropriate controlled pedestrian crossing should be provided. An acceleration lane may be provided for a right-turn from the minor road in the case of a seagull treatment. For further guidance, refer to <i>Part 4 of the Guide to Road Design (Austroads 2017a)</i>.</p>

User group	Context	Guidelines
	Medians	<p>Medians at traffic signals may be part of an extensive median along the road, or be part of a traffic island on the approach. The primary function of medians is to separate opposing traffic flows. However, medians may be used to accommodate:</p> <ul style="list-style-type: none"> • a right-turn (and/or U-turn) lane to shelter turning vehicles • pedestrians • traffic signals • signs • roadway lighting • public utilities (e.g. power poles). <p>Painted medians should not be used where the median is expected to store pedestrians. Raised medians, where pedestrians are expected to store in a two-stage crossing, should be placed and designed so that pedestrians are not at risk from the body overhang of large vehicles.</p> <p>The minimum median width is that required to accommodate signal pedestals, traffic signs, lighting poles and pedestrians when required.</p> <p>The desirable maximum width should enable operation of diamond right-turns wherever practicable. Wider medians can result in reduced capacity due to excessive median width (clearance times) and hooked right-turns. Guidelines on median width are available in <i>Part 4A of the Guide to Road Design (Austroads 2017b)</i>.</p> <p>Consideration should be given to the need for pedestrian pushbuttons to call a pedestrian movement.</p> <p>Line marking, signs and traffic signals should be arranged so as to avoid confusion and clearly present the requirements to the driver. For example, where vehicles may store within the median area while completing a right turn or U-turn.</p>
	Traffic islands	<p>Traffic islands are primarily used to channelise traffic into separate streams. The most common form is a left-turn island but they may be used to separate traffic within complex intersections. Traffic islands are also used to accommodate:</p> <ul style="list-style-type: none"> • pedestrians • traffic signals • signs • roadway lighting • public utilities (e.g. power poles). <p>Painted traffic islands should not be used where they are expected to store pedestrians. Raised traffic islands that are expected to store a considerable number of pedestrians should be placed and designed so that pedestrians are not at risk from the body overhang of large vehicles.</p> <p>Left-turn islands should desirably be large enough to enable:</p> <ul style="list-style-type: none"> • the correct placement of pedestrian cross walk lines, traffic signals and stop lines • poles to be located away from the island nose. <p>Guidelines on the design and dimensions of traffic islands are available in <i>Part 4 and Part 4A of the Guide to Road Design (Austroads 2017a, 2017b)</i>.</p>
	Service roads and outer separators	<p>Where a very wide road reservation exists, service roads (or frontage roads) may be provided and are separated from the major road by outer separators. By controlling the ingress and egress of main road traffic, service roads result in safer conditions.</p> <p>For safety and efficiency reasons, service roads should generally not be allowed to continue through a signalised intersection. The additional space at the intersection resulting from the service road termination can be used to provide extra space for landscaping and pedestrian activity, or be allocated for a separate left-turn roadway.</p>

User group	Context	Guidelines
Motorcyclists	Through lanes and turn lanes	<p>Motorcyclists are susceptible to crashes at intersections.</p> <ul style="list-style-type: none"> Enhanced sight lines at intersections may help: motorcyclists recognise and interpret intersections (supplemented with warning signage when required), recognise other vehicles approaching the intersection and make early and informed choices drivers see motorcyclists in the intersection. Motorcyclists can be difficult to see when performing a right-turn manoeuvre or when other drivers are turning at an intersection. Separation of movements may help improve motorcyclist conspicuity: <ul style="list-style-type: none"> fully controlled right-turn phase provides separation in time channelised right-turn lanes provision of motorcycle lanes may also be considered.
Pedestrians	Road crossings	<p>Pedestrian marked foot crossings should be considered across all approaches of signalised intersections.</p> <p>At T-intersections and intersections at freeway/motorway ramp terminals (e.g. diamond interchanges) crossings are sometimes not provided across the continuing road on the right hand side of the T. This practice eliminates conflict between pedestrians and traffic turning right from the stem of the T and improves the efficiency of this movement. If they are provided, some form of pedestrian protection must be considered.</p> <p>The provision of pedestrian crossings across left-turn roadways should also be considered. Adequate stopping sight distance should be provided to pedestrians, particularly to crossings of left-turn slip lanes where speeds are higher than locations with smaller corner radii. At higher turn radii drivers may tend to focus on the driving task and potentially conflicting traffic rather than pedestrians. Where significant pedestrian flows occur turning speed may have to be controlled through road geometry.</p> <p>Marked foot crossings should be located to minimise the potential for jaywalking. In central areas a separate special pedestrian (scramble or 'Barnes dance' in NZ) phase may be provided in which case the entire intersection is allocated to pedestrian movement each cycle.</p>
	Storage areas while waiting	<p>Medians should provide adequate pedestrian storage where a staged crossing is adopted. The desirable minimum width is that necessary to accommodate a pedestrian with a pram or a bicycle.</p> <p>At left-turn islands and other traffic islands, designers should provide:</p> <ul style="list-style-type: none"> an adequate pedestrian storage area pathways clear of obstructions such as road furniture to enable safe and comfortable passage by pedestrians (including wheelchairs) and sufficient room for road appurtenances and street furniture. <p>Where pedestrian flows are very high storage areas should be designed to provide adequate stopping sight distance and to maximise the capacity (pedestrian flow) of the pedestrian crossing, taking into account the various pedestrian characteristics and needs.</p>
	Footways serving the intersection	<p>Paths provide the network for pedestrian movement on the approaches to intersections and sometimes within large intersections. They link to the marked foot crossings at signalised intersections. To be effective the network must provide for pedestrian desire lines and should provide for the convenient, comfortable and safe movement of pedestrians. Barriers to pedestrian movement (e.g. excessive grades, narrow paths, poor surface, and chicanes) will lead to pedestrians choosing an alternate route and not using the facilities.</p> <p>Design for adequate capacity (<i>Part 3 of the Guide to Traffic Management, Austroads 2013</i>).</p> <p>Pedestrian ramps at all pedestrian crossing points must comply with AS 1428 (<i>Design for Access and Mobility</i>) or NZS 4121:2001.</p>

User group	Context	Guidelines
Cyclists	Bicycle lanes at intersection approach and departure	<p>Bicycle lanes should be provided on intersection approaches where:</p> <ul style="list-style-type: none"> the approach is on a designated bicycle route bicycle lanes are marked mid-block squeeze points exist for cyclists and it is feasible to develop sufficient space for the bicycle lane the layout of the intersection results in high traffic volumes or relatively high-speed vehicles weaving across the path of cyclists. <p>As a guide, a bicycle lane should be considered where a road carries or is likely to carry more than 3000 vehicles per day.</p> <p>In order to maximise cyclist safety:</p> <ul style="list-style-type: none"> Adequate space should be provided to accommodate a wider kerbside approach lane or a bicycle lane (1.0–1.8 m) adjoining the traffic lane. Provision of green coloured surface treatment in the bicycle lanes is recommended on the approaches and departure to signalised intersections. <p>For road design options and examples of bicycle lanes at signalised intersections, refer to the <i>Guide to Road Design Part 4</i> (Austroads 2017a).</p> <p>Some agencies have developed warrants for provision of the green surface treatment for bicycle lanes, for example TMR (2016c) <i>Supplement: Traffic and Road Use Management (TRUM): Volume 1: Guide to Traffic Management: Part 10</i> or ACT <i>Design Standards for Urban Infrastructure</i> (ACT Government 2007).</p>
	Cyclist hook turn	 <p>Where appropriate, consideration should be given to the provision of an exclusive lane for right-turning cyclists, placed between the right-turn lanes and through lanes for motor vehicles. Consideration should also be given to the manner in which right-turning cyclists may gain access to the bicycle lanes.</p> <p>In Australia, cyclists are generally permitted to undertake a 'hook turn' at intersections instead of a conventional right-turn (refer to diagram). This option is often used by cyclists at signalised intersections where they can complete the manoeuvre with a green signal, after waiting at the intermediate corner. Provision of a storage area at the corner is not common; however, additional space may be provided by setting back the pedestrian crosswalk lines and stop line on the intersecting approach. This 'head start area' may be marked with bicycle logos.</p> <p>Bicycle lanes should be provided on the departure side of intersections where:</p> <ul style="list-style-type: none"> a bicycle lane exists or is planned along a route cyclists are required to weave through high-volumes of traffic merging from the left (i.e. left-turning traffic joining the route) or high-speed merging traffic.
	Intersection stop line storage	<p>On bicycle routes a 'head start area' should be considered, to allow for cyclists to wait at the stop line at a position in advance of the motor vehicles. This facility ensures that cyclists waiting at the red light are visible to the first driver in the queue, particularly drivers of commercial vehicles that may have their view of cyclists impeded by the height of the left door of the vehicle.</p>
	Bicycle bypass lane	<p>As cyclists can't hook turn at a T intersection, consideration may be given to provision of a bicycle bypass lane at T-intersections (where cyclists travelling on the mainline are provided with a green bicycle display if the minor road turning traffic do not conflict with the cyclist facility at the intersection).</p>
	Bicycle paths, shared paths and separated paths	<p>Where paths exist along a route they should continue through the intersection desirably via shared pedestrian/cyclist crossings that are appropriately marked. The provision of hand rails to assist cyclists to remain mounted whilst waiting for a green signal should be considered.</p> <p>Medians and traffic islands should be large enough to accommodate cyclists along with pedestrians, including people in wheelchairs.</p>
Public transport	Special lanes	<p>The accommodation of trams and/or buses at intersections may involve:</p> <ul style="list-style-type: none"> sharing lanes with other traffic tram or bus lanes, or tramways or busways within medians delineated and signed tram or bus lanes within the road 'queue jump' lanes on the approach to intersections. <p>Tram or bus lanes at intersections may be an extension of a mid-block lane or may be introduced on the approach to give priority to trams or buses.</p> <p>Depending on road rules within a jurisdiction, buses may also utilise tram lanes.</p>

User group	Context	Guidelines
	Special traffic signals	Traffic signals with a B or T letter may be used to enable buses or trams respectively to move to and from positions in a manner not permitted for other vehicles, and also to prevent conflicts between buses, trams and other vehicles within the intersection phasing arrangement (refer to the <i>Guide to Traffic Management Part 10</i> , Austroads 2016d).
	Bus stops	<p>Bus stops are usually situated on the left verge of a road. They may be fully or partially indented into the verge. However, because of difficulties in re-entering the traffic stream bus companies often prefer to have the bus stop within the left hand traffic lane.</p> <p>Where a bus must turn right at a signalised intersection, the bus stop may be located some distance upstream from the stop line to enable the bus to access the right-turn lane; often a difficult manoeuvre. For this reason a bus stop may be incorporated into the approach and a separate signal bus priority phase provided to enable the bus to turn right from the left lane. The stop may be located within a:</p> <ul style="list-style-type: none"> • wide median • left-turn island • traffic island between left-turn lanes and through lanes. <p><i>A bus stop may be provided on an intersection departure to suit a particular route and/or passenger demands.</i></p> <p><i>For further guidance, refer to the Guide to Road Design Part 4 (Austroads 2017a).</i></p>
	Tram (light rail) stops	<p>Tram or light rail stops are often located on the approach to signalised intersections. They may be located at the kerbside or in a safety zone located between the tram tracks and the traffic lanes.</p> <p>Trams stops on the departure side of intersections should be provided only when the tram is in its own reservation.</p> <p>At heavily patronised stops, and to comply with the requirements of the Commonwealth <i>Disability Discrimination Act 1992</i>, special treatments may be required to enable people with disability or mobility difficulty to walk onto the tram without negotiating steps. Tram stop treatments may therefore involve:</p> <ul style="list-style-type: none"> • a raised platform with ramps, located between the trams and traffic lanes or, alternatively, between tram tracks, as a central island stop, with tracks separated to accommodate it • a raised kerb extension whereby the verge is extended to the tram track and cars and trams share a single-lane • a form of road hump located in the kerbside lane of a four-lane undivided road to raise the level of the road to tram floor level. In this case passengers wait behind the kerb line and walk across the hump when both the tram and motor vehicles have stopped. <p>On existing roads these stops often require use of a current traffic or parking lane and motor vehicle traffic flow may be restricted in order to enhance public transport services.</p> <p>In constrained situations tram stops are sometimes located on the departure side of intersections to enable width to be created for a right-turn lane on the corresponding intersection approach.</p>
	Transit lanes and freeway/motorway ramp shoulders	<p>Transit lanes for the use of high occupancy vehicles and buses may be provided on arterial roads and through intersections.</p> <p>Shoulders and ramps on freeways or motorways may be considered for use by buses to bypass traffic queues.</p>
Parking	Signal operation and intersection performance	<p>The allocation of space to parking on signalised intersection approaches and/or departures can have a substantial impact on traffic operation and performance. Clearways are often used on arterial roads to maximise capacity during peak periods. At other times of the day parking should be restricted on the immediate approach to intersections in order to utilise the capacity of the left lane. The extent to which parking may be restricted depends on the nature of abutting development, the availability of alternative parking areas and the level of intersection capacity that must be achieved.</p> <p>Parking must not impede the required stopping sight distance to pedestrian crossing facilities and pedestrian storage areas.</p>

4.3.3 Local Road Approaches to Signalised Intersections

Local roads that function as substantial traffic routes may have to be treated in a similar fashion to arterial roads on the approaches to traffic signals. However, many local roads that connect to signalised intersections have no special requirements with respect to space allocation. Table 4.4 provides guidance on the traffic management considerations that apply to the allocation of space on local road approaches to signalised intersections.

Table 4.4: Road user requirements for local road signalised approaches

User group	Context	Guidelines
Motor vehicles	Approach lanes	<p>Local roads that have a substantial traffic route function should be considered in relation to Table 4.3 which provides guidelines for arterial roads. These roads usually have a traffic volume in excess of 6000 veh/day.</p> <p>Collector roads and access streets that form a leg of a signalised intersection should have sufficient lanes to ensure that local traffic does not experience excessive delay in gaining access to the arterial road.</p> <p>In situations where a leg of an intersection is a single-lane then the width of that lane should be of sufficient width to allow a vehicle to pass a broken down vehicle.</p>
Motorcycles	Through lanes and turn lanes	<p>Issues for motorcyclists on local road signalised approaches are often similar to those experienced at arterial road signalised approaches (see Table 4.3). Improved sight lines and separation of movements (through provision of fully controlled right-turns and channelized turn lanes) can help reduce motorcyclist crash risk at intersections.</p>
Cyclists	Local streets	<p>Cyclists are expected to share traffic lanes on local streets (typically less than 3000 veh/day) except where the street forms part of a designated bicycle route with marked lanes.</p>
	Collector – distributor roads	<p>Where sufficient width is available, bicycle lanes should be provided and green coloured surface treatment should be provided on the lane approach and departure to signalised intersections. Local roads that have a substantial traffic route function should be considered in relation to Table 4.3 which includes guidelines for cyclists on approach to signalised intersections on arterial roads. An effective means of cyclist detection should be provided on local road approaches to signalised intersections.</p>
Pedestrians	Crossings and footways	<p>Similar requirements to arterial roads. Staging of pedestrians is not usually necessary across local road intersection approaches. However, provision of well-directed crossings, smooth flat ramps, audio-tactile devices, and tactile ground markings should be considered to assist people with disability or mobility difficulty.</p>
Public transport	Bus routes	<p>Bus routes often pass through collector-distributor roads and sometimes local streets. However, it is rare that specific provision is made for buses as they are expected to mix with local traffic. However, signal systems may detect buses waiting in a queue on a local street approach and provide some form of priority to the approach.</p>
	Bus stops	<p>Should be located so that they do not adversely affect the operation of the intersection approach or departure and facilitate safe and convenient access by passengers as well as the bus entry and exit from traffic streams.</p>
Parking	Signal operation, particularly delay to local street traffic	<p>Parking prohibitions should be considered on local street approaches in order to fully utilise the green time and minimise delay to local traffic.</p>

4.4 Lane Management

The principles, context and guidance relating to lane management in mid-block sections of road (Section 4 of *Part 5 of the Guide to Traffic Management*, Austroads 2014b) also apply to signalised intersections. Lane management at signalised intersections may relate to general traffic movements or to the movement of particular road users. It may involve part-time use of lanes or prohibition of movements, or in some situations reversal of traffic lanes.

Lane management is achieved through the use of traffic control devices that may include physical devices, static signs and road markings, electronic signs and markings, or coloured pavement. Guidance on traffic control devices and their use is provided in *Part 10 of the Guide to Traffic Management* (Austroads 2016d), AS 1742 *MUTCD* and New Zealand *TCD Manual* (NZTA 2008c⁸). Table 4.5 provides guidance on traffic management considerations that may apply to lane management at signalised intersections.

Table 4.5: Lane management at signalised intersections

User group	Context	Guidelines
Motor vehicles	Through lanes	<p>Multilane approaches are managed by using lane lines and pavement arrows. Regulatory signs or signals may reinforce use as a through lane (e.g. turn bans). Turn bans may be permanent or part-time.</p> <p>On multilane undivided roads direction of traffic flow through the intersection may be reversed during peak periods (tidal flow) by using changeable overhead signals or other available technologies including in-pavement solutions. Pavement arrows should not be provided within these lanes.</p> <p>Through lanes are not normally delineated through signalised intersections. Where lanes curve through an intersection or are misaligned across an intersection it is desirable that turning lines or raised pavement markers are used for lane delineation within the intersection.</p>
	Turning lanes	<p>Arrows should be used to indicate required use (e.g. through and turn, right or left-turn only). However, where all movements are permitted, a combined left, through and right arrow should not be marked.</p> <p>Turning lanes should preferably be indented to separate turning traffic from through lanes.</p> <p>Shared through and right-turn lanes should generally only be used where both movements occur only in the same phase (e.g. split phase). To allow the through movement to continue when the right-turn movement is stopped can lead to rear end crashes.</p> <p>Where multiple turning lanes are used, broken turning lines within the intersection are desirable to guide drivers through their turn the <i>Guide to Traffic Management Part 10</i> (Austroads 2016d) provides additional guidance on turn lines within signalised intersections).</p> <p>Where practicable left-turn slip lanes should be provided.</p> <p>In special circumstances there may be situations that require alternative treatments such as:</p> <ul style="list-style-type: none"> • a through lane may be designated for use as a turn lane during peak periods through illuminated overhead signs and active advance warning signs • part of an opposing through lane may be converted to an indented right-turn lane by installing an automatically deployed moveable median island.

8 Note the relevant part of the TCD Manual may be unpublished, in which case refer to the Manual of Traffic Signs and Markings (MOTSAM) (NZ Transport Agency (NZTA) 2010a, 2010b). MOTSAM is being progressively replaced by the TCD Manual (in press).

User group	Context	Guidelines
	Transit lanes	<p>Transit lanes (e.g. 'T2' or 'T3') are also referred to as High Occupancy Vehicle (HOV) lanes. While not available for use by all traffic, where policy permits transit lanes are implemented where they will result in an increase in the average number of people carried in private vehicles and travel time savings for transit lane users compared to drivers using the adjacent traffic lanes.</p> <p>Transit lanes normally extend over a considerable distance and may pass through signalised intersections. They are usually created by designating an existing traffic lane as a transit lane during peak periods. Cars with the specified number of occupants or more (usually two or three including the driver), buses, taxis, trams, mopeds and motorcycles are allowed to use transit lanes.</p> <p>Transit lanes in Australia must have signs and road markings in accordance with AS 1742.12.</p> <p>Under the Australian Road Rules, traffic that is not allowed to use a transit lane throughout its length may enter and travel in a transit lane for 100 m in order to leave the road. This also applies on the approach to an intersection in order to undertake a turning movement.</p> <p>For New Zealand refer to the Land Transport New Zealand (Road User) Rule.</p>
Motorcycles	Motorcycles	<p>Motorcycle lane filtering is permitted in New Zealand and some Australian jurisdictions. It allows motorcyclists to reach the front of traffic queues at intersections. This enables them to accelerate ahead of passenger vehicles reducing the likelihood of a rear end crash. However, it may lead to an increase in side swipe crashes (particularly where lane widths are narrow) or an increase in loss-of-control crashes due to the combination of rapid acceleration coupled with potentially poor skid resistance (due to pavement surface deterioration and/or surface contaminants such as debris, fuel or oil).</p>
Cyclists	On-road lanes	<p>On-road lanes are designated by standard bicycle lane signs (usually located beside the road but sometimes overhead.) However, in New Zealand road markings without signs can define a bicycle lane; refer to Land Transport Rule: Traffic Control Devices and Land Transport (Road User) Rule.</p> <p>They are generally delineated with a continuous lane line (except in motor vehicle diverge and merge areas where a two continuity lines are used) and bicycle logos.</p> <p>The Australian Road Rules limit motor vehicle travel along a bicycle lane to a distance of 50 m, in order to turn left.</p> <p>Pavement arrows may be used to define directional use of a bicycle lane (right-turn arrow in a bicycle lane that is situated between the through lane and right-turn lane for motor vehicles).</p> <p>A green surface treatment is recommended at conflict points to enhance delineation of a lane and maximise cyclist safety.</p> <p>A bicycle lane may be marked within a signalised intersection (if other traffic lanes are also marked) where there is a long crossing distance, or where cyclists have to ride with heavy vehicle flows on both sides of the bicycle lane.</p>
Pedestrians	Shared use	<p>The only circumstance under which pedestrians may share lanes longitudinally with motor vehicles is through the establishment of a 'shared zone' under the ARR. Shared zones should only be implemented if the street has a design and environment that is conducive to very low vehicle speeds (i.e. usually 10 km/h) and the minimisation of conflict between pedestrians and vehicles. See <i>Part 8 of the Guide to Traffic Management</i> (Austroads 2016g).</p>
Public transport	Buses	<p>A designated bus lane may be provided on the approach to traffic signals as part of a longer bus facility or as a 'queue jump' lane. These lanes are designated through the erection of regulatory bus lane signs and bus lane markings.</p> <p>See AS 1742.12 and <i>Part 10 of the Guide to Traffic Management</i> (Austroads 2016d).</p> <p>Bus lanes may operate 24 hours a day (full-time) or part-time.</p> <p>In Australia, only full-time bus lanes may be provided with a coloured surfacing to highlight use of the lane.</p>

User group	Context	Guidelines
	Trams	<p>Tram lanes may be provided on roads (e.g. the 'Fairway system' in Melbourne). They are signed in a similar fashion to bus lanes.</p> <p>In Australia trams usually share the centre lanes of four-lane undivided roads with motor vehicles. Part-time or full-time tram lanes are separated from adjacent lanes by broken or continuous lines. Full-time tram lanes may be separated by raised semi-mountable kerbs (forming a tram reservation).</p> <p>Tram lanes may extend over a considerable distance or be used as 'queue jump' lanes on the immediate approach to traffic signals. These lanes are designated through the erection of regulatory tram lane signs.</p> <p>See AS 1742.12 and <i>Part 10 of the Guide to Traffic Management (Austroads 2016d)</i>.</p>
Trucks	Trucks	<p>While truck lanes have not been used in Australasia they are covered in AS 1742.12. If implemented they require appropriate regulatory signs, either beside the road adjacent to the truck lane or mounted over the truck lane.</p>
Parking	Traffic flow and small business	<p>The performance of signalised intersections can be adversely affected to a considerable extent by vehicles parked in the left lane on the approach or departure. The Australian Road Rules (ARRs) specify statutory distances from the intersection within which parking is prohibited. These distances provide for a basic level of safety and are often insufficient to enable the left lane to make a substantial contribution to capacity.</p> <p>As a general principle, parking should be banned on signalised intersection approaches and departures for a distance sufficient to provide acceptable operating conditions. On major urban arterial road approaches this may involve a permanent restriction over a significant distance and a clearway during peak periods. On less important arterial roads the distance should be determined through detailed traffic analysis and/or site observations. On local road approaches parking may be allowed relatively close to the intersection.</p> <p>Historically, drivers have been able to park in the left lane of urban arterial roads to undertake activities associated with abutting properties. Roadside parking is usually seen as extremely important to commercial enterprises abutting arterial roads and these are often located near signalised intersections. Consequently, changes to parking restrictions are usually the subject of negotiation between all stakeholders.</p> <p>The regulatory signs and markings associated with parking and parking restrictions comprise <i>no stopping</i> signs and <i>clearway</i> signs. See <i>Part 10 of the Guide of Traffic Management (Austroads 2016d)</i>, AS 1742.11 and NZ <i>TCD Manual (NZTA 2008c⁸)</i>.</p>

4.5 Traffic Signal Operation

Traffic signal operation involves consideration of signal phasing, timing, coordination and detection (Table 4.6). Guidance on signal phasing, timing, coordination and detection are provided in *Part 9* of the *Guide to Traffic Management* (Austroads 2016c), while capacity analysis and measures of performance at signalised intersections are discussed in *Part 3* of the *Guide to Traffic Management* (Austroads 2013).

Table 4.6: Elements of traffic signal operation

Traffic signal operation	Description
Signal phasing	A signal phase is a state of the signals during which one or more movements (streams of vehicles) receive right-of-way subject to resolution of any vehicle or pedestrian conflicts by priority rules. A phase is identified by at least one movement gaining right-of-way at the start of it and at least one movement losing right-of-way at the end of it. Needs of different road user groups, for example motorcyclists, should be taken into consideration when design of the signal phasing is undertaken.
Signal timings	Signal timing at a signalised intersection, including the allocation of appropriate green times to competing traffic movements, requires consideration of: <ul style="list-style-type: none"> • safety • adequate capacity • efficient traffic operation • equity in levels of service for different movements • priority for different road users.
Coordination of traffic signals	Coordination of traffic signals is implemented to improve the level of service of a road or a network of roads.
Traffic detection	The effectiveness of traffic signal systems and hence signalised intersections depends on the ability to detect traffic on intersection approaches and respond with appropriate changes of phase and timing requirements. Pedestrian demands are usually recorded when a pedestrian presses a push button mounted on the side of the signal post, although other (often automated) sensors may be used. Detection of bicycles and light motorcycles is more difficult, but may be achieved by attention to the design of detection loops.

4.6 Signs and Road Markings

Specific signs may be provided at signalised intersections to reinforce regulations that apply to the safe and efficient operation of the intersection and signals. The efficient operation is also dependent on the clear delineation of traffic movements through the intersection. This can be achieved by adequate maintenance of lane lines, stop lines, turning lines, island chevron markings, lane arrows, and raised pavement markers, where appropriate. For further guidance, refer to the *Guide to Traffic Management Part 10: Traffic Control and Communication Devices* (Austroads 2016d), AS 1742.14 and *TCD Manual* (NZTA 2008c⁸).

4.7 Road Lighting

Most signalised intersections are installed in urban areas and therefore roadway lighting usually exists. Further information on lighting at intersections is provided in the *Guide to Road Design Part 6B: Roadside Environment* (Austroads 2015f) and AS/NZS 1158.

Designers should be mindful of the safety advantages of joint use traffic signal/roadway lighting poles, and of the use of other utility poles on which to mount traffic signal hardware (*Guide to Traffic Management Part 10*, Austroads 2016d).

5. Unsignalised Intersections

5.1 Introduction

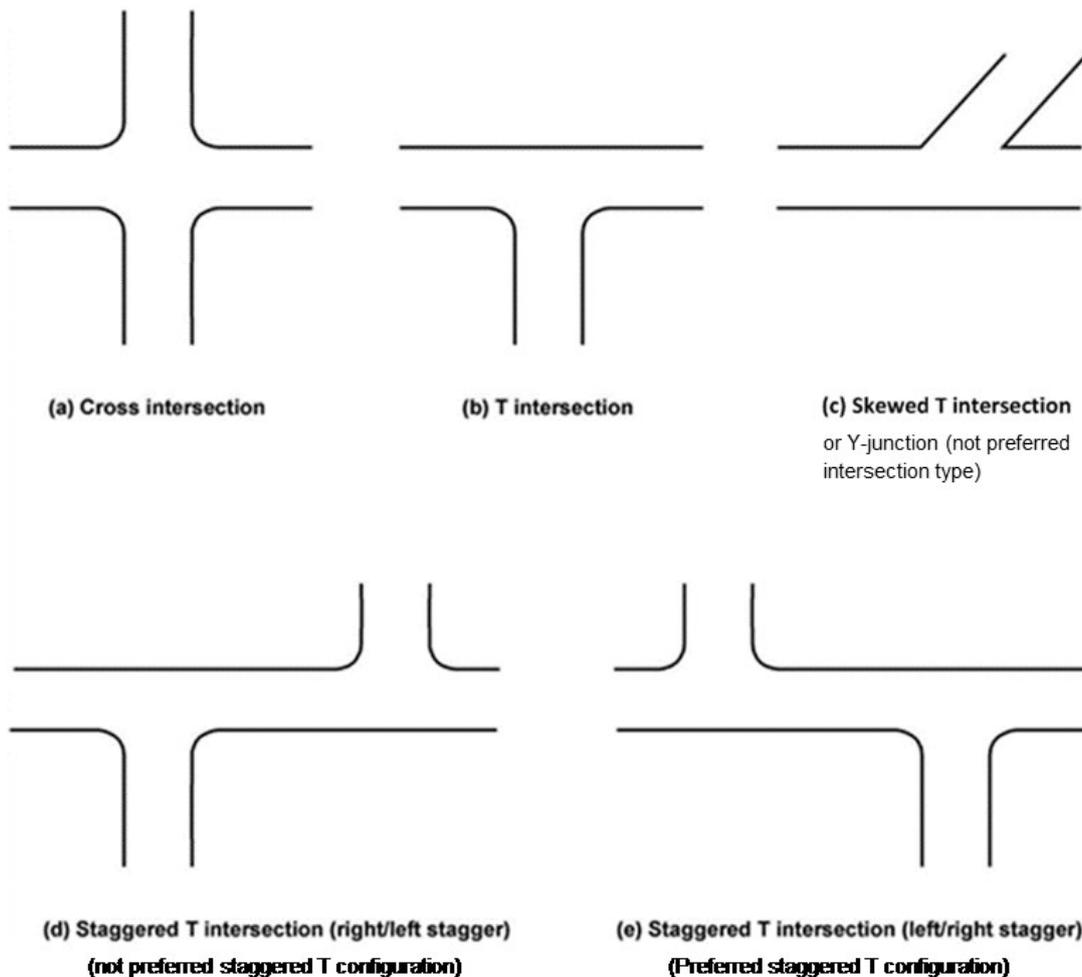
The efficiency and safety of the road network as a whole is more dependent on its intersections than on any other component. The vast majority of intersections are unsignalised and account for a high proportion of network delay, conflict between motor vehicles, and conflict between motor vehicles and other road users (e.g. pedestrians).

Unsignalised intersections are suitable for situations where there are no (or are not likely be) operational problems, such as excessive delays/queues or safety problems, that would justify the provision of a roundabout (Section 3) or traffic signals (Section 4). Such situations would typically include:

- low traffic volume situations
- residential streets
- major roads that have sufficient gaps to accommodate low flows from intersecting minor roads safely and without excessive delay.

The most common forms of unsignalised intersection are shown in Figure 5.1.

Figure 5.1: Forms of unsignalised intersection



Note: While multi-leg (more than four legs) intersections exist they should only be adopted for new or remodelled intersections where they can be demonstrated to have benefits and no safety or operational issues.

Variations within each form may include one or more of the following:

- multilane approaches
- left and/or right-turn deceleration (storage) and acceleration lanes
- channelisation (i.e. provision of traffic islands) including triangular left-turn islands
- one or more movements prohibited by channelisation or regulatory signs
- one-way traffic flow on one or more approaches.

In general unsignalised intersection treatments are classified as:

- Basic (BA) treatments that have no additional lanes or channelisation
- Auxiliary (AU) treatments that have additional lanes for right and/or left-turning drivers, but no channelisation (AUR treatment, AUR lane without channelisation is not used in some jurisdictions)
- Channelised (CH) treatments that have a painted or raised median island to shelter a right-turn lane.

Unsignalised intersections may also take the form of a specific type of treatment such as a seagull or roundabout (Section 3).

5.2 Traffic Controls

5.2.1 General

Priority between conflicting traffic movements at unsignalised intersections is controlled by one or more of the following:

- *stop* signs or *give way* signs
- physical devices
- general regulations.

Forms of traffic control at unsignalised intersections are described in Table 5.1.

Table 5.1: Forms of traffic control

Form of traffic control	Comment
Application of road rules ⁽¹⁾	<ul style="list-style-type: none"> • All control of potential conflicts, including those achieved by regulatory signs or road markings, are supported by relevant road rules. However, in some cases, control is achieved only by such regulatory controls without supporting signs or road markings. For example: <ul style="list-style-type: none"> - T-intersections - right-turn across opposing traffic - give way to pedestrians when turning into a road - parking near an intersection - not block an intersection. • Except in the case of most T-intersections, the <i>Australian Road Rules</i> (National Transport Commission 2012) indicate that <i>stop</i> or <i>give way</i> signs (and/or lines) should always be installed at unsignalised intersections.
Regulatory signs and/or pavement markings ⁽²⁾	<ul style="list-style-type: none"> • Designate or clarify priority rules (<i>stop</i> or <i>give way</i> signs/lines). • Control or guide vehicle trajectories where deficient road geometry exists (e.g. road marking and pavement arrows). • Restrict or ban movements (e.g. 'No Left/Right-turn', full-time or part-time). • Provide parking controls near the intersection.

Form of traffic control	Comment
Physical devices ⁽³⁾	<ul style="list-style-type: none"> • Include traffic Islands and medians which direct traffic into the appropriate path through intersections. • Prevent or discourage inappropriate traffic movement. • Provide staged pedestrian and cyclist crossings. • Separate conflicting movements. • Warn of the presence of an intersection and of traffic control devices. • Provide space to accommodate traffic signs and road lighting. • Used as local area traffic management devices.
Control by police officer (or authorised person) ⁽⁴⁾	<ul style="list-style-type: none"> • Used in unusual circumstances (e.g. road works). • In some jurisdictions persons other than police officers may be authorised to control traffic and unplanned events or traffic disruptions, e.g. a crash or break down causing road congestion.

1 Refer to Australian Road Rules and New Zealand Land Transport Rules.

2 Refer to Australian Road Rules Schedule 2 or New Zealand Land Transport Rules, and AS 1742.2 or NZ TCD Manual⁹ (NZTA 2008c).

3 Refer to AS 1742.10, AS 1742.2 or NZ TCD Manual⁹ (NZTA 2008c), and Part 8 of the Guide to Traffic Management (Austroads 2016g).

4 Refer to Australian Road Rule 304 (National Transport Commission 2012) and New Zealand Land Transport Rules (NZTA 2017).

5.2.2 Stop Signs and Give Way Signs

The circumstances under which *stop* or *give way* signs should be installed are described in AS 1742.2, New Zealand TCD Manual (NZTA 2008c⁹) and also the New Zealand *Planning Policy Manual: for Integrated Planning and Development of State Highways* (Transit New Zealand 2007).

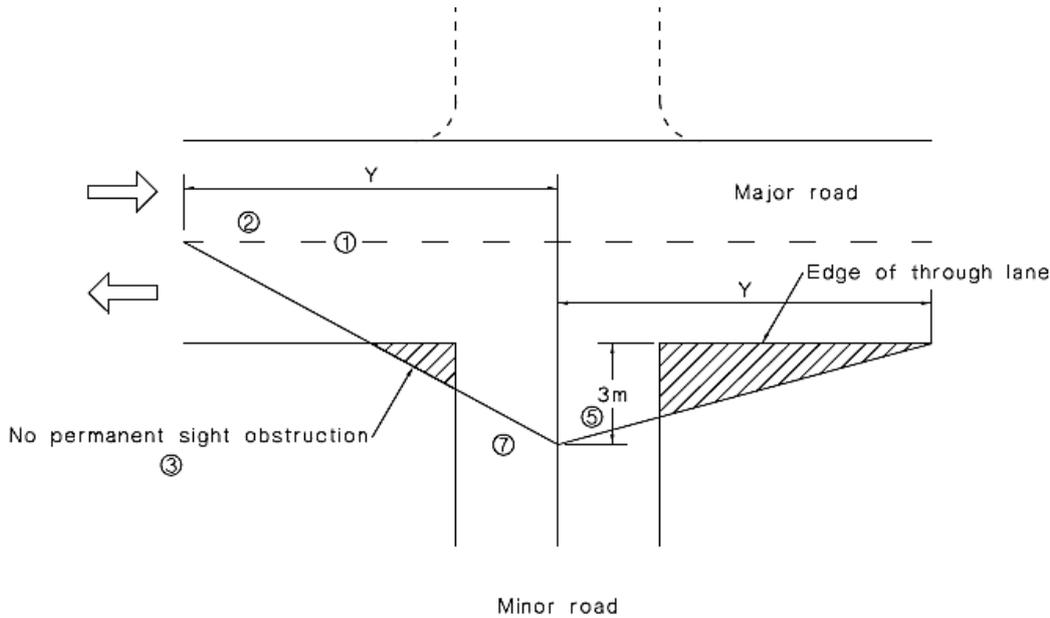
Stop or *give way* signs should **always** be installed at unsignalised intersections with four or more legs. They should also be provided at three-leg unsignalised intersections involving a major road and where the layout is such that it is not clear that the T-intersection rule would operate (e.g. at a skewed location).

A decision as to whether a *stop* sign rather than a *give way* sign is required is based on sight distance requirements for drivers on the minor road approach as shown in Figure 5.2, reproduced from AS 1742.2.

Stop signs should normally be installed only where justified on the basis of sight distance requirements. That is where, for the minor road traffic, the sight distance in either direction is deficient when measured in accordance with the requirements of AS 1742.2 or New Zealand TCD Manual⁹. It has been found that the use of *stop* signs in locations with adequate sight distance does not provide additional safety benefits and can lead to a loss of 'credibility' and their effectiveness in general will be compromised. An exception to this may apply in some jurisdictions where the use of *stop* and *give way* signs within the same intersection is not allowed.

9 Note the relevant part of the TCD Manual may be unpublished, in which case refer to the Manual of Traffic Signs and Markings (MOTSAM) (NZ Transport Agency (NZTA) 2010a, 2010b). MOTSAM is being progressively replaced by the TCD Manual (in press).

Figure 5.2: Sight distance restrictions requiring use of stop signs



Major road speed (km/h) (4)	Distance along major road: Y (m) (6)
40	20
50	30
60	40
70	55
80	65
90	80
100	95
110	115
120	140

- 1 Separation line (undivided road), or right hand edge of right hand through lane (divided road).
- 2 A check to the left is required at a divided road except where the median is wide enough for a crossing or turning manoeuvre to be staged in the median.
- 3 Where visibility is limited due to some removable obstruction, (e.g. vegetation or earth bank) attempts should be made to remove the obstruction rather than install a stop sign.
- 4 The posted or general speed limit is used, unless the 85th percentile speed is significantly higher.
- 5 Where the minor road approach is an arterial road this dimension should be increased to 4.5 m (Roads and Maritime Services, New South Wales practice for the stop sign sight triangle apex is 10 m back from the edge of the nearest traffic lane (Roads and Maritime Services 2011)).
- 6 Where checking sight distance a car driver's eye height of 1.10 m is to be used (Austroads Guide to Road Design Part 3, Austroads 2016e). Further guidance (including object height) is provided in Austroads Guide to Road Design Part 3.
- 7 If the safety of the surveyor is likely to be a problem, sighting may be taken from the kerb in the minor road, with appropriate adjustments to the sight triangle.

Note: The distances in the table along both the minor road and major road are based empirically on the ability of a driver on the minor road approaching the intersection at a speed of 10 km/h or less being able to stop before reaching a conflict point if there is insufficient gap for crossing or joining the major road stream.

In New Zealand the following applies: Subject to formal authorization by the controlling authority, stop signs should be erected at a blind intersection where lack of visibility makes it unsafe to approach the intersection at a speed greater than 10 km/h. It is unsafe to approach an intersection at more than 10 km/h if, from a point 9 metres from the intersection limit (holding) line on the controlled approach, a driver cannot see a vehicle on the uncontrolled approach at a distance (metres) of 1.2 times the 85th percentile speed (measured in km/h) (MOTSAM Part 1: Traffic Signs, NZTA 2010a).

Source: Based on AS 1742.2.

5.3 Intersection Capacity and Flow

General guidance on intersection performance, including issues relating to capacity and flow, is provided in Section 2.5. This section provides more specific guidance relating to capacity of unsignalised intersections.

The capability of the traffic stream that has priority to absorb additional traffic (practical absorption capacity), average delay and storage requirements for entering or turning traffic are dependent on the:

- priority stream flow rate
- critical acceptance gap for the manoeuvre to be undertaken
- follow-up headway for following vehicles in the non-priority stream.

As an unsignalised intersection approaches capacity the supply of acceptable gaps in the major traffic stream reduces, queues and delays increase and drivers are tempted to accept smaller gaps. This can have an adverse effect on safety.

There are several ways to assess the existing or likely extent of delays and queues at unsignalised intersections. Methods may involve:

- traffic surveys, in the case of an existing intersection
- using analytical methods based on gap acceptance criteria and absorption capacity of the major flows
- analytical computer programs such as SIDRA INTERSECTION
- micro-simulation programs (e.g. VISSIM or Paramics) for complex situations such as staggered T-intersections.

For additional guidance on the analysis of unsignalised intersections, refer to *Parts 2 and 3 of the Guide to Traffic Management* (Austroads 2015j and 2013) and the *Highway Capacity Manual* (Transportation Research Board 2016). The Austroads report *Guidelines for Selecting Techniques for the Modelling of Network Operations* (Austroads 2010) provides guidance on selecting an appropriate modelling technique for analysis.

5.4 Traffic Control Devices

Traffic control devices are an integral part of an intersection design. It is essential for designers to have knowledge of the road rules that affect design and the correct use of the traffic control devices that support the rules. Many features may be incorporated into intersection designs to meet the needs of various road users and these features may depend on signs and pavement markings to achieve the appropriate outcome (e.g. no *stopping* signs to ensure adequate capacity or sight distance; bus lane signs to ensure correct lane use).

Standards and guidelines for various traffic control devices that might be used at unsignalised intersections are contained in:

- AS 1742 Manual of Uniform Traffic Control Devices
- in New Zealand, TCD Manual (NZTA 2008c¹⁰) and the Land Transport Rules
- Austroads *Guide to Traffic Management Part 10: Traffic Control and Communication Devices* (Austroads 2016d).

AS 1742 comprises 14 parts that address general or specific aspects of the design and use of traffic control devices.

A number of emerging, less conventional or innovative designs are discussed in Commentary 6.

¹⁰ Note the relevant part of the TCD Manual may be unpublished, in which case refer to the Manual of Traffic Signs and Markings (MOTSAM) (NZ Transport Agency (NZTA) 2010a, 2010b). MOTSAM is being progressively replaced by the TCD Manual (in press).

6. Road Interchanges

6.1 Introduction

Interchanges along a motorway form the principal means of drivers gaining access to, and egress from, the motorway. The spacing, locations and layout of interchanges should be carefully planned and designed to ensure motorways operate efficiently and safely within the arterial road network as a whole (Austroads 2016h, Guide to Smart Motorways).

A road interchange is a combination of grade separations and interconnecting roadways at the junction of two or more roads, at least one of which is a freeway, motorway, expressway or major arterial road.

6.1.1 Terminology

Terminology varies between jurisdictions to describe major arterial roads on which interchanges are provided, for instance freeways, motorways and expressways. In this document the terms freeway and motorway are generally used.

In this section, the terms 'merge' and 'diverge' are used in a generic sense to describe traffic movements in which two separate lanes of traffic combine to form a single-lane, or divide from a single-lane into two separate traffic lanes. Such movements may or may not involve a lane line being crossed. The Australian Road Rules have a more technical meaning and usage of the term 'merge' and place different obligations on drivers depending on the presence or absence of a lane line in the merging area. For New Zealand, the technicalities of the Land Transport Road Rules are subtly different, but the principles similar.

The primary purpose of an interchange is to facilitate an appropriate level of access to the freeway/motorway in a safe and effective way. It improves road safety and traffic capacity by reducing or eliminating traffic conflicts that would occur if grade separation were not provided. Crossing conflicts are eliminated and turning conflicts are either eliminated or minimised.

This section covers traffic management aspects relating to the design of various types of interchanges and their use. The detailed design of interchanges is covered in *Part 4C of the Guide to Road Design (Austroads 2015b)*.

6.2 Planning Considerations

6.2.1 General

Planning of freeways or motorways at a project level should always be preceded by strategic planning of the road network and surrounding area in order to optimise the spacing of arterial roads, including freeways or motorways and their interchanges. The form of the road network provides the basis for network traffic estimation which in turn is the basis for the development of traffic estimates used for traffic management and road design purposes.

The function of an existing road network may be altered by the addition of a freeway/motorway. The planning process should consider present and future land development and the resulting demand for transport (*Guide to Road Transport Planning, Austroads 2009b*). Alternative routes must be available for road users and vehicles that are prohibited from using a freeway/motorway so it is important that the whole road network is integrated and appropriately interconnected through interchanges and intersections.

The type of interchange adopted may also be influenced by planning decisions relating to existing and future land use, and by environmental and economic constraints.

In the planning and design stages of motorway projects, it is important to ensure that effective connections are provided to enable cyclists and pedestrians to safely and efficiently cross the motorway reservation.

6.2.2 Warrants

A numerical warrant for the provision of an interchange or grade separation is difficult to specify due to the wide variety of circumstances that may apply at each site. A decision on whether or not to build an interchange must be based on a broad assessment of all relevant factors and sound engineering judgment. The justification for an interchange should be established from a comprehensive traffic study of the proposed road network with the aims of optimising road safety, traffic service and community interests.

Interchanges may be proposed to:

- provide access across and to a freeway or motorway
- separate conflict points between traffic movements that have high relative speeds
- provide uninterrupted traffic flow between intersecting freeways or motorways
- increase capacity by replacing critical intersections on an expressway or arterial road
- suit particular topography where an interchange can be built at justifiably additional cost to an at-grade intersection
- provide for traffic generated by future land development via existing or future intersecting arterial roads.

An interchange must be provided where:

- the major intersecting road is a freeway or motorway, or a major arterial road
- all practicable forms of at-grade treatments would be unsafe or would not meet level of service objectives for major traffic flows
- an economic analysis demonstrates that it is justified
- provision of at-grade intersections in an otherwise grade separated facility would result in a combination of treatments not expected by motorists and lead to unsafe operating conditions.

6.3 Route Considerations

6.3.1 Spacing of Interchanges

General

The *Guide to Smart Motorways* (Austroads 2016h) identifies factors that determine the 'location and spacing of motorway interchanges with arterial roads' including:

- arterial road network requirements for motorway accessibility, traffic distribution and route interconnectivity
- accessibility, including the capacity of the crossing roads and their strategic connections
- proximity to motorway-to-motorway interchanges
- the physical suitability of the site, including horizontal and vertical alignment as well as the availability of land.

Interchange spacing is defined as the distance between the centrelines of successive crossroads with interchanges on the motorway. Some further guidance on interchange spacing is provided in *Guide to Road Design Part 4C: Interchanges* (Austroads 2015b).

Rural freeways or motorways

In rural areas the minimum desirable spacing of interchanges is 5 to 8 km, depending on the configuration of the roads being intersected by the freeway/motorway. The desirable maximum spacing is less definite but is dependent on the level of service required for local access and the relative costs, benefits and difficulties of providing frontage and local access roads compared to an interchange. However, a spacing greater than 12 km should be adopted only after a review of traffic service afforded by the abutting road network.

Where freeways or motorways bypass rural towns, the location and number of interchanges is normally based on the level of accessibility required between the motorway and the town. This may be an issue for smaller settlements that are economically dependent on tourism.

Urban freeways or motorways

The location and spacing of interchanges in urban road networks is influenced by many factors including:

- the strategic purpose of the section of freeway or motorway
- network efficiency in provision for traffic movement between the motorway and major arterial roads
- reducing community severance, including provision for walking and cycling at interchanges
- traffic management strategies for abutting areas
- physical limitations on the ability to provide connections (ramps)
- availability of land.

In urban areas there is often limited flexibility regarding the location of the horizontal and vertical alignment of the main motorway and this may influence the feasibility of providing an interchange or a particular form of interchange and the spacing that results.

Entry and exit ramps create turbulence in the traffic stream as drivers change lanes, diverge and merge (the distance of this impact is known as the influence area). Where insufficient distance exists between ramps, turbulence is also created between the end of an entry ramp merge taper and the start of the downstream exit ramp diverge taper as drivers weave and change lanes to position themselves for the desired movement. The desirable spacing of interchanges in urban areas should therefore be based on a traffic analysis of the likely traffic operating conditions in the design year. For further guidance, refer to the *Guide to Smart Motorways* (Austroads 2016h), *Part 3 of the Guide to Traffic Management* (Austroads 2013) and Transportation Research Board (2016).

The disturbance to traffic flow on the freeway/motorway can be critical where a high-volume on-ramp precedes a high-volume off-ramp and the motorway is operating near capacity. In such cases, weaving manoeuvres can cause operational and safety problems if the proposed distance between interchanges is too short. Care should be taken to ensure that adequate separation of the ramps (and hence interchange spacing) is provided, based on a weaving analysis.

The *Guide to Smart Motorways* (Austroads 2016h) notes that 'when determining interchange spacing, due consideration should also be given to the design, operation, safety and signing considerations of the ramps, as well as the capacity and operation of the weaving areas between interchanges. The desirable minimum interchange spacing distance in the urban motorway context is generally based on the total of' the following:

- length of the entry ramp
 - length from the arterial road to the ramp nose (including desirable vehicle storage at the ramp metering signals)
 - length of the merge taper entering the mainline
- distance required for lane changing and weaving

For single lane entries and exits (i.e. without excessive weaving movements), the desirable minimum distance is four seconds of travel time between the end of the entry ramp merge taper and the start of the exit ramp diverge taper (i.e. around 100 m for travel at 100 km/h).
- length of the exit ramp
 - length of the diverge taper from the mainline
 - length of the exit ramp from the ramp nose to the arterial road (includes deceleration distance and vehicle storage area at the exit ramp intersection).

The minimum spacing between successive urban motorway interchanges is (Austroads *Guide to Road Design Part 4C*):

- 2 km for four-lane motorways (two lanes in each direction)
- 3 km for six-lane motorways (three lanes in each direction)
- 4 km for eight-lane motorways (four lanes in each direction).

Roads and Maritime Services have developed additional guidance on this topic suggesting that rather than emphasising distance between interchanges, the focus should be on design, operational, safety and signing needs between interchanges, i.e. that spacing is generally the total of (Roads and Maritime Services 2017):

- the length of the entry ramp
- the distance required for lane changing and weaving – desirable minimum distance is four seconds of travel time
- the length of the exit ramp.

The effectiveness of interchange exit signage and the distance required for a driver to change lanes is also an important factor with respect to spacing, as there is a greater potential for driver confusion when advance signs for one interchange have to be placed close to or within a preceding interchange. Therefore, in order to avoid driver confusion, 'the distance between interchanges may also need to consider the positioning and effectiveness of exit ramp direction signing ... when advance signs for one interchange have to be placed close to, or within, a preceding interchange' (Austroads 2016h, *Guide to Smart Motorways*).

Interchange designs and spacing may also impact the form and/or layout of adjacent interchanges. 'For example, motorway alignment and location, or skew of the arterial road crossings, can reduce the ramp spacing' (refer to Figure 6.1) (Austroads 2016h, *Guide to Smart Motorways*).

In restricted situations, if appropriate interchange spacing cannot be achieved for satisfactory operation of adjacent ramps, one of the following solutions may need to be considered:

- *Choose a form of interchange that increases separation (e.g. using a loop ramp rather than diamond ramps (refer to Figure 6.2), subject to volume, capacity and space considerations.*
- *Provide a single interchange with a second diverge off the initial exit ramp, and/or combine two entry ramps to enter the mainline as a single entry.*
- *Provide separate collector-distributor roads parallel to the mainline between two interchanges, which provide one entry and one exit ramp in each direction to service two or more interchanges, as shown in Figure 6.3.*
- *Provide braided ramps (grade separation), as shown in Figure 6.4.*

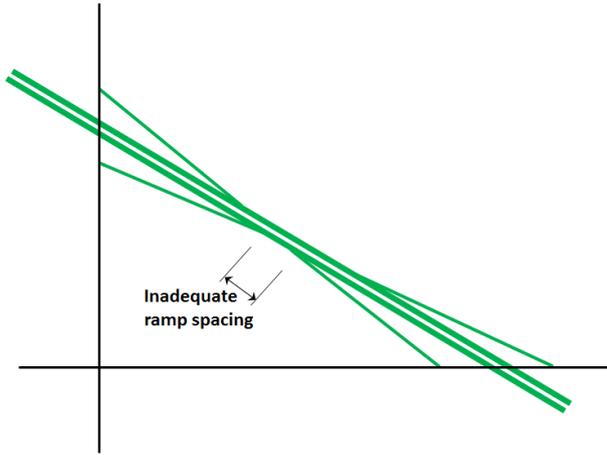
Maximum spacing is rarely a consideration in urban areas. A review of traffic service provided by the total road system is recommended when spacings exceed 4 km in urban areas.

Major Single Entry Compared with Multiple Entrances

The *Guide to Smart Motorways* (Austroads 2016h) notes that 'interchange options relating to the use of a single major entry, collector-distributor road or braiding of ramps, bring together vehicles from two or more ramps so that traffic enters or leaves the motorway at a single location. This arrangement may provide flexibility in the ramp location and minimise weaving. However, a single major entrance concentrates traffic and can have the following disadvantages':

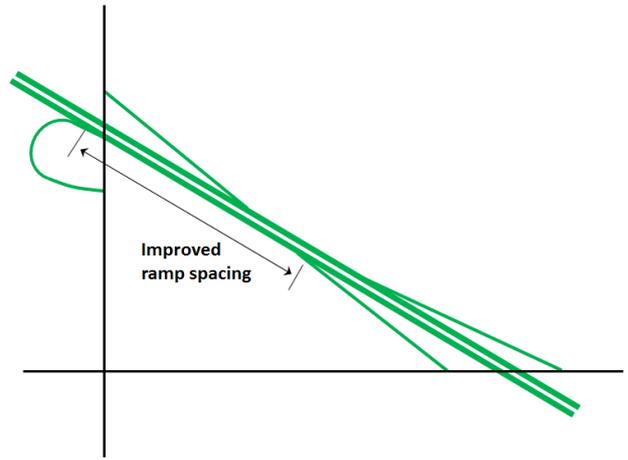
- lane continuity may not be maintained (i.e. the number of continuous through lanes along the motorway to minimise unnecessary lane changing)
- balancing traffic flow and capacity along the route can be more difficult (i.e. the motorway is unable to 'unload' the left lane of the mainline at an exit before accepting entering traffic at the downstream entry ramp)
- more weaving and lane changing movements generally occur downstream of a major entry or before a major exit
- it can be more difficult to provide ramp storage capacity for ramp metering of higher volumes (number of lanes and storage length).

Figure 6.1: Example of motorway alignment and arterial road layout impacting ramp spacing



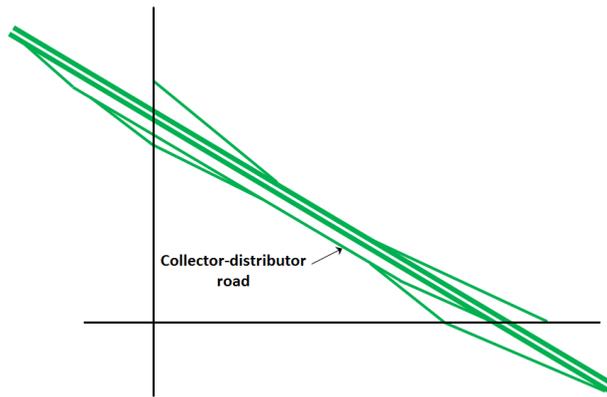
Source: Roads and Maritime Services (2017).

Figure 6.2: Example of using a loop ramp to improve ramp spacing



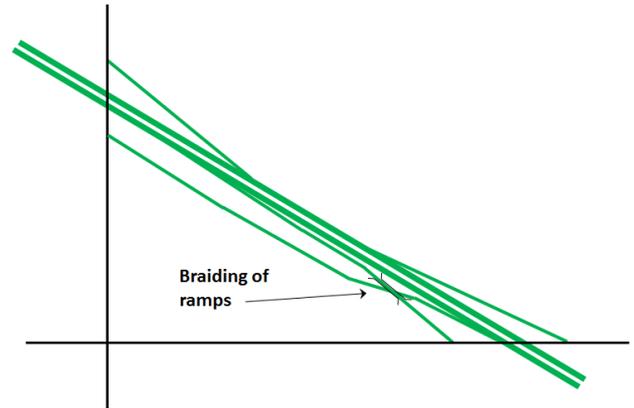
Source: Roads and Maritime Services (2017).

Figure 6.3: Example of collector-distributor road



Source: Roads and Maritime Services (2017).

Figure 6.4: Example of braided ramps

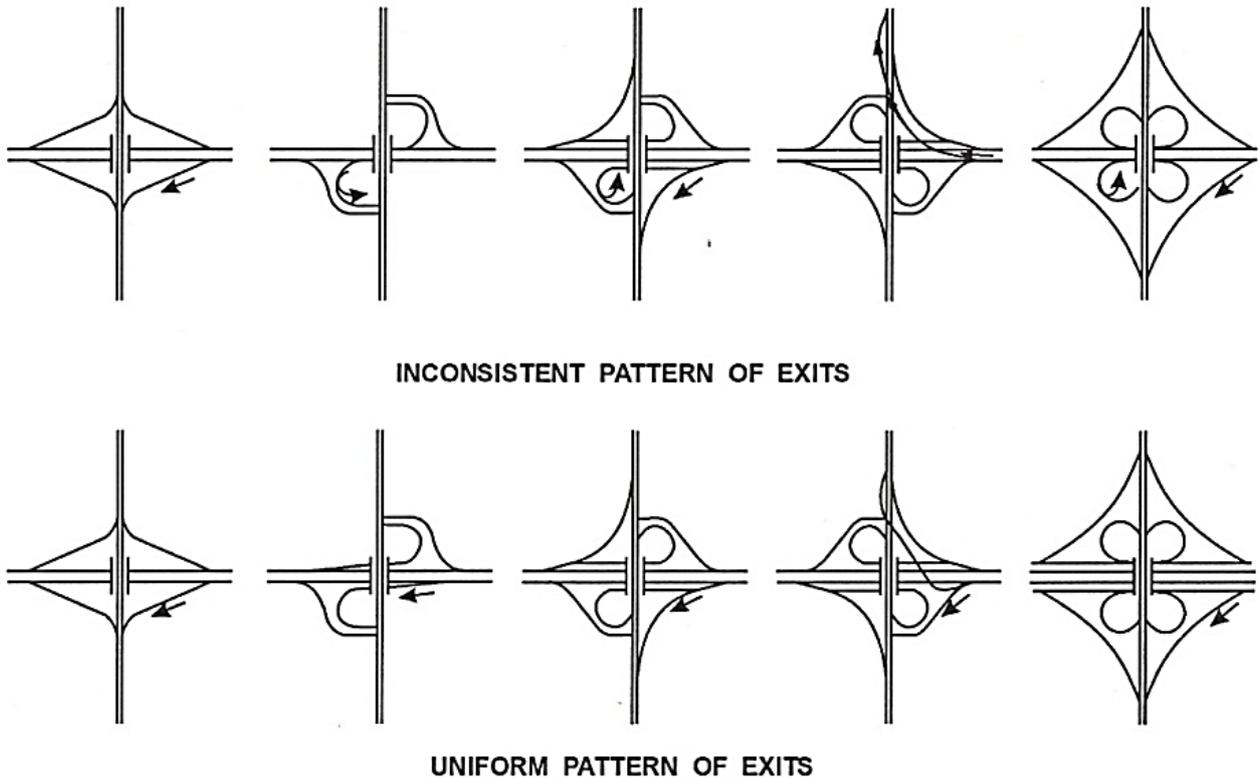


Source: Roads and Maritime Services (2017).

6.3.2 Consistency of Interchange Form

Driver perception of the ease of negotiating interchanges from both the major and minor roads is an important factor in efficiency of operation and the safety of the network. This can be achieved through the use of a consistent form of interchange, but it is also achieved by a consistent approach to the placement and signing of ramps. For example, drivers expect to exit to the left and they expect the ramp to start in advance of the grade separation structure. If this feature is incorporated regardless of the form of the interchange beyond the exit, consistency will have been achieved. This is illustrated in Figure 6.5. A similar approach should be taken for entrance ramps.

Figure 6.5: Consistency in design – uniformity of exit treatment



Source: Adapted from American Association of State Highway and Transportation Officials (AASHTO) (2011).

6.3.3 Route Continuity and Consistency

An important element of consistency is route continuity. Drivers expect to travel a designated (i.e. numbered and/or named) route in a directional path and for it to be treated as a through route. They expect to be able to adopt consistent behaviour throughout the route.

Route continuity simplifies the driving task by:

- reducing lane changes
- simplifying signing
- delineating the through route
- reducing a driver's search for directional signing.

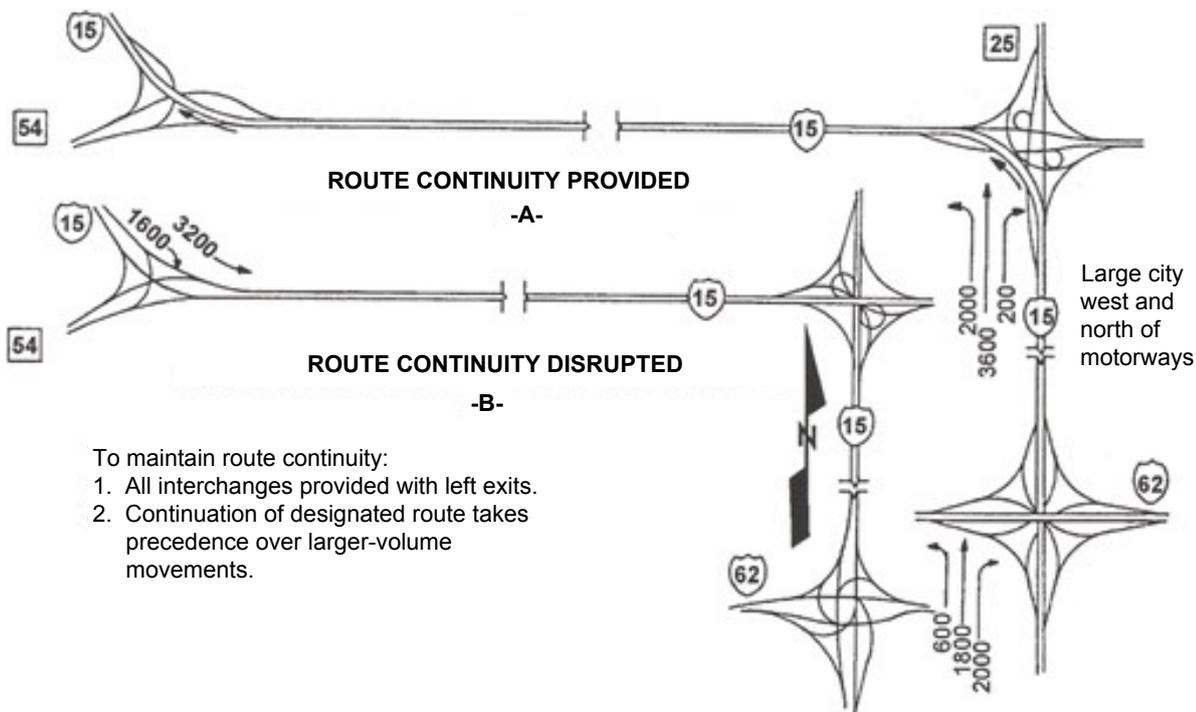
Where routes pass through cities, interchange configurations may favour the through route, rather than the direction of the heavy movements.

Figure 6.6 illustrates a hypothetical example of this concept where it is desired to provide route continuity between a city to the south and another city located west and north of the motorways. Given this requirement, the preferred design (diagram A) is to align the motorway within the interchanges so that the desired traffic movements travel on a continuous route (i.e. are the through movement). For a driver of the designated route, all traffic enters and exits on the driver's left.

However, route continuity must be considered in the context of the overall operational needs of an interchange, such as accommodating high-volume movements. In Figure 6.6, diagram A provides the largest volume movement (i.e. 3600 vehicles travelling northbound) with a flat curve and a reasonably direct connection. This heavy movement may also be supplemented with auxiliary lanes to achieve the operational equivalent of a through movement.

Diagram B shows a less preferable design where route continuity is disrupted because traffic travelling on Route 15 must use ramps rather than following a continuous motorway alignment.

Figure 6.6: Consistency in design – interchange forms to maintain route continuity



Source: Adapted from AASHTO (2011).

6.4 Road Space Allocation and Lane Management

6.4.1 General

Road space allocation at rural and urban interchanges primarily involves the allocation of lanes for through movements and turning movements. Road space allocation is readily determined in most rural situations but can be an issue at urban interchanges where space is limited, traffic demand is high and specific provision may be required for some road user groups. In situations where insufficient space is available to satisfy all demands, it is necessary for road agencies to determine the most appropriate distribution of the available space depending on the transportation and traffic objectives and strategies for the road network or corridor.

A NOP can be used to guide the suitable allocation of road space and lanes on interchanges.

The allocation of road space for particular users is managed through the use of road markings and signs. Depending on the nature of the facility, signage may be located beside the road or overhead, and may be static or variable.

For further guidance, refer to *Part 4* of the *Guide to Road Design* and *Part 10* of the *Guide to Traffic Management* (Austroads 2017a, 2016d).

Special user groups that may have to be accommodated include:

- high occupancy vehicles
- public transport
- pedestrians, including people with disability or mobility difficulty
- cyclists.

6.4.2 High-Occupancy Vehicle Lanes

As the traffic demand on a major road increases, the capacity of the road, in terms of the number of people carried, can be increased by the use of high-occupancy vehicle lanes (or transit lanes, under the Australian Road Rules and the NZ Land Transport Rules). These are lanes set aside for the exclusive use of high-occupancy vehicles such as buses and cars carrying at least a specified number of occupants. They may be developed by using an existing lane or a lane specially constructed for the purpose (*Part 5* of the *Guide to Traffic Management*, Austroads 2014b).

A high-occupancy vehicle lane may be provided on a freeway/motorway and, in relation to an interchange:

- in conjunction with a ramp meter to allow multi-occupant vehicles to bypass the meter, thereby giving them priority of access to the freeway/motorway and savings in travel time
- on exit ramps and at ramp terminals to give priority to high occupancy vehicles leaving the freeway/motorway.

Buses are normally permitted to use high occupancy vehicle lanes. It may be permissible to also allow trucks to use a bypass lane at a ramp meter under appropriate circumstances (Section 6.9).

The geometric design of lanes is addressed in *Part 3* of the *Guide to Road Design* (Austroads 2016e).

To be effective a high occupancy vehicle lane must be well signed, marked and enforced.

Where a toll applies to a motorway it may be desired to have a different toll apply to a high occupancy vehicle lane in order to support transportation objectives and strategies. These lanes may be referred to as high occupancy toll lanes.

6.4.3 Integration of Public Transport

It is often necessary to integrate facilities for public transport into interchange layouts. This may include:

- a busway on the freeway/motorway
- light rail (or, less commonly, heavy rail) in the freeway/motorway reservation
- bus lanes on ramps, the freeway/motorway or the intersecting arterial road
- separate busway terminal intersections
- a modal interchange to provide efficient passenger transfer between public transport services on the arterial road and the freeway/motorway
- indented bus bays
- bus stops within traffic islands
- special signal phases and priority measures.

Where a busway is located in the median of a motorway, it may be necessary to provide separate ramps that intersect directly with overpasses and/or underpasses of the motorway. Passenger access to or from public transport stops (for bus, light rail or heavy rail) in the median of a motorway must be grade-separated and stops therefore are most likely to be situated within an interchange. The design of a modal interchange should enable passengers to transfer efficiently and safely to and from services on an intersecting arterial road.

On some urban motorways, provision may be made for express buses to leave and re-enter the motorway via normal ramps at interchanges, in which case it is generally preferable that the buses use the left lane or the left shoulder.

At diamond interchanges, bus stops should be located near the ramp terminals either in an indented bay on the entry ramp or within the left-turn islands at the exit and entry ramp terminals. At other interchange types, provision for bus movements may be more complex. At some interchanges, a bus route may leave the motorway and continue by way of the arterial road system. The need for bus priority signal phasing (passive, active or pre-emptive) at ramp terminal intersections should also be considered. For further guidance on bus priority at traffic signals, refer to *Part 9* of the *Guide to Traffic Management* (Austroads 2016c).

6.4.4 Pedestrians and Cyclists

General

Pedestrians are generally prohibited from travelling along freeways/motorway and cyclists may also be prohibited depending on the jurisdiction and location¹¹. Where prohibitions are in force, separate facilities that provide an equivalent level of service may be provided parallel to freeways or motorways, particularly in urban areas. At interchanges, it is essential that facilities are provided to enable pedestrians and cyclists to cross and travel along the intersecting arterial or local road in a safe and convenient manner.

Pedestrians

Where pedestrians need to cross from one side of an interchange to the other, it is essential that they are able to do so in a convenient and safe way. Interaction between future land uses on both sides of the motorway should be examined to ensure that the intersecting road (e.g. bridge over motorway) has adequate provision to meet future pedestrian demand. Fences and barriers should be provided to ensure the safety of pedestrians and on some bridges it may be necessary to erect screens to prevent objects from being dropped onto the motorway.

Footpath crossings at ramp terminals should be suitable for pedestrians with disability and/or mobility difficulty to cross the intersecting road and the motorway ramps. Where traffic signals are provided, the design should incorporate appropriate pedestrian signal phases, tactile paving, footpaths and crossings within the channelisation.

Details of pedestrian crossings are provided in *Part 4* of the *Guide to Road Design* (Austroads 2017a) and AS 1742.10.

¹¹ Pedestrian and cyclist use of motorways in NZ is restricted by the Transit NZ Act.

Cyclists

Where cyclists are permitted to travel on roads that have interchanges (freeways, motorways or arterial roads), they should be provided with safe and convenient facilities, such as wide shoulders that have smooth, clean surfaces suitable for cycling. Cyclist access to freeways or motorways will often be prohibited due to:

- the difficulties and hazards associated with high-speed and high-volume traffic environments
- geometric features that are not conducive to safe cycling (e.g. narrow shoulders)
- use of shoulders for other purposes (e.g. public transport)
- the inherent danger associated with cyclists attempting to cross high-volume ramps at the nose (even if directed to use other routes), particularly two-lane exits.

It is important that the interchange design provides continuity of the bicycle route through the interchange and for the safe and convenient movement of cyclists across ramps and the intersecting arterial road. General issues relating to cyclists are summarised in Table 2.12 and some of them will relate to interchanges between freeways/motorway and intersecting roads.

At interchanges the route to be taken by cyclists should be established and signed on the following basis:

- Where it can be established that sufficient gaps will occur in the motorised traffic flow along ramps to enable cyclists to cross safely, then the route shown in Figure 6.7(a) should be encouraged.
- If calculations or site observations confirm that insufficient gaps will exist in the flow of motor vehicles using the ramp, cyclists should be directed to use the route shown in Figure 6.7(b).
- At freeway/motorway ramps where a significant number of cyclists have to cross through a large volume of motor vehicles, delays to cyclists may be excessive, causing them to either take unreasonable risks or use an alternative route. In these instances, consideration may be given to providing cyclists with a grade separation of the ramps. The treatment may link to the motorway shoulder or to a shared use path that is located parallel to an urban motorway close to the shoulder.

Further guidance on provision for cyclists at interchange ramps is provided in Commentary 22.

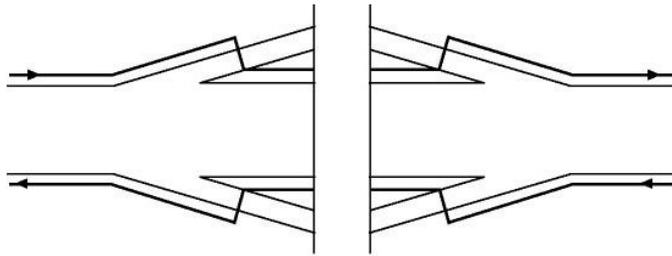
[\[see Commentary 22\]](#)

Treatments that may be used if it is desired to formalise an at-grade crossing of a freeway/motorway ramp are provided in *Part 4C* of the *Guide to Road Design* (Austroads 2015b). Where cyclists are permitted to cross motorway ramps in the vicinity of the noses at motorway interchanges, it is generally not necessary or desirable provide a channelised crossing. However, in such cases signing should be installed to direct cyclists to the appropriate crossing location (i.e. to cross the ramp at right-angles near the nose).

Existing and/or proposed land uses should be considered in determining the need for and nature of pedestrian/cyclist overpasses or underpasses in the vicinity of interchanges. For example, a shared use path may be required on a freeway/motorway overpass, or an underpass of an intersecting road may be required to provide continuity of a shared use path.

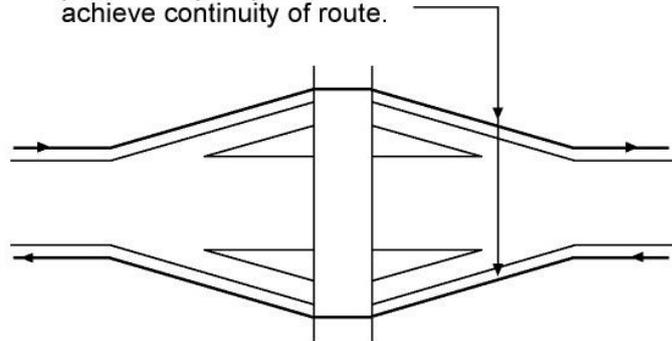
Some less conventional intersection designs aimed at minimising conflicts are discussed in Commentary 6.

Figure 6.7: Bicycle routes through interchanges



(a) Cyclists path through interchange when crossing ramps

NOTE: At half diamond interchanges provide bicycle paths to achieve continuity of route.



(b) Cyclists path through interchange avoiding need to cross ramps

6.5 Interchange Forms

6.5.1 General Categories

In selecting the appropriate form of interchange, consideration should be given to level of service for all relevant road users (drivers, pedestrians, cyclists, heavy vehicle operators) as well as maintaining the operational capacity under the predicted demand conditions. Topography, site constraints and many other considerations may also affect the type that is adopted.

Interchanges broadly fall into two categories:

- 'system interchanges' – those which provide for free flow between major roads, usually between two freeways/motorways or major rural highways.
- 'service interchanges' – those which provide connections between a freeway/motorway and an arterial or local road, or between two arterial roads.

6.5.2 System Interchanges

System interchanges provide for free flow on all ramps. All movements between the intersecting roads occur as diverges and merges with no at-grade crossings within the interchange. However, system interchanges between major rural roads may provide at-grade terminals for minor turning movements, and direct, semi-direct, or loop ramps for major turning movements.

A significant amount of lane changing often occurs within system interchanges and the layout should be designed to minimise this, but not to the detriment of route continuity and consistency considerations (Section 6.3).

System interchanges are large, complex and expensive, especially if provision is made for all possible movements. In the extreme case, where all turning volumes are so heavy that direct connections are required for them all, a four level interchange is required.

Traffic management issues that may arise in designing these complex interchanges include:

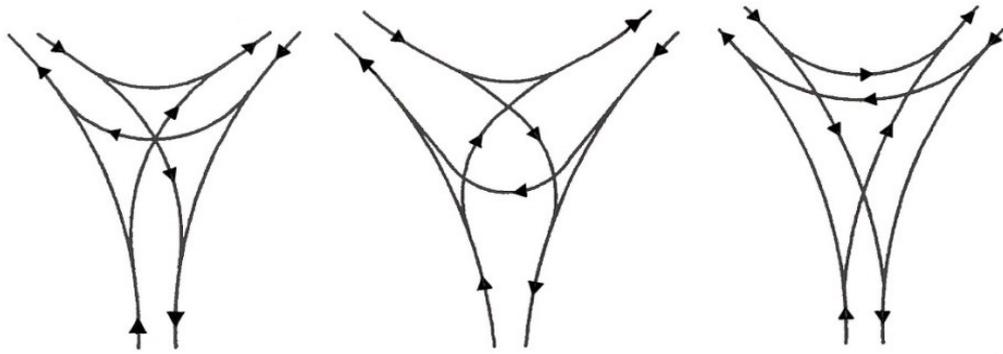
- management of the speed of vehicles using ramps that have a lower design standard than the freeway/motorway
- inferior operating conditions on relatively short weaving sections within some forms of interchange (e.g. urban clover leaf)
- management of slow vehicles along ramp connections
- effectiveness of signing the approaches to complex interchanges and the road elements within them.

Typical system interchanges are shown in Figure 6.8 (three legs) and Figure 6.9 (four legs). Common types include:

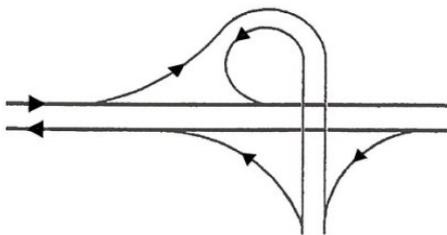
- Y
- T (Trumpet)
- stacked four-legged
- clover leaf.

Motorway to motorway interchanges in rural areas are relatively rare in Australia and New Zealand but an all-directional system interchange may be appropriate if traffic turning volumes are high. A combination of direct, semi-direct and loop ramps may be appropriate where turning volumes are high for some movements and low for others. It is desirable that loop ramps be arranged so that a weaving section will not occur.

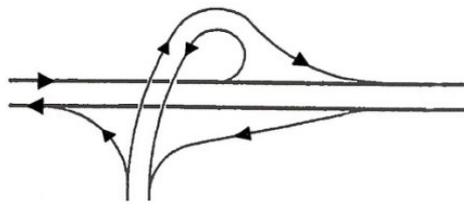
Figure 6.8: Typical system interchanges with free-flow ramps (three legs)



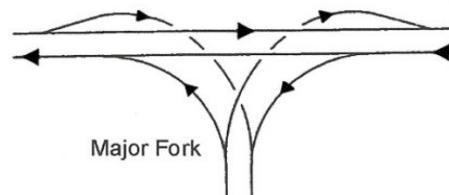
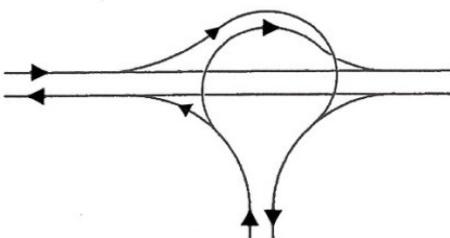
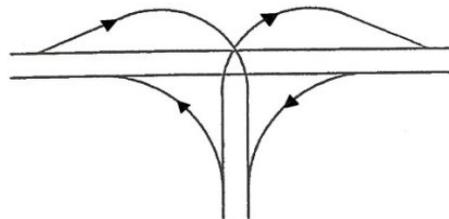
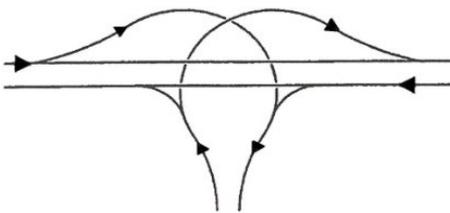
Y-Interchanges with Direct Connections to Legs



Trumpet Type A

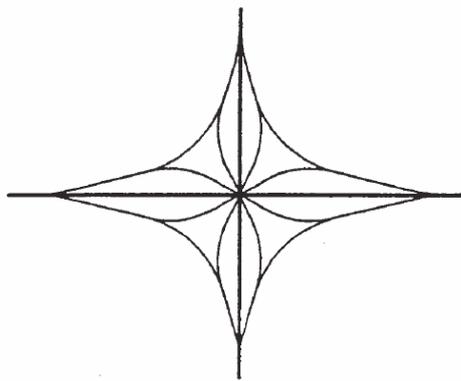


Trumpet Type B

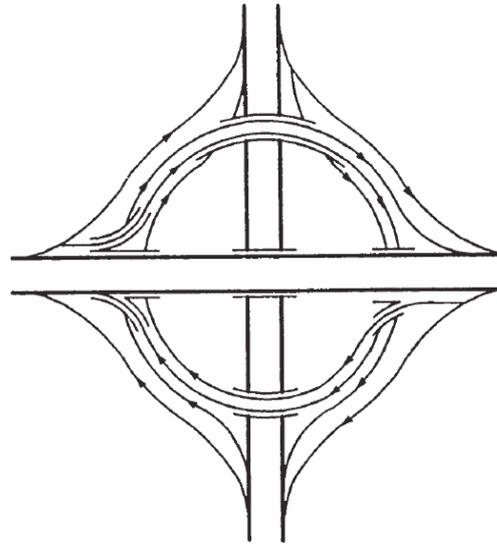


Major Fork

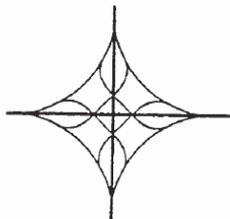
Figure 6.9: Typical system interchanges with free-flow ramps (four legs)



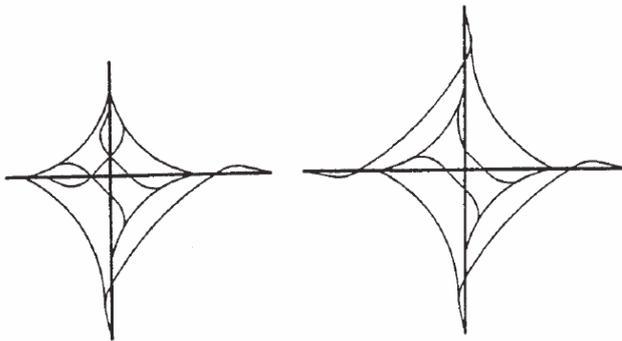
The Basic Stack



The Turbine Interchange

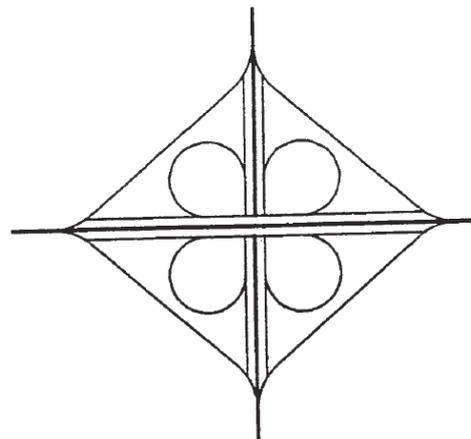


Basic Open Stack

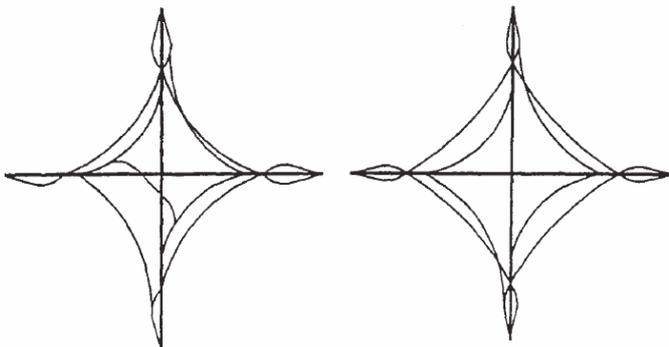


Open Stack
(1 inner ramp)

Open Stack
(2 inner ramps)



Cloverleaf with Two Sets of
Collector-Distributor Roads



Open Stack
(3 inner ramps)

Open Stack
(4 inner ramps)

6.5.3 Service Interchanges

A service interchange is an interchange between:

- a freeway/motorway and an arterial road
- a freeway/motorway and a local road
- two arterial roads.

These interchanges are characterised by ramps ending in at-grade intersections, which may be controlled by regulatory signs, traffic signals or roundabouts. Signs are most common in rural areas, with roundabouts being provided in special circumstances. Traffic signals are the most common form of control in urban areas. The intersections should be designed in accordance with *Parts 4, 4A, 4B and 4C* of the *Guide to Road Design* (Austroads 2017a, 2017b, 2015c, 2015b). The selection of the appropriate intersection type at the end of ramps should follow a similar process to that outlined in Section 2.3.2, including consideration of relevant Safe System and network performance objectives, site specific considerations and constraints. It is particularly important that vulnerable users who are likely to use an intersection at a service interchange are identified and the form of intersection meets their needs safely.

In urban situations, service interchanges should not be located close to an intersection on the intersecting road, as operational and safety issues may arise if queues from a signalised intersection interfere with the operation of the interchange.

In rural and urban areas, local traffic movements from an unsignalised intersection near an interchange may be at risk if the design allows traffic to exit from ramps into the intersecting road at high-speed. Ramp terminals should be designed to control the speed at which traffic from the ramps can enter a normal arterial road.

It is also desirable that driveways to individual properties and developments are not provided on the intersecting road near interchanges because of the inconvenience and reduced safety for people using the driveways and the interference to traffic moving to and from the ramps. Interchange planning and design should ensure that alternative access is provided.

Typical service interchanges include the following types:

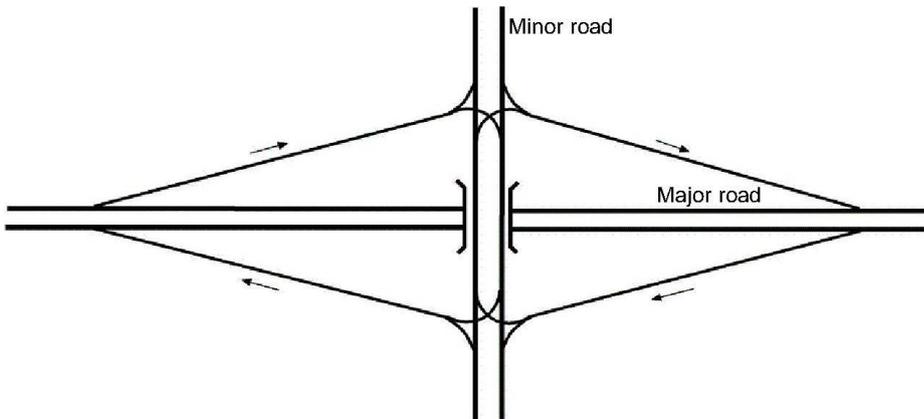
- diamond interchange
 - conventional diamond (Figure 6.10)
 - spread diamond (Figure 6.11)
 - closed diamond (Figure 6.12)
 - half diamond (Figure 6.13)
 - split diamond (Figure 6.14)
 - diamond with roundabout terminals (Figure 6.15)
- grade separated roundabout (Figure 6.16)
- single point urban interchange: fast diamond (Figure 6.17)
- parclo (partial cloverleaf, i.e. has loop ramps)
 - parclo A (Figure 6.18)
 - parclo A4 (Figure 6.19)
 - parclo B (Figure 6.20)
 - parclo B4 (Figure 6.21)
 - parclo A–B (Figure 6.22)
- three level diamond (Figure 6.23)
- three level diamond with single point intersection (Figure 6.24).

Information on some innovative interchange forms that have been recently implemented or are in the process of being implemented (e.g. Tennis ball interchange in WA and diverging diamond interchange in Queensland) is provided in Commentary 6.

6.5.4 Characteristics of Service Interchange Types

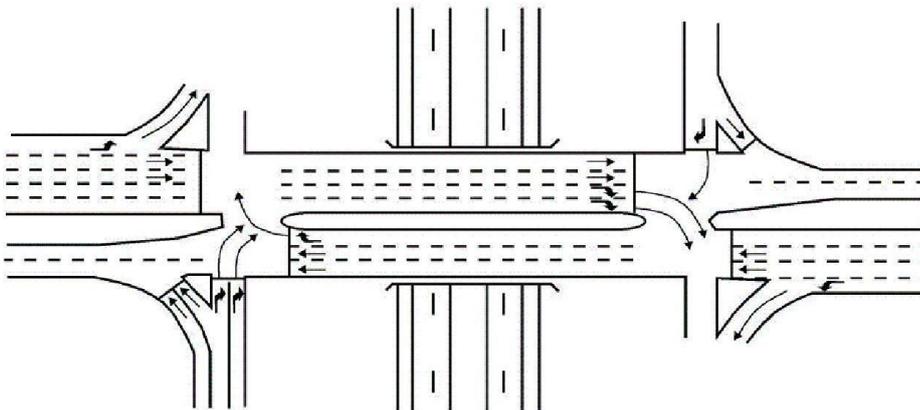
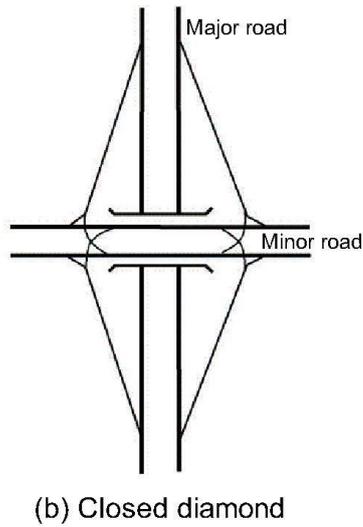
Different types of service interchanges are presented in this section (Figure 6.10 to Figure 6.24), together with a brief description and a summary of the advantages and disadvantages of each type. Figure 6.10 illustrates the conventional diamond interchange that is the most common form of interchange. The advantages and disadvantages of the conventional diamond also apply to the variations of the diamond interchange shown in Figure 6.11 to Figure 6.15. The advantages and disadvantages associated with Figure 6.11 to Figure 6.15 are peculiar to that form of diamond interchange.

Figure 6.10: Conventional diamond interchange



General comment	Advantages	Disadvantages
<ul style="list-style-type: none"> The conventional diamond is the most common form of service interchange. Variations are spread diamond (Figure 6.11), with ramps a significant distance apart, and closed diamond (Figure 6.12), with ramp terminals relatively close to the major road alignment. 	<ul style="list-style-type: none"> 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 exiting traffic and the acceleration of entering traffic. Single exit feature simplifies major road signing. There is no need for speed change lanes on or under the structure (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. 	<ul style="list-style-type: none"> Results in conflicting movements on the minor road 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 required to stop or give way. There is little possibility of allowing for future expansion of the interchange, but increased volumes may be handled by channelisation and/or signalisation of the ramp terminals.

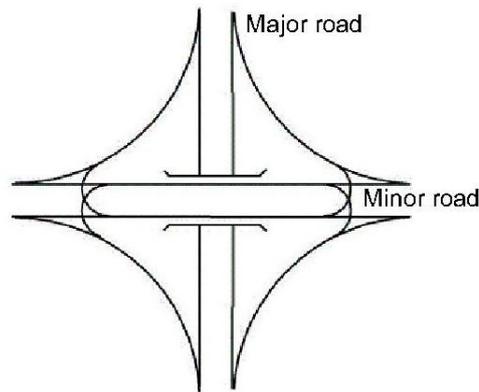
Figure 6.11: Spread diamond interchange



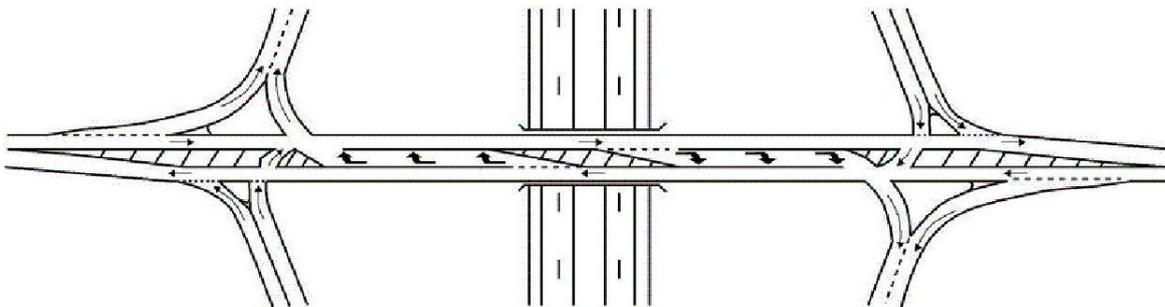
Detail for (b)

General comment	Advantages	Disadvantages
<ul style="list-style-type: none"> • 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. 	<ul style="list-style-type: none"> • Has smaller land requirements than conventional or spread diamond. 	<ul style="list-style-type: none"> • Effectiveness may be limited by 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.

Figure 6.12: Closed diamond interchange



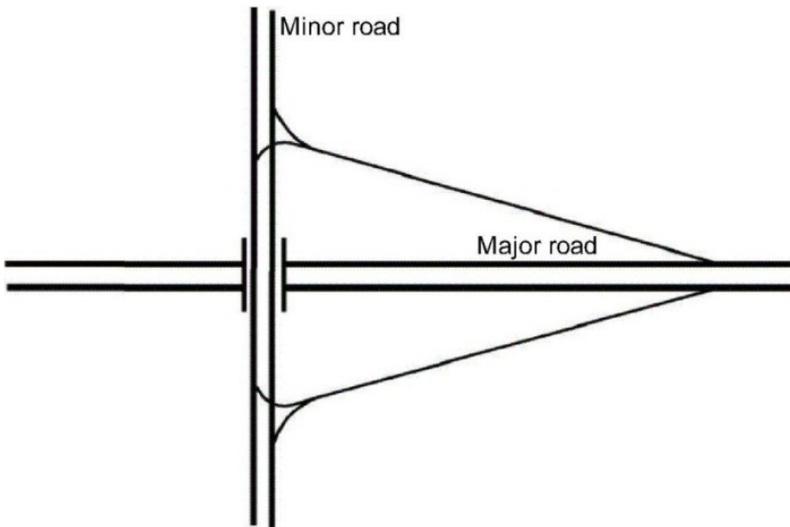
(a) Spread diamond



Detail for (a)

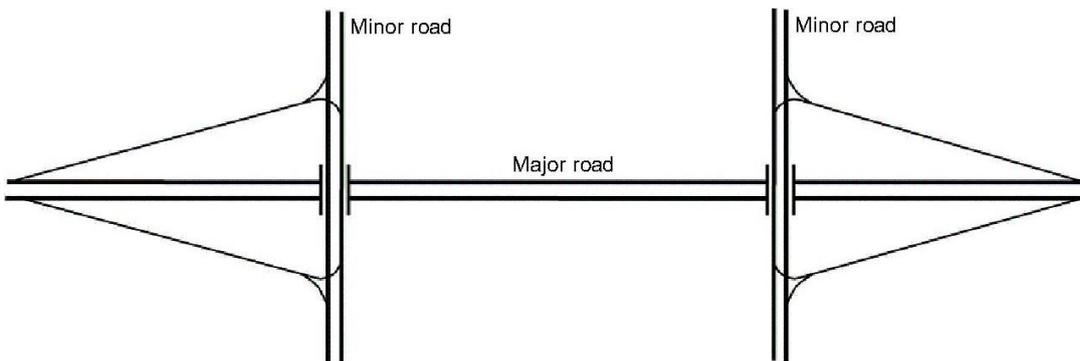
General comment	Advantages	Disadvantages
<ul style="list-style-type: none"> • The spread diamond is the most common type in rural areas. • Typically, ramp terminals about 500 m apart along minor road, terminals being 250 m either side of major road centreline, to meet SISD requirements. 	<ul style="list-style-type: none"> • Where intersecting road is taken over the major road, usually requires only one bridge. • Compared with closed diamond (Figure 6.12): <ul style="list-style-type: none"> - has smaller embankments and lower earthwork costs - right-turn lanes are on embankment rather than bridge, reducing costs. • Unlikely to require additional measures to address sight distance issues, compared to closed diamond interchanges. 	<ul style="list-style-type: none"> • Requires more land than conventional or closed diamond, so not as applicable in urban areas as in rural areas.

Figure 6.13: Half diamond interchange



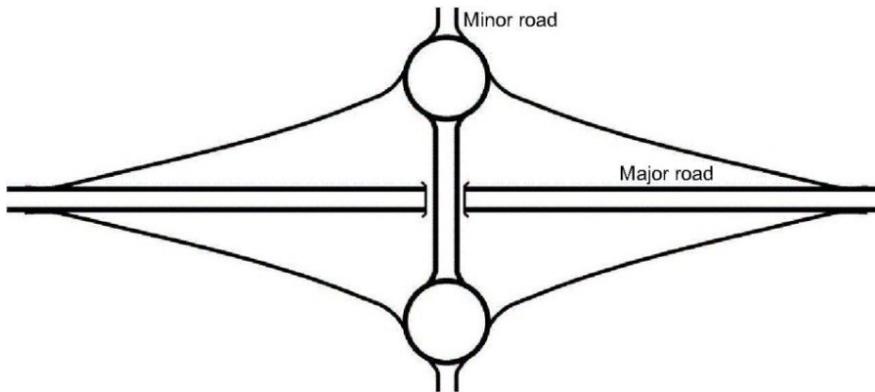
General comment	Advantages	Disadvantages
<ul style="list-style-type: none"> The half diamond provides entry to and exit from the major road on only one side of the intersecting road. 	<ul style="list-style-type: none"> Often used in urban areas where they can be appropriate because of close spacing of intersecting roads along a motorway. May also be appropriate because of network requirements and topography. Simpler intersections because of limited number of movements. 	<ul style="list-style-type: none"> 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.

Figure 6.14: Split diamond interchange



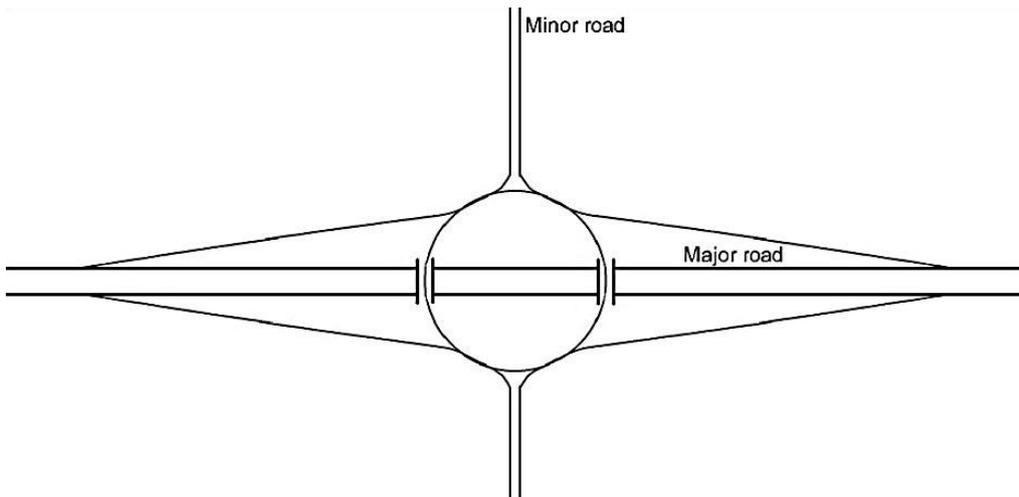
General comment	Advantages	Disadvantages
<ul style="list-style-type: none"> The split diamond is essentially two half diamonds a short distance apart, each providing entry to (and exit from) the major road in the opposite direction from the other. 	<ul style="list-style-type: none"> Provides the same advantages as half diamond but permits access to and from the major road in both directions. 	<ul style="list-style-type: none"> 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.

Figure 6.15: Diamond interchange with roundabout terminals ('spectacles' type)



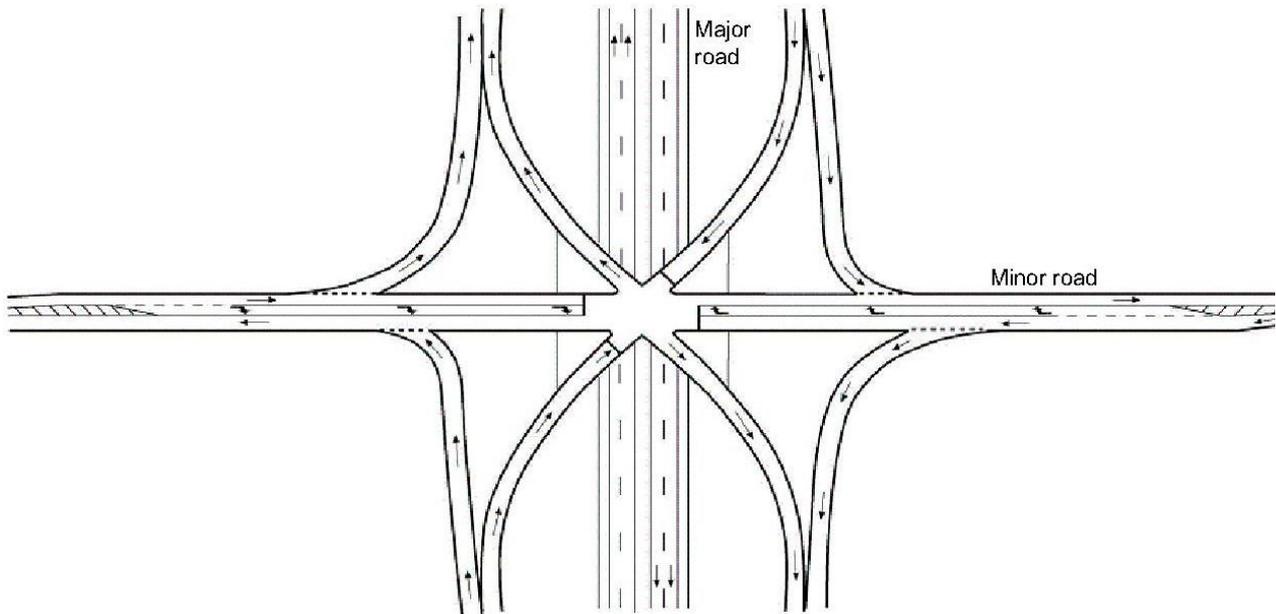
General comment	Advantages	Disadvantages
<ul style="list-style-type: none"> The intersections of the diamond ramps with the minor road are designed as roundabouts. 	<ul style="list-style-type: none"> With certain mixes of traffic volumes on its various elements, this form of interchange can provide fewer delays and a higher level of safety than alternatives. 	<ul style="list-style-type: none"> Requires the availability of sufficient space for its implementation.

Figure 6.16: Grade separated roundabout



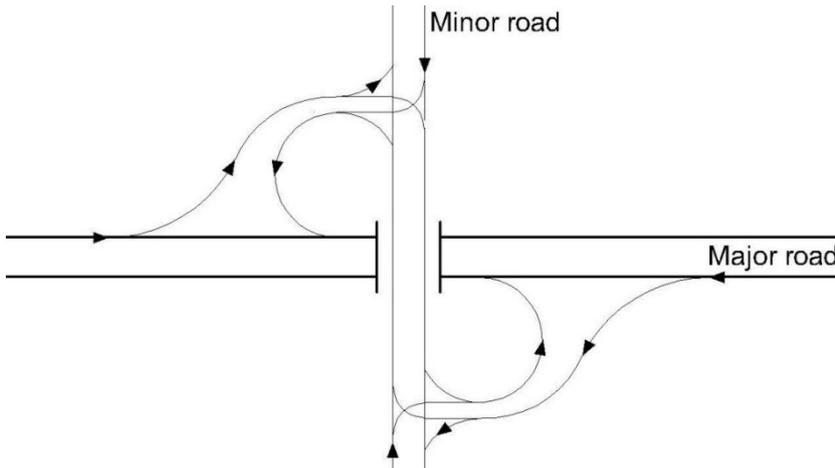
General comment	Advantages	Disadvantages
<ul style="list-style-type: none"> The grade separated roundabout is an alternative to the diamond interchange and is suitable for both urban and rural situations involving moderate requirements for capacity. The numbers of lanes at entries and exits are comparable to those in a diamond interchange with roundabout terminals. 	<ul style="list-style-type: none"> 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 exiting traffic and the acceleration of entering traffic. Single exit feature simplifies major road signing. No weaving occurs on the major road. Reduces possibility of wrong-way movements. Has lower average delay than for signalised diamond for low to moderately high traffic volumes. 	<ul style="list-style-type: none"> Is higher cost than conventional diamond – two overpasses or underpasses are required. Parapets could interrupt the sight line 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.

Figure 6.17: Single point urban interchange (fast diamond)



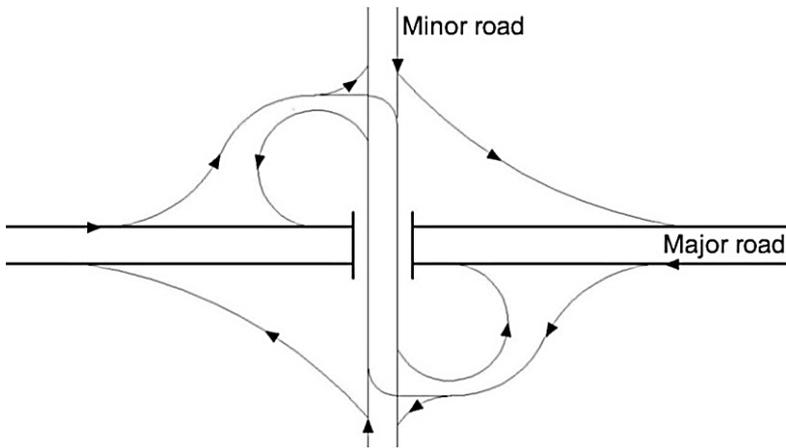
General comment	Advantages	Disadvantages
<ul style="list-style-type: none"> • The single point (or fast diamond) interchange normally is used only in urban areas. • All right-turns are simple diamond turns that do not overlap and pass near the centre of the interchange. • The minor road should have a minimum grade, so that trucks turning on larger than normal radius do not become unstable. 	<ul style="list-style-type: none"> • Requires less land than a conventional diamond (Figure 6.10) – can be advantageous where available land is severely restricted and capacity must be maximised. • The opposing right-turns do not cross each other's path, therefore eliminating a major source of conflict. • Reduced delay through the intersection since there is only one set of traffic signals. • The right-turns operate on larger radius curves and are therefore more efficient than at conventional intersections. • The operational efficiencies result in an interchange with higher capacity than the conventional diamond. • All turns are stored outside of the intersection (as opposed to between paired signals). 	<ul style="list-style-type: none"> • May have relatively high construction cost associated with the bridge – whether over or under, the size of the structure has to be large. • The length and geometry of the vehicle path through the intersection can lead to confusion if adequate guidance is not provided, particularly where the intersecting road is on a curve. Guidance is required such as painted lines, raised median, airport runway lights flush with the pavement within the ramp terminal intersection. • The potential relative speeds of the vehicles are increased. • If the intersecting roadways are on a skew, the length of structures required may become excessive, clearance distances are increased and sight distance can be adversely affected. • It is not possible to provide for the through movement from an exit ramp to an entry ramp, an aspect that may be important for transit bus operation. • Higher-speed right-turns from ramps may be hazardous unless the design provides good sight distances and delineation of turning lanes. • There is a possibility of wrong-way movements if no median is provided on the minor road.

Figure 6.18: Parclo A

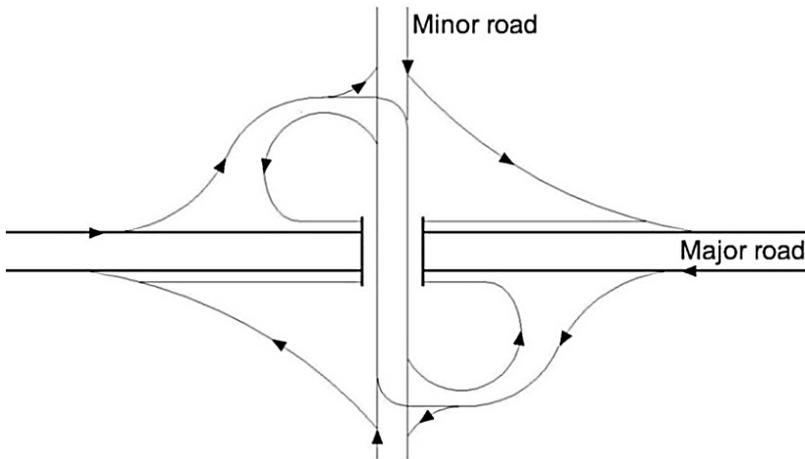


General comment	Advantages	Disadvantages
<ul style="list-style-type: none"> • Parclo (partial cloverleaf) interchanges provide some of the advantages of a full cloverleaf without requiring so much land. • The Parclo A has loop ramps in only two quadrants, each being in advance of the overpass structure. 	<ul style="list-style-type: none"> • Appropriate where land is not available in one or two quadrants or where two movements are large compared to the others and grade separation would provide superior operation. • May be used to achieve greater ramp spacing between adjacent interchanges. 	<ul style="list-style-type: none"> • Having ramps in only two quadrants, drivers cannot make a direct left-turn from the minor road onto the major road, but must turn right off the minor road onto the ramp in order to achieve the desired direction change. • Intersecting right-turns occur at both intersections on the minor road. • The loops constitute a low-speed element and this can result in safety issues due to the large speed decrement, particularly with respect to heavy vehicle stability. • Drivers turning left or right from the minor road are required to turn in the opposite direction to that which is intuitively expected. This may lead to drivers who are not familiar with the road choosing the incorrect lane on the approach to the turn.

Figure 6.19: Parclo A4



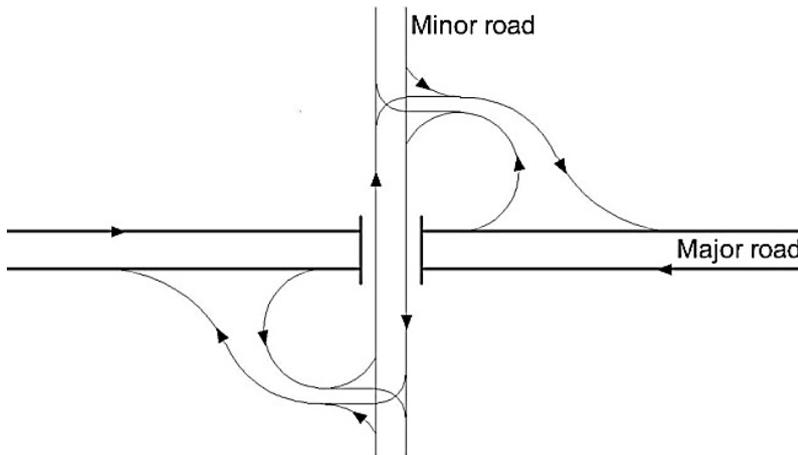
(a) Without collector roads



(b) With collector roads

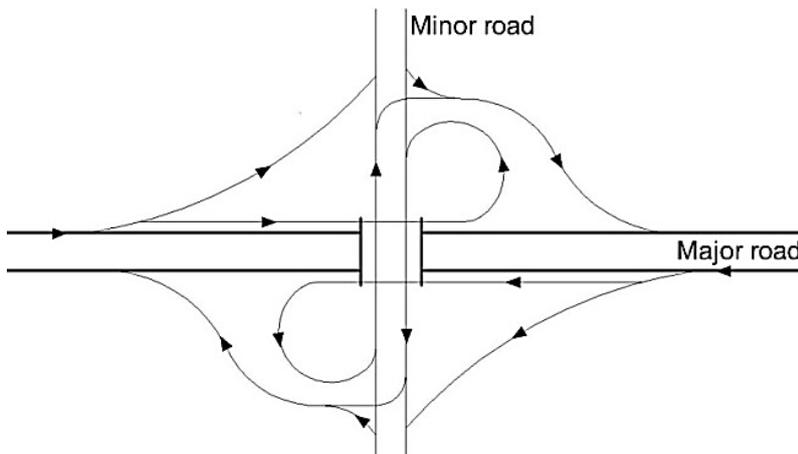
General comment	Advantages	Disadvantages
<ul style="list-style-type: none"> The Parclo A4 has ramps (in advance of the overpass structure) in all four quadrants, allowing all movements from the minor road to be free flow. The final part of each on-ramp may be shared by the direct and loop movements, Figure 6.19(b), to provide a single entrance to the major road. 	<ul style="list-style-type: none"> Single exit feature simplifies major road signing. No weaving occurs on the major road. Is not conducive to wrong-way movements. Depending on right-turn volumes, this is a high capacity interchange. 	<ul style="list-style-type: none"> The right-turn from the ramp to the minor road will require storage on the ramp and additional lanes may be required. Signals required on the minor road when the through and turning movements are high. Future expansion of the interchange cannot easily be achieved. Property and construction costs are higher than for a diamond interchange. The loop ramps constitute a low-speed element, this can result in safety issues due to the large speed decrement, particularly with respect to heavy vehicle stability. Drivers turning left or right from the minor road are required to turn in the opposite direction to that which is intuitively expected. This may lead to drivers who are not familiar with the road choosing the incorrect lane on the approach to the turn. Parclo A4 with collector roads, Figure 6.19(b), introduces additional merge conflict points.

Figure 6.20: Parclo B



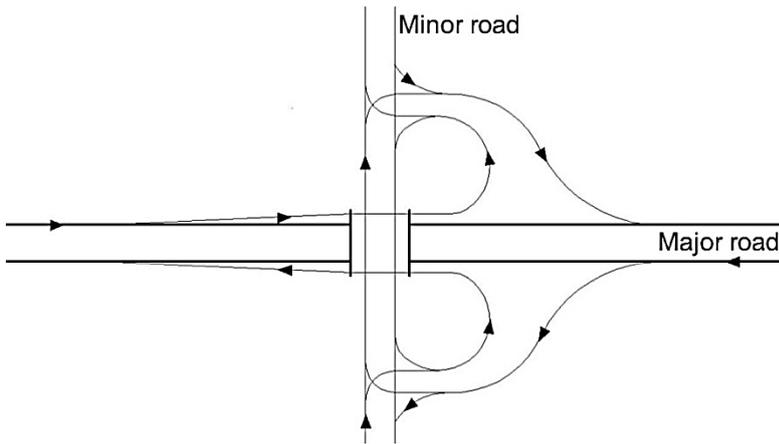
General comment	Advantages	Disadvantages
<ul style="list-style-type: none"> The Parclo B has loop ramps in only two quadrants, each being beyond the overpass structure. 	<ul style="list-style-type: none"> Similar advantages to those of Parclo A (Figure 6.18) in accommodating space restrictions and achieving greater ramp spacing between adjacent interchanges. Unlike Parclo A, permits direct left-turns from the major road and conventional right-turns from the minor road. 	<ul style="list-style-type: none"> Intersecting right-turns occur at both intersections on the minor road. The loops constitute a low-speed element with a high-speed approach and this can result in safety issues due to the large speed decrement, particularly with respect to heavy vehicle stability. Adequate sight distance to the loops is essential and advance signing desirable.

Figure 6.21: Parclo B4



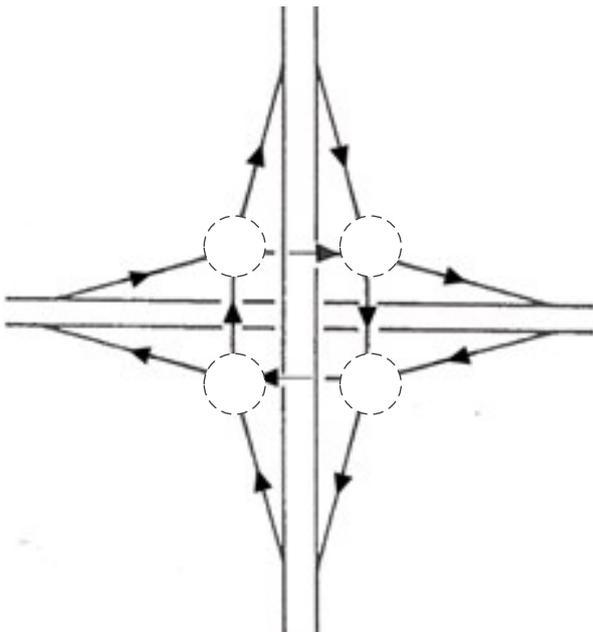
General comment	Advantages	Disadvantages
<ul style="list-style-type: none"> The Parclo B4 has loop ramps (beyond the overpass structure) in two quadrants and ramps in all four quadrants, allowing all movements from the major road (e.g. freeway) to the minor road to be free flow. Must have collector/distributor roads to ensure there is only one exit from the major road. 	<ul style="list-style-type: none"> Single exit feature simplifies signing and promotes consistency of operation. No weaving occurs on the major road. Is not conducive to wrong-way movements. Depending on right-turn movements, this is a high capacity interchange. 	<ul style="list-style-type: none"> Property and construction costs are higher than for a diamond interchange. Requires signals on the minor road when through and turning volumes are high (usually in urban areas). Right-turn movement from the minor road may require storage on or under the bridge between the ramp terminals. The loops constitute a low-speed element with a high-speed approach and this can result in safety issues due to the large speed decrement, particularly with respect to heavy vehicle stability. Adequate sight distance to the loops is essential and advance signing desirable.

Figure 6.22: Parclo A-B



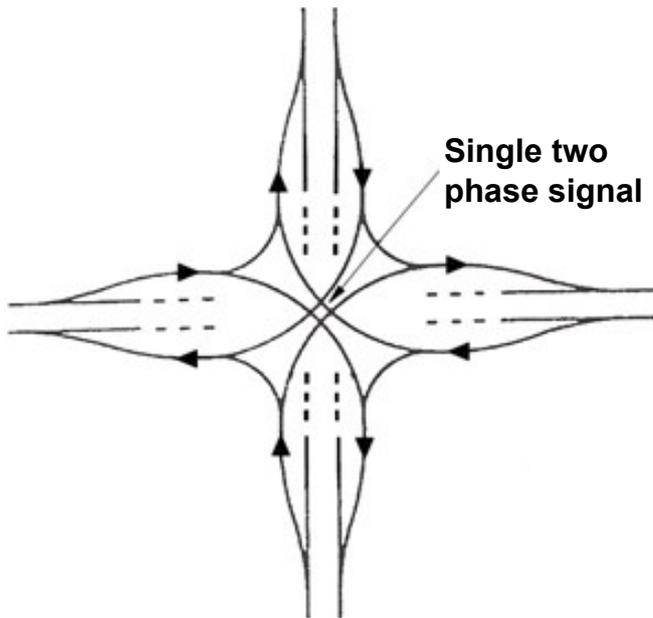
General comment	Advantages	Disadvantages
<ul style="list-style-type: none"> The Parclo A-B provides a combination of direct and loop ramps in each of two adjacent quadrants. 	<ul style="list-style-type: none"> Similar advantages to Parclo A and B, but suitable for use where land is available on only one side of the minor road. 	<ul style="list-style-type: none"> From the major road, the exit loop is approached on a long straight, requiring measures to ensure the loop is entered at an appropriate speed.

Figure 6.23: Three level diamond



General comment	Advantages	Disadvantages
<ul style="list-style-type: none"> The three level diamond provides for all turning movements to occur at signalised at-grade intersections (circled in Figure 6.23) separate from the two intersecting roads. It is also an appropriate type for a system interchange. 	<ul style="list-style-type: none"> Is of high capacity. Both intersecting roads are free of stop conditions. Uses high standard single exits and entrances. Is economical in property use compared to directional interchanges. Features single exits which simplify signing on both roads. No weaving is required. No need for speed change lanes on or under structures. 	<ul style="list-style-type: none"> Requires high construction costs with three structures and increased earthworks. Requires a complex coordinated signal installation.

Figure 6.24: Three level diamond – single point intersection



General comment	Advantages	Disadvantages
<ul style="list-style-type: none"> In this interchange form, the turning movements occur at a single intersection (see also the single point urban interchange, Figure 6.17). 	<ul style="list-style-type: none"> Is high capacity. Both intersecting roads are free of stop conditions. Uses high standard single exits and entrances. Is economical in property use compared to directional interchanges. Single exit feature simplifies signing on both roads. No weaving is required. No need for speed change lanes on or under structures is necessary. Requires only a single set of two-phase signals. 	<ul style="list-style-type: none"> Requires high construction costs because of the major bridges required over the intersection.

6.5.5 Interchange Selection Factors

The form of interchange that should be adopted is a function of a number of factors including:

- site conditions
- land availability
- safety
- forecast traffic volume for each traffic movement
- economic factors
- environmental factors (noise, visual impact, flora and fauna, heritage, cultural)
- staging of construction
- requirements for proposed or future mass transit systems
- high and/or wide load movements.

6.6 Ramp Layouts

6.6.1 General

The interchange of traffic between grade separated roads is accomplished by ramps. The type of ramp used is influenced by a range of factors including the volume and characteristics of traffic, the required operating speed, gradients, physical restrictions (including topography), and the angle of intersection of the highways. Possible free-flow left-and right turn movements are illustrated in Figure 6.25 and are outlined below:

- A **direct ramp** is one on which vehicles are at all times turning in the same direction as the overall change of direction ultimately achieved. They may cater exclusively for left or right turning movements. For example, turning 90° left through a continuous turn to the left, as in the 'Outer Connector' in Figure 6.25a). An exclusive right-turn movement can also be used to provide a direct right-turn connection, as per the 'Direct' ramp in Figure 6.25b).
- A **semi-direct ramp** is one on which vehicles are at some points turning in the opposite direction to and at other points turning in the same direction as the overall change of direction ultimately achieved (e.g. turning 90° right through a 45° turn to the left, followed by a 135° turn to the right, as in the 'Semi-direct A' in Figure 6.25b).
- A **loop ramp** is one on which vehicles are at all times turning in the opposite direction to the overall change of direction ultimately achieved (e.g. turning 90° right through a 270° turn to the left, as in the 'Loop' in Figure 6.25b).
- A **diagonal ramp** is similar to those used at diamond interchanges and require traffic to pass through an at-grade intersection.
- An **outer connector** provides the most direct left-turn connection between two roadways.

System interchanges use only direct or semi-direct ramps, except where a minor movement can be safely accommodated at-grade within a rural interchange between two major roads. A direct or semi-direct ramp may also be used within service interchanges or to cater for a particularly heavy traffic movement at a major at-grade intersection. Extensive use is made of diagonal ramps at service interchanges.

The types of ramps and their use are summarised in Table 6.1. For further details of ramp types and selection considerations refer to Commentary 23 and Part 4C of the *Guide to Road Design* (Austroads 2015b).

[\[see Commentary 23\]](#)

Figure 6.25: Free-flow turn movements

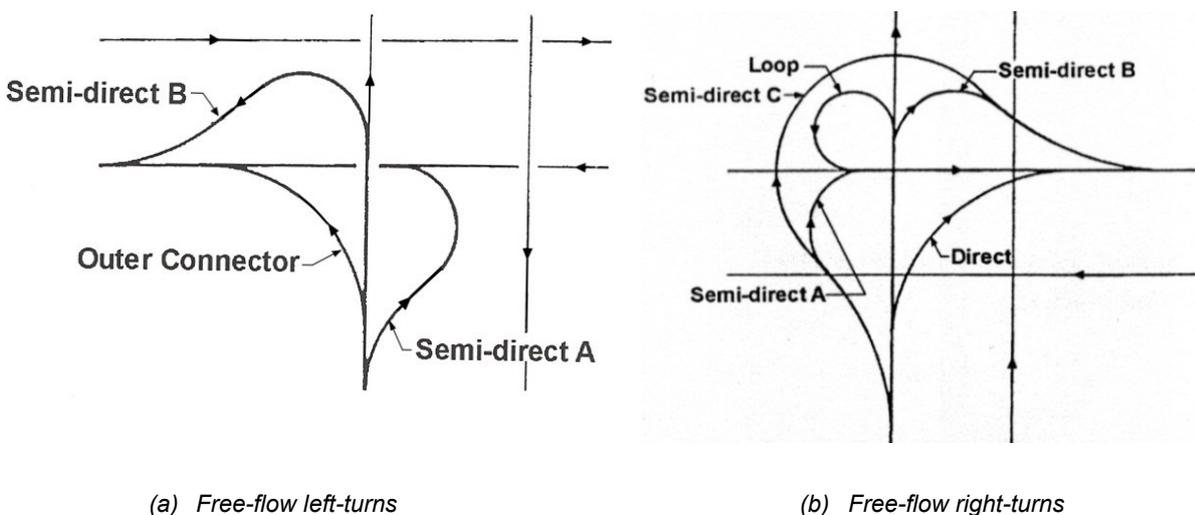


Table 6.1: Appropriate ramp treatments

Turning movement	Ramp type*	System interchange		Service interchange
		High turning volumes	Low turning volumes	
Left	Outer connector	Most desirable	Most desirable	Not appropriate
	Semi-direct A	Not preferred – right hand exit	Not preferred – right hand exit	Unsuitable
	Semi-direct B	Not preferred – forced right hand merge	Not preferred – forced right hand merge	Unsuitable
	Loop	Not suitable	Not suitable	Use only in constrained locations
	Diagonal	Not suitable	Not suitable	Common usage
Right	Direct	Major forks and branch connections	Generally not economical. Other types more suitable	Unsuitable
	Semi-direct A	Not preferred – forced right hand merge	Not preferred – forced right hand merge	Unsuitable
	Semi-direct B	Acceptable	Generally not economical	Unsuitable
	Semi-direct C	Desirable	Generally not economical	Generally not economical
	Loop	Use in constrained situations	Common usage	Use for moderate turning volumes
	Diagonal	Not suitable	Not suitable	Common usage

* See Figure 6.25 and for illustrations of ramp types.

6.6.2 Speed Management for Ramps

Direct, semi-direct and outer connectors

It is desirable that the design speed for direct ramps, semi-direct ramps and outer connectors with high-volume left-turn movements, is not substantially less than the design speed adopted for the motorway. Where this cannot be achieved it is recommended that:

- The 85th percentile speed of the ramp traffic should desirably be no less than the 85th percentile approach speed of the through road minus 10 km/h.
- Speed drops of more than 20 km/h should be adopted only where dictated by economic constraints and must be accompanied by treatments to reduce speed (Section 6.8.3).

Loop ramps

Loop ramps require drivers to travel through an angle up to 270° on a circular alignment and are generally used where ‘Parclo’ type interchanges provide an advantage (Section 6.5.3). They may provide for continuous traffic flow or lead to a terminal intersection where drivers are expected to stop or give way. The speed of traffic on the approach to the loop must be carefully managed through design and traffic management, as heavy vehicle stability can be an issue on loop ramps. Further, the lower speed at which drivers negotiate the loop requires significant deceleration distance prior to the ramp and significant acceleration distance after the ramp in cases where continuous traffic flow is intended. It is essential that drivers have good sight distance to the start of the loop.

Diagonal ramps

On exit diagonal ramps, the 85th percentile speed prior to the intersection should be limited to 60 km/h or less. This can be achieved by the treatments described in Section 6.8.3.

6.6.3 Lane Numbers

At the intersecting road

Where a ramp forms an at-grade intersection with the intersecting road, the ramp usually will require two or more lanes at the terminal, depending on the traffic capacity or operation required. (*Part 3 of the Guide to Traffic Management, Austroads 2013*). Additional lanes may be added to:

- off-ramps to meet capacity requirements on approaches to at-grade terminal intersections
- on-ramps to accommodate multiple turning lanes from the intersecting road
- on-ramps to provide a bypass of ramp meters.

At the nose

The number of lanes required adjacent to ramp noses depends on the volume of traffic entering or leaving a freeway/motorway. Traffic analysis is recommended in assessing the number of lanes required on ramps and the level of service at merge and diverge areas (*Transportation Research Board 2016*).

However, Table 6.2 can be used as a guide to the number of lanes required at, and just beyond, the nose. The table is based on design hour volumes that represent an acceptable level of service. The capacity of ramps is addressed in *Transportation Research Board (2016)*.

Table 6.2: Warrants for lanes on ramps

Ramp description	Criteria for provision
Single-lane ramp	DHV < 1000 pcu/h
Single-lane loop	DHV < 900 pcu/h and indirect connection acceptable
Single-lane at nose, two lanes on ramp	1000 < DHV < 1800 pcu/h
Two lanes at nose, two lanes on ramp	DHV > 1800 pcu/h

Notes:

DHV denotes Design Hour Volume.

pcu/h denotes passenger car units per hour.

Free-flow turning roadways

Free-flow turning roadways (direct or semi-direct ramps) should normally have two-lane operation, with provision for emergency stopping, unless the expected volume exceeds the capacity of two through lanes, in which case a three-lane ramp should be provided. Entry and exit ramps may be one lane or two lanes at the nose, depending on traffic volumes. Two lanes may be necessary to enable overtaking of slower drivers and this is often the subject of traffic analysis.

Entry ramps

Where an entry ramp with a single-lane at the nose joins a motorway or major rural highway with an operating speed of 80 km/h or more, a second entry ramp lane should be provided when:

- the length of a single-lane ramp would exceed 300 m on a level grade, a significant number of trucks use the ramp and a truck accelerating from rest at the ramp terminal would not be expected to reach 50 km/h at the nose (*Commentary 24*)
- very long (> 600 m) ramps are provided as provision for overtaking is likely to be required over this length.

[\[see Commentary 24\]](#)

The ramp length is measured from the edge of the intersecting roadway to the ramp nose or between ramp noses in the case of free-flow ramps.

Two-lane ramps with a single-lane at the nose are effectively one-lane ramps with provision for overtaking. It is therefore not necessary to have full shoulder widths on these ramps. A 1.0 m shoulder on each side to support the pavement may be sufficient provided that no provision for cyclists is planned.

If the design year traffic volumes require two lanes on the ramp, two alternative approaches may be taken:

- provide a single-lane at the nose and use the restricted capacity of this lane to control the volume of traffic entering the freeway/motorway
- provide a full two-lane entry with an added (auxiliary) lane on the freeway/motorway.

These ramps require the capacity of the two lanes and must therefore be provided with sufficient shoulder width to allow a stalled vehicle to be passed.

Exit ramps

As a guide, a single-lane at an exit ramp nose should be widened to two lanes when:

- a truck will exit at less than 50 km/h at the nose, and a significant number of trucks use the ramp
- the ramp is longer than 600 m as provision for overtaking is likely to be required over this length.

Shorter ramps may be widened for storage at the minor road intersection. Where two lanes are required at the nose to meet the traffic demand, the cross-section must allow space for a stalled vehicle to be passed, in addition to the full traffic lanes.

6.6.4 Access Control

Control of access (e.g. to driveways and local streets) in the vicinity of interchanges may be required to ensure operational efficiency of the interchange and the ramp terminal. Factors to be considered include:

- existing and future development in the vicinity of the interchange
- intersection design at the ramp terminals
- provision for pedestrians/cyclists
- costs involved in prohibiting abutting access
- the status of the road involved.

Complete control of access must be enforced over the full length of all ramps in the interchange. No driveway entrance or intersection controlled by *stop* or *give way* signs should be permitted along a ramp, as they invariably result in unsafe conditions related to traffic speed and driver expectation. A special case may exist where a road network or major service centre requires access and there is no alternative but to intersect the ramp alignment. In such cases, access should only be permitted through a roundabout or signalised intersection that effectively becomes the ramp terminal.

6.6.5 Ramps on Two-lane, Two-way Freeways or Motorways

Two-lane two-way freeways or motorways sometimes occur as a result of stage construction. In such cases the interchange design must provide protection for drivers who may mistakenly believe that they are entering a divided motorway. The interchanges should therefore provide signage and a median and/or a median barrier on the motorway of sufficient length to prevent wrong-way and other inappropriate movements where entry and exit ramps meet the motorway.

A suitable treatment of sufficient width must be installed over the full extent of the interchange geometry (including tapers) to a point beyond the final entry ramp taper. This extent of median is necessary to ensure that the entering traffic is prevented from crossing to the oncoming lane in the mistaken belief that they are entering a one-way roadway.

Appropriate signing should be provided throughout the interchange. In particular, two-way signs and pavement arrows should be used to remind drivers that they have entered a two-way road.

6.6.6 Ramp Spacing

The spacing of ramps is important with respect to:

- traffic operating conditions on a freeway/motorway and at entry and exit locations
- the effectiveness of advance and direction signing at exit ramps.

Each exit and entry ramp creates some level of turbulence in the traffic stream on each side of the exit or entry point (the physical traffic separation or joining point). The extent of this disturbance, known as the influence area, is approximately:

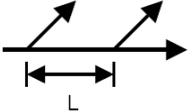
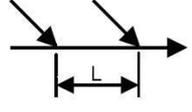
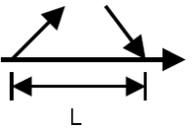
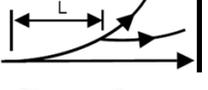
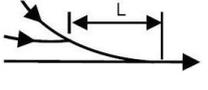
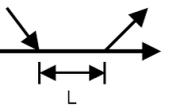
- 450 m upstream from the physical diverge point of the exit ramp
- 450 m downstream of the physical merge point of the entry ramp.

In cases where an entry is followed by an exit, a weaving section will be created if the points of entry and exit of the ramps are close, in which case an auxiliary lane between the ramps might be appropriate. In addition to reducing disturbance and enabling satisfactory weaving, a significant distance is needed for drivers to change lanes in response to exit signage and to position their vehicles for the exit manoeuvre.

Proposed freeway and interchange layouts, whether for new, upgraded or existing freeways, should be analysed to determine that the proposed ramp spacing is satisfactory. Each section where traffic streams separate or join, or where weaving takes place, should be analysed for peak and off-peak periods to ensure that the freeway will operate at the required level of service (*Part 3 of the Guide to Traffic Management, Austroads 2013*). Although greater spacing is always preferred, Table 6.3 provides a guide to the minimum spacing that should be provided.

Where service centres are to be introduced between existing or proposed interchanges, adequate spacing must be achieved to ensure that the level of service and level of safety are satisfactory, including clear and appropriate signing of the facility and the adjacent interchanges. It is essential that access conditions applying to the development take account of the potential expansion of the road in the long-term. To meet these requirements, it is desirable that the distance between successive on and off ramps should be not less than 1500 m, measured between adjacent ramp entry and exit points.

Table 6.3: Ramp spacing

Case ⁽¹⁾	Type of roadway ⁽¹⁾	Desirable (m) ⁽¹⁾⁽³⁾	Minimum (m) ⁽¹⁾⁽³⁾
Successive exits (i.e. exit followed by exit) or successive entrances (i.e. entry followed by entry) ⁽²⁾ .  	Freeway/motorway	–	300 ⁽⁷⁾
	Service road or collector-distributor road	–	240 ⁽⁷⁾
Exit followed by entrance. 	Freeway	–	150 ⁽⁷⁾
	Service road or collector-distributor road	–	120 ⁽⁷⁾
Successive exits or successive entries on connecting roads (or turning roadways, i.e. distance between terminals within interchange itself).  	System interchange	–	240 ⁽⁷⁾
	Service interchange	–	180 ⁽⁷⁾
Entrance followed by exit ⁽⁶⁾ . 	2 lanes	900 ⁽⁴⁾⁽⁶⁾	(6)
	3 lanes	1200 ⁽⁶⁾	(6)
	4 lanes	1500 ⁽⁵⁾⁽⁶⁾	(6)

- 1 This table is a guide only. All configurations should be analysed in accordance with the Highway Capacity Manual (HCM) (Transportation Research Board 2010). The distance/s (i.e. 'L') should be increased where required to achieve the design level of service (analysed using the HCM) or to achieve a consistent level of service along the link. The distances given do not apply to major forks or branch connection merges. In determining the required spacing the number of lanes in the ultimate stage of the motorway should be used.
- 2 Not a preferred configuration for a motorway/freeway.
- 3 It is preferable for the distances to be greater than the minimum to provide drivers with more decision making time.
- 4 Based on providing no overlapping areas of turbulence.
- 5 Based on signage and lane changing requirements of a four-lane one-way roadway on a freeway.
- 6 The distance 'L' is usually measured between the gore areas (i.e. the point at each entry/exit to which the left edge line of the freeway and the right edge line of the ramp converge). Dimensions less than the desirable should only be accepted if supported by a complete analysis undertaken in accordance with the HCM. Notwithstanding this table or the HCM analysis, it is desirable that not less than four seconds of travel, at the desired speed of the major road, be provided between the end of the last taper of the entry terminal and the start of the first taper of the following exit terminal.
- 7 The distance 'L' is measured from like point to like point. This length is subject to signage requirements (i.e. length may need to be increased so that the motorway and ramps can be signed adequately [e.g. to provide sufficient distance between signs or between sign and exit/entry]) and a HCM analysis (as per note (1) of this table).

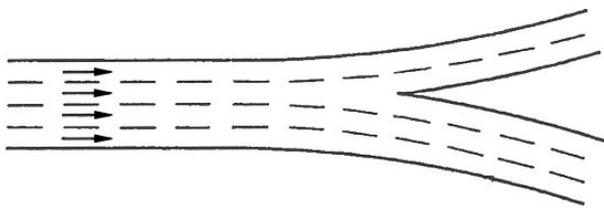
Source: Adapted from Queensland Department of Main Roads (2005).

6.6.7 Major Forks

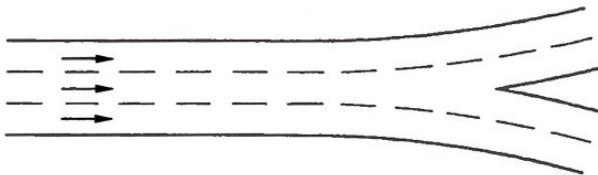
A major fork is the bifurcation of a one-way roadway into two lesser one-way roadways of about equal importance. They often occur in major road to major road interchanges such as Y and T interchanges. Figure 6.26 illustrates two examples of major fork design. The exit treatment used at major forks depends on the distribution of traffic volumes:

- direct right hand exits (i.e. right-turning direct ramp) should be used when the traffic in that direction exceeds 50% of the total approach traffic
- a normal exit to the left (i.e. right-turning semi-direct C – Figure 6.25b) should be used if the right-turning traffic is less than 30% of the total approach traffic
- for right-turning traffic between 30 and 50%, the decision on whether the right-turning traffic should depart from the traffic stream on the left or the right has to take account of route continuity considerations.

Figure 6.26: Examples of major forks



(a) Major Fork Lanemarking - Example 1



(b) Major Fork Lanemarking - Example 2

Aspects important to traffic operation are:

- correct lane balance must be achieved
- the approach to the nose should be straight or nearly so
- generous sight distances (based on standard driver eye height to zero object height) should be provided, both on the approach to the gore area and to all signs, to allow drivers adequate time to assess the situation and take the appropriate action
- gantry mounted signs must be used to ensure that drivers can readily identify which lane to follow.

Downstream of the fork, the speeds on the two roadways should be consistent with the operating speed on the single upstream roadway (speed drop of 10 km/h acceptable if sight distance to roadways is adequate).

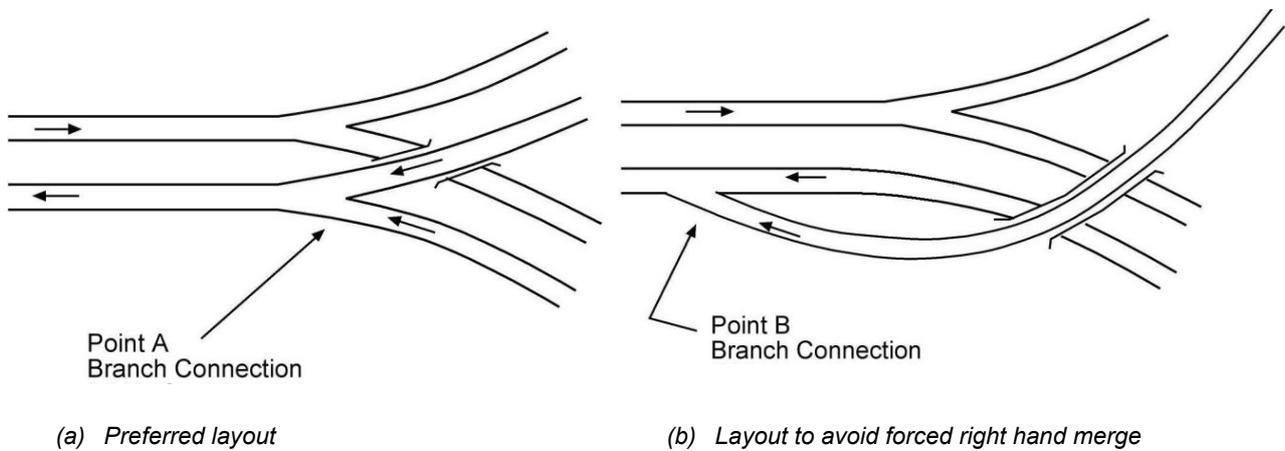
6.6.8 Branch Connections

A branch connection is defined as the convergence of two one-way roadways into a single one-way roadway (e.g. the convergence of two freeway routes to form a single freeway route). These connections often form part of major road to major road interchanges.

Figure 6.27 shows two possible branch connections. Layout (a) is preferred unless the volume of traffic entering from the right is low and the provision of exclusive lanes for the right entering traffic is impracticable. If this occurs, layout (b) may be the most suitable solution, although the bridge is likely to be more expensive. If exclusive auxiliary lanes can be provided, layout (a) is the preferred option.

Details of lane arrangements for branch connections are provided in *Part 4 of the Guide to Road Design* (Austroads 2017a).

Figure 6.27: Branch connections



6.7 Basic Lane Numbers and Lane Balance

6.7.1 Basic Lane Numbers

Determining the basic number of lanes for a major road is fundamental to safe and efficient operation of traffic. Arterial routes of importance should maintain consistency in the number of lanes provided along their length. The basic number of lanes is therefore defined as the minimum number of lanes designated and maintained over a significant length of route, exclusive of auxiliary lanes. This basic number of lanes is maintained throughout the length, irrespective of changes in traffic volume as vehicles enter and leave the facility. This is a further extension of the principle of driver expectation with respect to consistency in traffic operational conditions. In addition, forced lane changes over the length of the facility are reduced.

The basic number of lanes is predicated on the traffic volume over a substantial length of road. The selection of that number of lanes is undertaken using volumes from traffic forecasts developed with the aid of traffic models as part of the planning process. It is important to appreciate, however, that traffic forecasts are based on various assumptions and may be of limited accuracy (*Part 3 of the Guide to Traffic Management*, Austroads 2013).

While traffic forecasts are used as the basis for determining basic lane numbers, as well as turning and weaving volumes, the development of design volumes for a length of road should also draw upon all other relevant data and information, and the use of sound judgment.

The following factors and situations can cause high peaks in traffic flows and should be considered in addition to normal peak hour flows derived from traffic models:

- unforeseen concentration of development
- holiday or weekend travel
- special events
- stage construction and partial development of the freeway network
- flexibility during unplanned incidents (e.g. crashes)
- flexibility during extensive maintenance operations.

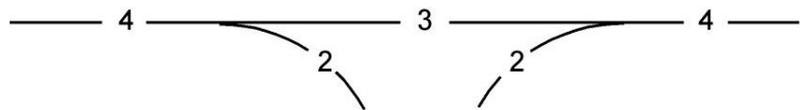
6.7.2 Lane Balance

Once the basic number of lanes is determined the balance in the number of lanes can be assessed using the following principles:

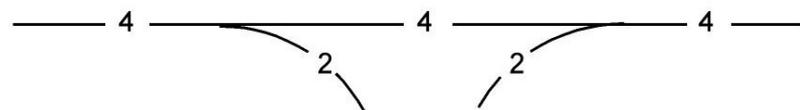
- the number of lanes beyond the joining of two traffic streams should not be less than the sum of traffic lanes on the joining one-way roads minus one, and not more than the sum
- the number of lanes on the combined road before a separating movement should be equal to, or one less than, the sum of all the traffic lanes following the separation
- the number of lanes on the one-way road should be reduced by no more than one lane at any location.

Correct use of these principles should ensure that lane balance is designed into interchange exits and entrances, through the use of auxiliary lanes where appropriate, and that a consistent level of service is achieved. Figure 6.28 shows how the concept of lane balance and basic number of lanes is applied if the basic number of lanes is four in each direction. In the figure (a) and (b) are incorrect whilst (c) shows the correct application, coordinating both basic number of lanes and lane balance.

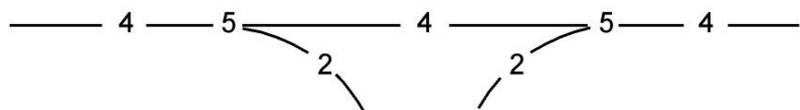
Figure 6.28: Coordination of lane balance and basic number of lanes



(a) Lane balance but no compliance with basic number of lanes



(b) No lane balance but compliance with basic number of lanes



(c) Compliance with both lane balance and basic number of lanes

Source: AASHTO (2011).

Other considerations related to lane balance are:

- when it is considered necessary to decrease the basic number of lanes, say near the end of a freeway/motorway, the lane drop should preferably be at an exit ramp or a major fork
- a freeway/motorway lane should never be dropped abruptly after an exit ramp. Where the traffic reduction is such that a lane can be dropped, this lane should be carried past the nose for an adequate distance and then tapered to meet the basic lanes. The lane drop should be carried out on a uniform grade or in a sag and preferably on a straight alignment so that drivers can see the full length of the taper.

The primary consideration is the achievement of a consistent level of service, which, if applied, will assure correct lane balance.

6.8 Traffic Considerations

6.8.1 General

Movement between two freeways, or between a freeway and a normal arterial road, is associated with changes in driver behaviour and both design and traffic management must allow for this transition.

The speed adopted by a driver, and other aspects of driver behaviour within an interchange, depend upon a number of factors including:

- the types of roads intersecting and consequent geometric limitations on speed
- numbers and spacing of driver decision points
- characteristics of ramps and ramp terminals
- presence of manoeuvring vehicles
- proportion of heavy vehicles in the traffic stream
- speed when approaching the interchange
- traffic volumes and levels of service.

The design standards adopted, particularly sight distances, must enable drivers approaching at the prevailing speed to observe the road within transition areas and hence travel in an efficient and safe manner. In addition, signing and delineation should provide additional cues to drivers so that appropriate responses are achieved (*Parts 3, 4 and 4C of the Guide to Road Design and Part 10 of the Guide to Traffic Management, Austroads 2016e, 2017a, 2015b and 2016d*).

Interchanges should provide adequate capacity and level of service for the through and turning traffic expected to use them. This will require estimation of traffic volumes in the design year (usually 20 years after opening). An estimate of traffic at the date a project opens is also of interest to decision makers because, in urban situations, it often is not feasible to provide for long term demands, and the road may reach capacity a relatively short time after opening. In these cases, it is desirable that the interchange should at least provide reasonable capacity at opening, even if capacity to meet long term demands is not available, and should achieve a balanced level of service throughout. Where it is expected that demand may exceed capacity a relatively short time after opening, provision for additional capacity should be considered, or ramp metering (Section 6.9).

6.8.2 Traffic Data Requirements

The traffic data required for the design of the interchange includes:

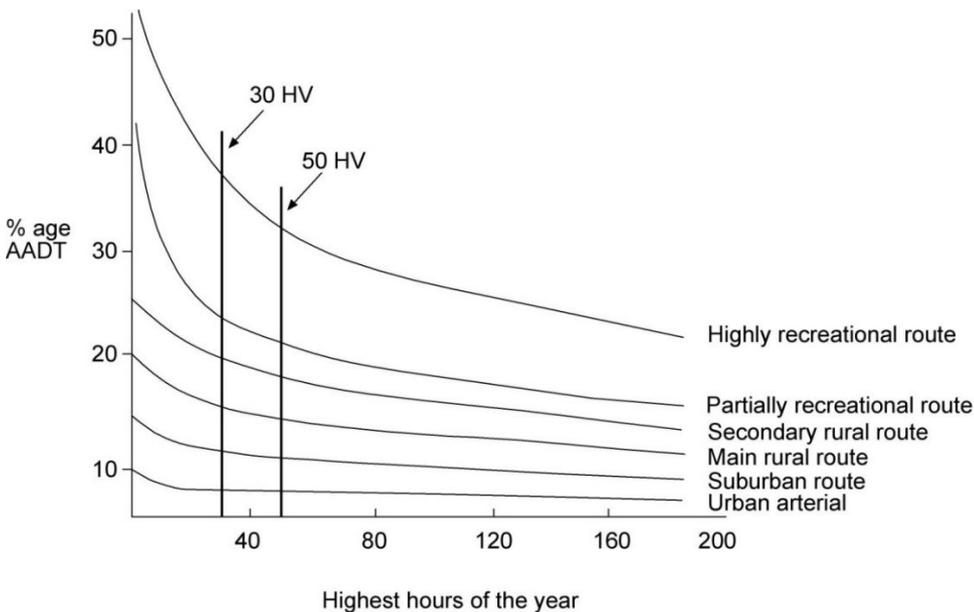
- through traffic volumes (including vehicle classifications)
- turning volumes (including the origins and destinations of entering and exiting traffic)
- approach speeds
- crash rates and types where an existing interchange is being modified
- pedestrian and cyclist movements and volumes to be accommodated
- public transport movements and volumes.

In urban areas, the design volumes will be determined from transport planning studies taking account of land use, public transport use, other mode shares and distribution to the overall network of roads. The influence of various transport strategies on the generation and distribution of traffic in the future has to be taken into account in determining the design volume.

In rural areas, a design hourly volume is estimated from the traffic patterns peculiar to the given road and area. This can vary from the 30th highest hour to the 120th highest hour depending on the type of route. A guide to the most economical design hour can be gained from a plot of hourly volumes from a continuous count station, usually expressed as a percentage of AADT, against the number of hours with a volume greater than the ordinate.

The resulting graph (Figure 6.29), for example will usually have two portions – a steep part near the origin, and a flatter part as the number of hours increases. The design hour can then be estimated from the intersection point of the slopes of the two sections of the plot.

Figure 6.29: Rural design hour volume estimation



Note: 30 HV and 50 HV denote the thirtieth and fiftieth highest hourly volumes respectively. These volumes are commonly used for design purposes.

Source: Austroads (2013).

Future volumes can be estimated by simple projection or by modelling. Simple projection may be suitable where growth rates are known and stable, and future development is taking a steady path. In other areas, a more comprehensive modelling approach should be adopted to obtain a better insight into likely future requirements (*Part 3 of the Guide to Traffic Management, Austroads 2013*).

6.8.3 Operating Speeds

The speed adopted by a driver within an interchange depends on:

- driver decision making requirements of the design
- types of roads intersecting and their geometric limitations on speed
- characteristics of terminals and ramps, principally the length of acceleration lane
- the presence of manoeuvring vehicles
- physical speed limitations due to the overall geometry
- the approach speed of the vehicle entering the interchange area – determined by the speed environment of the approaches
- the proportion of heavy vehicles in the traffic stream
- traffic volumes and levels of service.

While any one of these can be the predominant factor, it is a combination of the factors that influence speed. The difference in the type of geometry used for the freeway and the interconnecting ramps can lead to large differences in speed between vehicles when moving from one element to another and it is important for this to be carefully considered in the design of the interchange elements. For further details of interchange design considerations, refer to *Part 4C* of the *Guide to Road Design* (Austroads 2015b).

If it is impracticable to use the geometric alignment of the ramp to control speed on the approach to the intersecting road or ramp terminal, the following traffic management measures may be considered:

- large advance warning signs
- appropriate advisory speed and/or speed limit signs
- pavement markings across the pavement
- lighting, especially at the intersections.

6.8.4 Level of Service

Level of service is a qualitative measure describing operational conditions within a traffic stream and the perception by drivers and/or passengers of the conditions. The description is in terms of:

- speed and travel time
- freedom to manoeuvre
- traffic interruptions
- comfort and convenience.

Six levels of service, designated A to F, are used to define the range of traffic conditions that can occur, each level representing a range of operating conditions.

Each traffic movement through an interchange should be provided with a consistent level of service with particular attention given to:

- merge and diverge areas
- weaving sections between ramps
- acceleration and deceleration areas and lanes.

When analysing ramp traffic movements, density is the key parameter for determining level of service. Further guidance on level of service criteria for ramp movements is provided in *Part 3* of the *Guide to Traffic Management* (Austroads 2013) and the *US Highway Capacity Manual* (Transportation Research Board 2016).

The US *Highway Capacity Manual* provides guidance for determining the level of service for origin-destination demands through service interchanges, including procedures for signalised intersections and roundabouts. This methodology enables the comparison of different types of interchanges (Section 6.5.3) based on operational performance. Delay is the key parameter used to determine the level of service of the origin-destination demands.

6.9 Ramp Metering

A ramp metering system (or ramp meter) is a control system that regulates the flow of traffic entering a freeway in order to minimise flow breakdown on the freeway. It regulates the number of vehicles able to enter the freeway by measuring traffic conditions on the mainline to detect the onset of congestion and providing feedback to traffic lights controlling entering traffic at the on-ramp. The metering rate is varied by controlling the red time at each ramp meter signal.

If the combination of upstream mainline and ramp flows exceeds the capacity of the freeway, ramp metering can be used to keep downstream traffic volumes below critical levels. Even if the volume of vehicles only temporarily exceeds capacity, a critical volume can result in a breakdown of smooth traffic flow by creating turbulence with the resulting traffic shock waves degrading flow to stop-and-go movement. Metering reduces the chance of exceeding the capacity of the mainline by temporarily storing vehicles on ramps and in storage areas adjacent to ramps.

Ramp metering can also reduce the chance of turbulent flow due to grouping of entering vehicles attempting to merge with traffic on the mainline. Platoons of vehicles from an entry ramp may attempt to force themselves into the mainline creating turbulence and contributing to flow breakdown. By using metering to break up platoons attempting to merge with the mainline, the merging process can be smoothed, allowing traffic volumes to reach the capacity of the facility.

‘Ramp metering is most effective when a series of entry ramps along a section of freeway/motorway are metered as part of a coordinated ramp signals system to provide access equity across all ramps through the balancing of queues and wait times’. (Austroads 2016h, *Guide to Smart Motorways*).

Section 11 of the *Guide to Smart Motorways* (Austroads 2016h) provides guidance on ramp control metering including principals and benefits, criteria for provision, fundamentals, operations and design elements. The document also provides guidance on arterial road and motorway interfaces, including outlining treatment options for arterial road/entry ramp interfaces. The benefits of ramp metering have been documented in a number of studies. Some of the advantages and disadvantages identified by these studies are shown in Table 6.4. The results of a number of ramp metering evaluations are discussed in *Part 9* of the *Guide to Traffic Management* (Austroads 2016c).

Table 6.4: Advantages and disadvantages of ramp metering

Advantages	Disadvantages
<ul style="list-style-type: none"> • Reduced travel time on freeway. • Reduced travel time variability. • Reduced crashes and incidents <ul style="list-style-type: none"> - improved flow stability with less braking and stop-start flow during unstable conditions or when flow breaks down - less lane changing, particularly for vehicles approaching in the left lane - improved merging in areas of high weaving. • Increased throughput. • Managed ramp utilisation • Reduced fuel consumption and emissions as a result of efficient travel conditions. 	<p>Ramp queues:</p> <ul style="list-style-type: none"> • Ramp metering is usually a post hoc treatment, rarely allowed for in the original ramp design. • Adequate and safe storage for the number of vehicles expected to queue at ramp meters may be an issue. • Vehicle storage problems may be reduced if both the ramp meters and surface street traffic signals are coordinated to manage traffic approaching interchange ramps, however care needs to be taken that this does not impair freeway flow. <p>Public acceptance can be problematic:</p> <ul style="list-style-type: none"> • The traffic-flow relationships which allow ramp metering to be beneficial involve abstract concepts which are not easily understood by the general public. • The benefits of ramp metering may need to be widely publicised at implementation.

Ramp metering can be implemented:

- locally (i.e. at a single ramp assessed as contributing unduly to mainline flow breakdown)
- as a coordinated (route-based) system at all (or nearly all) on-ramps over a substantial length of freeway.

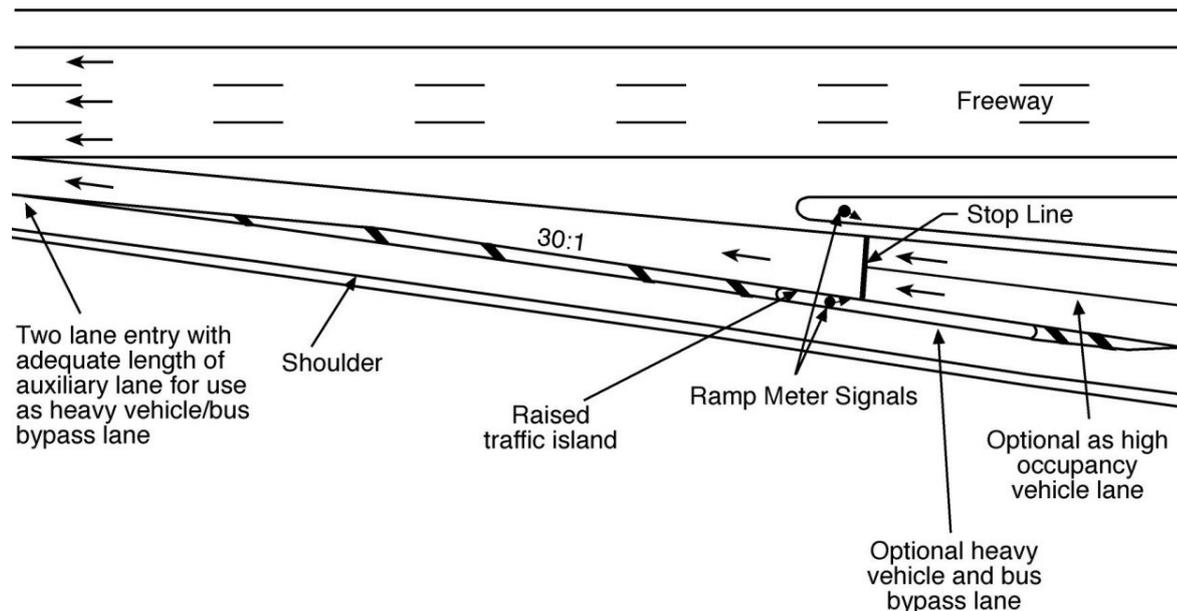
The advantage of an integrated system of ramp meters is the opportunity to manage ramp utilisation. Metering rates at each ramp can be set to manage queue lengths and, if desired, to redistribute traffic to alternative ramps. When ramp metering is employed as a method of preventing flow breakdown on a freeway, the more ramps that are metered, the less each ramp has to contribute to the reduction in entering flow.

Ramp metering operation can be:

- pre-timed (fixed timed), on the basis of historical traffic flow data
- traffic adaptive (dynamic operation), commencing and ceasing operation and changing the metering rate in near real time in response to changes in mainline traffic flow conditions and to ramp queue lengths. The SCATS Ramp Metering System (SRMS), employing algorithms similar in concept to the widely used SCATS area traffic control system, is an Australian example of a ramp metering system with traffic adaptive capabilities.

Where priority is required for buses or heavy vehicles to enter the freeway, a bypass lane can be provided to bypass the ramp meter signals, as shown in Figure 6.30.

Figure 6.30: Ramp metering arrangement including optional HOV and bypass lanes



For additional guidance on ramp metering refer to:

- *Guide to Smart Motorways* (Austroads 2016h).
- *Development of Guide Content on Managed Motorways* (Austroads 2014c).
- Part 2 of the *Guide to Traffic Management* (Austroads 2015j), which discusses the theory and conditions leading to flow breakdown on a freeway (where ramp metering may be considered).
- Part 9 of the *Guide to Traffic Management* (Austroads 2016c) that provides an overview of the operational aspects of ramp metering.
- Part 10 of the *Guide to Traffic Management* (Austroads 2016d), which discusses ramp metering signal displays, appropriate signs and road markings.
- Part 4C of the *Guide to Road Design* (Austroads 2015b) that considers aspects of the geometric layout and design of ramp metering installations.

6.10 Signing, Marking and Lighting

Signing and marking is essential to the efficient and safe operation of interchanges. However, it is essential that the design provides clear and logical cues to drivers so that they can readily recognise the type of interchange and the required travel path through it. The effective and safe operation of an interchange should not rely on signs and markings, although signs and marking are required to complement the design layout.

AS 1742.2, the *MUTCD: Part 2: Traffic Control Devices for General Use in Australia* and TCD Manual¹² in New Zealand set out the requirements for signing and marking of major roads including freeways and interchanges. Significant issues for traffic management and safety that should be considered are:

- locating signs to ensure adequate decision distances
- positioning signs with respect to the major road lanes (overhead, to the side)
- determining and locating support legs for signs including:
 - not placing fixed base signs in the gore areas at ramps, in run out areas or within clear zones
 - using breakaway sign supports and lighting poles within clear zones (*Part 6B of the Guide to Road Design, Austroads 2015f*)
 - locating non-frangible posts behind safety barriers, shielded with impact attenuators or placed outside the clear zone
 - not placing breakaway sign post supports in medians or adjacent to pedestrian areas
- to avoid driver confusion, using gantry signs at major forks where the painted gore is long and narrow because of the large radius curves involved
- utilising gantry signs for roadways with three or more lanes
- providing signs to cater for pedestrians and cyclists
- ensuring that signs are clearly visible in all conditions and considering individual lighting of signs if general lighting is not adequate (*Part 10 of the Guide to Traffic Management, Austroads 2016d*).

Lighting must be provided at all interchanges in accordance with the requirements of AS/NZS1158 (*Part 6B of the Guide to Road Design, Austroads 2015f*).

Where lane control signals or signs are installed as part of a freeway/motorway management system, they must be coordinated with all other signs that are necessary in the vicinity of the interchange (*Parts 5 and 10 of the Guide to Traffic Management, Austroads 2014b and 2016d*).

¹² Note the relevant part of the TCD Manual may be unpublished, in which case refer to the Manual of Traffic Signs and Markings (MOTSAM) (NZ Transport Agency (NZTA) 2010a, 2010b). MOTSAM is being progressively replaced by the TCD Manual (in press).

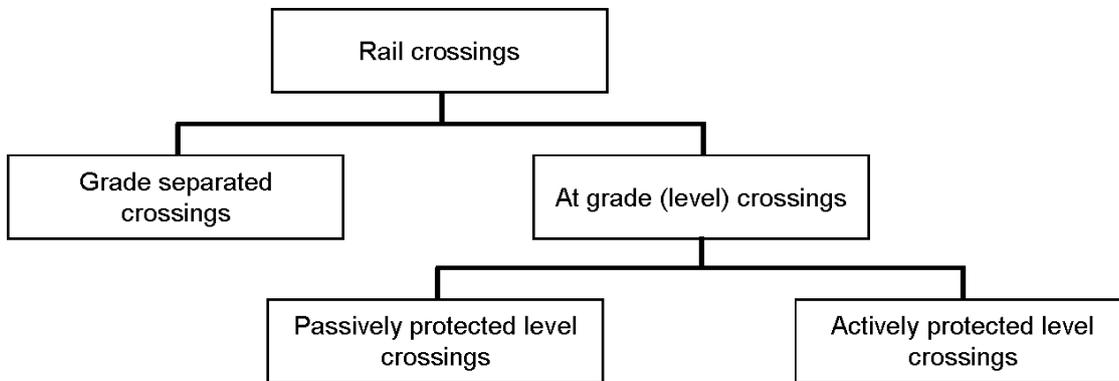
7. Rail Crossings

7.1 Levels of Protection

A railway crossing is an intersection between a road and a railway. For traffic management purposes at-grade railway crossings are classified in terms of the levels of protection provided to reduce the likelihood of crashes between trains and motor vehicles, pedestrians and cyclists. In recognition of their mass, speed and braking characteristics, trains have right of way at level crossings under the Australian Road Rules (National Transport Commission 2012) and the New Zealand Land Transport Rules. All level crossings must be protected to ensure the safety of both road and rail users. The level of protection refers to treatments and devices that are provided to control road users at railway crossings and may also be included in legislation relating to level crossings.

Figure 7.1 illustrates the options available to treat intersections between roads and railways.

Figure 7.1: Railway level crossing protection options



This section provides guidance on the traffic management aspects of grade separated and at-grade railway crossings.

7.2 Grade Separated Vehicle Crossings

Grade separation of rail crossings removes conflict between trains and road users by providing a structure that separates the road and railway in the vertical dimension. Whether a road should form an overpass or underpass of a railway depends primarily on the vertical and horizontal alignments of the railway and the road, and the topography at the crossing location. However, other factors, such as abutting land use, particularly in urban situations, may also influence the choice (*Part 4 of the Guide to Road Design*, Austroads 2017a).

Railways should always be grade separated where they cross freeways or motorways. Similarly new railway crossings of major rural and urban roads should also be grade separated. From a traffic management perspective, road/rail grade separations usually are provided to:

- eliminate the risk of collision between trains and road users
- reduce delays to road users to an acceptable magnitude.

The decision to grade separate a rail crossing should include an economic analysis, based on long term, fully allocated life cycle costs, including both road and rail user costs, rather than simply on initial construction cost (*Guide to Project Evaluation*, Austroads 2005–2012).

Traffic management and road safety factors that should be considered in the development of proposals for road/rail grade separations are listed in Table 7.1.

Table 7.1: Factors considered in assessing the need for grade separation of rail crossings

Factor	Considerations
Road traffic characteristics	<ul style="list-style-type: none"> • Motor vehicle traffic volume and speed. • Driver delay cost savings. • Pedestrian and cyclist volume and age.
Train characteristics	<ul style="list-style-type: none"> • Train speed. • Frequency of arrival. • Proximity of railway stations. • Shunting. • Sight distance. • Closure times. • Reduced delays.
Road safety	<ul style="list-style-type: none"> • Elimination of train/vehicle collisions (including the resultant property damage, medical costs, and liability). • Elimination of collisions between trains and pedestrians/cyclists. • Proximity of minor roads and driveways to the crossing.
Road network	<ul style="list-style-type: none"> • Effects of any spill over congestion on the rest of the roadway system if grade separation is not provided. Conversely, reduction of congestion and delay at other crossings. • Improved safety at other crossings. • Potential for closing one or more adjacent crossings or grade separating them as part of a general rail realignment (where crossings are closed to vehicular traffic, consideration should be given to the provision of safe pedestrian access across the railway within a reasonable distance of the site, see Commentary 25). • Potential for traffic queues to adversely affect adjacent intersections is reduced or eliminated. <p style="text-align: right;">[see Commentary 25]</p>
Road space	<ul style="list-style-type: none"> • Avoids provision and management of increased road storage capacity to accommodate traffic stored at level crossings. • Road space may be allocated to other uses (e.g. public transport or bicycle lanes).

7.3 Rail Crossings At-grade

All at-grade rail crossings of roads that are used by the general public should be protected through the use of appropriate traffic control devices. Treatments for various situations are provided in AS 1742.7 *MUTCD Part 7: Railway Crossings*, and *TCD Manual* (NZTA 2008c¹³). Traffic control of at-grade rail crossings may be achieved through the use of passive or active traffic control devices.

7.3.1 Passive Protection

Passive protection (or passive control) is the control of the movement of vehicular or pedestrian traffic across a railway crossing by signs and devices, none of which are activated during the approach or passage of a train, and which relies on the road user including pedestrians detecting the approach or presence of a train by direct observation.

Devices used for passive control treatments are summarised in Table 7.2.

¹³ Note the relevant part of the TCD Manual may be unpublished, in which case refer to the Manual of Traffic Signs and Markings (MOTSAM) (NZ Transport Agency (NZTA) 2010a, 2010b). MOTSAM is being progressively replaced by the TCD Manual (in press).

Table 7.2: Traffic control devices for passive control

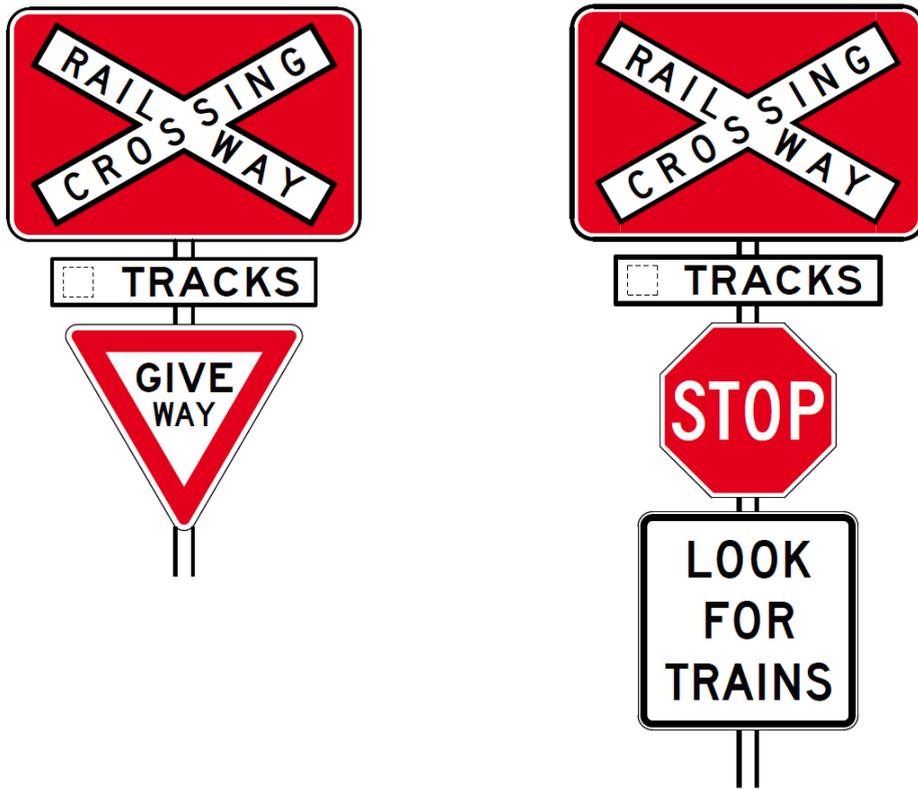
Device	Notes
Give way signs	<ul style="list-style-type: none"> • Railway crossing sign assembly that incorporates a give way sign (Figure 7.2). • Provides the minimum level of control at any railway level crossing on roads open to the public. • Give way lines are required on sealed surfaces.
Stop signs	<ul style="list-style-type: none"> • Railway crossing sign assembly that incorporates a stop sign, instead of a give way sign (Figure 7.2). • Used in situations where all road traffic is required to stop at the crossing because road users approaching the crossing have restricted sight distance to trains (AS 1742.7). • Stop lines are required on sealed surfaces.
Advance warning signs	<ul style="list-style-type: none"> • Used to give the first advance warning of a railway level crossing. • Signs with a pictorial steam engine are used for passive crossings.
Diagrammatic warning signs	<ul style="list-style-type: none"> • A diagrammatic warning sign assembly is used comprising a warning sign depicting an intersection between a road and a track, together with a look for trains sign. • Used as the second or intermediate advance warning of the crossing at railway level crossings controlled by give way signs. • Are located in between the advance warning sign and the crossing. • Where a stop sign assembly is used, advance warning is normally provided by a stop sign ahead sign. • If the railway is at an oblique angle to the road, or the railway and/or road is on a curve, the sign selected should be the one that most clearly indicates the direction of search at or just in advance of its position.
RAIL X pavement markings	<ul style="list-style-type: none"> • Placed beyond the initial mandatory warning sign to provide adequate visual impact and a clear view to the near edge of the marking.
Pedestrian and cyclists devices on paths ⁽¹⁾	<ul style="list-style-type: none"> • Provide signs to warn pedestrians and cyclists to look for trains; pavement markings to define footway and safe waiting position. • Where cyclists are permitted to ride over the crossing, provide a cyclist warning sign on approaches to the crossing. • Where cyclists are not permitted to ride over the crossing, provide cyclist must dismount signs on the approaches to the crossing. • Ensure surface condition is safe including flangeway gaps (within practicable limitations). • Where necessary (e.g. urban areas) provide pedestrian mazes or gated enclosures; where mazes are provided, people with vision, mobility or hearing impairments, or people pushing prams should be able to easily negotiate them. • Requirements also apply to pedestrian crossings remote from vehicular crossings.

¹ Path includes footpath, shared path, separated path and bicycle path.

The provision of either a give way or stop sign is based on sight distance. Detailed guidance on the use of signs and markings for passive railway crossing treatments is provided in Australian Standard AS 1742.7 and in the New Zealand *TCD Manual* (NZTA 2008c¹⁴). For guidance on sight distances and other geometric design considerations, refer to *Part 4* of the *Guide to Road Design* (Austroads 2017a). VicRoads (2012) discusses other considerations related to assessing passive level crossings.

¹⁴ Note the relevant part of the TCD Manual may be unpublished, in which case refer to the Manual of Traffic Signs and Markings (MOTSAM) (NZ Transport Agency (NZTA) 2010a, 2010b). MOTSAM is being progressively replaced by the TCD Manual (in press).

Figure 7.2: Examples of a passive railway crossing sign assembly



Source: AS 1742.7.

7.3.2 Active Protection

Active protection (or active control) is the control of the movement of vehicular or pedestrian traffic across a railway crossing by devices such as flashing lights, gates or barriers (also half-arm barriers in NZ), or a combination of these, where the device is activated prior to and during the passage of a train through the crossing.

Devices used for active control treatments are summarised in Table 7.3.

For further guidance on the use of active devices refer to *Part 10 of the Guide to Traffic Management* (Austroads 2016d).

Where the visibility of the sign assembly and lights is impeded due to the road alignment, width of road or number of high trucks, the assembly can also be mounted overhead.

Table 7.3: Traffic control devices for active control

Device	Notes
Flashing signals	<ul style="list-style-type: none"> • A standard sign and signal assembly is used at actively protected level crossings. • Sign assembly comprises two alternately-flashing red signals mounted side by side under a railway crossing sign that is augmented by a stop on red signal sign (Figure 7.3). • Stop lines are required on sealed surfaces.
Gates	<ul style="list-style-type: none"> • May be used in conjunction with the flashing lights assembly for increased protection. • A stop sign is attached to the gates so that when they are closed the sign is clearly visible to approaching drivers. When double gates are used a stop sign is placed on each gate to face approaching traffic.
Boom barriers	<ul style="list-style-type: none"> • May be added to flashing signals for increased protection. • Should be considered, particularly for urban crossings and where there may be simultaneous movement of trains on two or more tracks.
Advance warning signs	<ul style="list-style-type: none"> • Permanent advance warnings showing a pictorial of the flashing assembly are used at crossings controlled by flashing signals, including those where boom barriers are installed in conjunction with the signals. • May also use active advance warning assemblies incorporating 'Railway level crossing flashing signals ahead' signs with flashing signals. For details of the assembly and its use refer to AS 1742.7.
RAIL X pavement markings	<ul style="list-style-type: none"> • Placed beyond the initial warning sign to provide adequate visual impact and a clear view to the near edge of the marking.
Pedestrian and cyclists devices on paths	<ul style="list-style-type: none"> • Provide red symbolic standing pedestrian signals, audible alarms and signs to warn pedestrians and cyclists to look for trains. Also use pavement markings to define the footway and a safe waiting position. • Where cyclists are permitted to ride over the crossing, provide a cyclist warning sign on approaches to the crossing. • Where cyclists are not permitted to ride over the crossing, provide 'Cyclist must dismount' signs on the approaches to the crossing. • Ensure surface condition is safe including flangeway gaps (within practicable limitations). • Where necessary (e.g. urban areas) provide pedestrian mazes or gated pedestrian enclosures; where gated enclosures and mazes are provided, people with vision, mobility or hearing impairments or people pushing prams should be able to easily negotiate them. • Requirements also apply to pedestrian crossings remote from vehicular crossings.

Detailed guidance on the use of signs and markings for active railway crossing treatments is provided in AS 1742.7 (*MUTCD Part 7: Railway Crossings*) and in New Zealand *TCD Manual* (NZTA 2008c¹⁵).

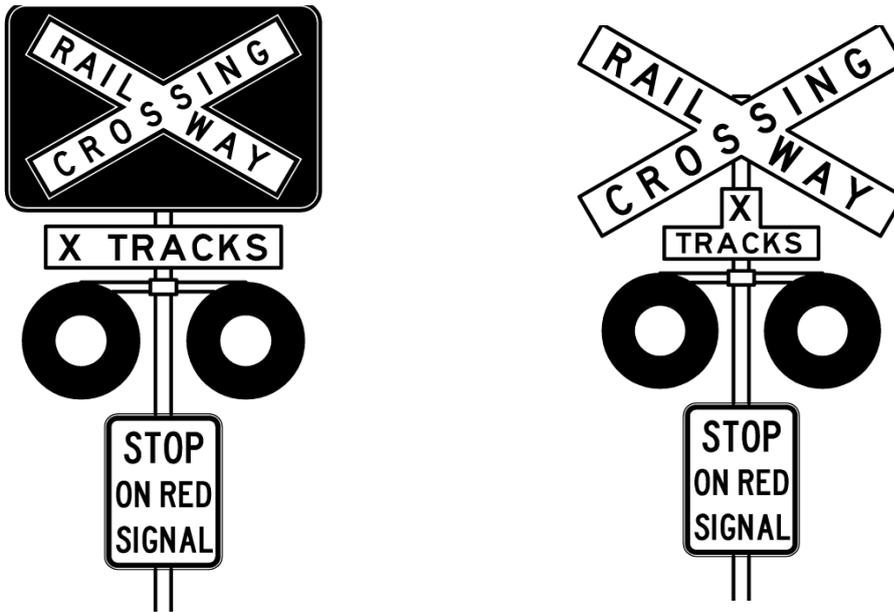
AS 1742.7 provides standards with respect to:

- signs, devices and assemblies, and their use
- pavement markings
- the application of signs and markings to railway crossings
- the avoidance of traffic queuing on crossings
- pedestrian and bicycle treatments at railway crossings.

In particular, practitioners should note the sight triangles that relate to the provision of *give way* and *stop* signs at passive control treatments, sight distance provision at passive control crossings and the requirements for path alignment, flangeway gaps and delineation of path edges on pedestrian crossings.

¹⁵ Note the relevant part of the TCD Manual may be unpublished, in which case refer to the Manual of Traffic Signs and Markings (MOTSAM) (NZ Transport Agency (NZTA) 2010a, 2010b). MOTSAM is being progressively replaced by the TCD Manual (in press).

Figure 7.3: Examples of an active railway crossing sign assembly



Preferred for new or refurbished installations

Alternative, may be maintained at existing installations

Source: AS 1742.7.

Active advance warning assemblies (comprised of alternating flashing yellow lights, a flashing signals ahead sign and a *prepare to stop* panel) may be provided in advance of a crossing to supplement railway crossing flashing signals (AS 1742.7 and New Zealand *TCD Manual*¹⁶). This provides visual warning to road users that there is a requirement to stop at a railway crossing due to the impending activation of the railway crossing flashing signals at the crossing.

An active advance warning assembly should be considered for use wherever a risk assessment indicates an unacceptable train/road user collision risk or the risk of a road user rear end collision can be reduced by the use of the device.

The assemblies are particularly effective in improving safety on high-speed road approaches used by heavy vehicles, such as road trains, and where the required visibility to the flashing signals at the crossing cannot be attained by normal measures. If the railway circuitry permits it may be beneficial to have the advance warning assembly lights begin to flash a predetermined number of seconds prior to the flashing lights at the crossing.

¹⁶ Note the relevant part of the TCD Manual may be unpublished, in which case refer to the Manual of Traffic Signs and Markings (MOTSAM) (NZ Transport Agency (NZTA) 2010a, 2010b). MOTSAM is being progressively replaced by the TCD Manual (in press).

7.3.3 Safety at Rural Rail Crossings

Railway crossings can present safety problems on rural roads, especially where road and rail traffic volumes are so low that active crossing control devices are not provided. Particularly on high speed rural roads, level crossings on inactive lines or those with infrequent services may lead to driver complacency and an increased risk of crashes. It is estimated that there are nearly 5500 railway crossings in Australia without active systems to signal the approach of a train, and there is currently no cost-effective method of converting these to active crossings (Austroads 2002 and Independent Transport Safety Regulator 2008). Also, in New Zealand, approximately half of all at-grade railway crossings (about 1400) are passively controlled. Designers should aim to eliminate, improve, or grade separate existing crossings and to avoid the introduction of any new at-grade railway level crossings where possible.

Sight distance at rural rail crossings should be maintained to facilitate motor vehicle driver’s view of the crossing. Sight lines may be hampered by overgrown vegetation or structures. Vegetation may require regular maintenance, or clearing may be considered. Occasionally structures/buildings may inhibit clear visibility, and again clearing or relocation should be considered. It should be noted that clearing of vegetation or structures on private property may be problematic.

7.3.4 Level Crossing Treatments

There is a range of treatment options that may be used for upgrading rail level crossings. Their implementation requires integrated solutions to meet the needs of the specific site, and coordination between road and rail authorities. Options are summarised in Table 7.4.

Table 7.4: Summary of treatment options for rail level crossings

Treatment option	Guidelines	Advantages/disadvantages
Active advance warning signs	<ul style="list-style-type: none"> High-speed approaches used by heavy vehicles. Visibility to crossing cannot be achieved by other means. 	<ul style="list-style-type: none"> Does not improve visibility of crossing. Ongoing maintenance is required. Requires power supply. Relatively low cost.
Rumble strips	<ul style="list-style-type: none"> Cause noise and vibration in the vehicle to alert the driver to the presence of a hazard such as curve, intersection or railway crossing. The profile used needs to be suitable so as to not present a hazard to motorcyclists. Signs need to be installed to inform motorists of the reason(s) to slow down. 	<ul style="list-style-type: none"> Increases alertness of drivers. Associated speed reduction. Relatively low cost. Ongoing maintenance is required. Can be noisy (may be an issue for urban areas).
Speed limit signs	<ul style="list-style-type: none"> Use of mandatory speed limit reductions (via static signage) on the approach to level crossings. 	<ul style="list-style-type: none"> Increases awareness of crossing. Associated speed reduction. Relatively low cost. Ongoing maintenance is required. Requires enforcement to have full effect.
Queuing control treatment	<ul style="list-style-type: none"> Where there is an unacceptable risk that a recurrent queue will extend from a traffic control signal at an intersection or crossing) onto railway tracks. 	<ul style="list-style-type: none"> Positive protection against queues extending onto railway tracks. Requires an expensive and complex control system. Detection required early enough to force a change of signal phase at the intersection and to disperse the queue.
Yellow box marking in addition to the queue relocation and passive signs	<ul style="list-style-type: none"> Where there is an unacceptable risk that a recurrent queue will extend onto railway tracks. 	<ul style="list-style-type: none"> Positive protection against queues extending onto railway tracks. Relatively low cost. Ongoing maintenance is required.

Treatment option	Guidelines	Advantages/disadvantages
Provision of additional storage or an escape lane	<ul style="list-style-type: none"> Where there is a risk that a recurrent queue will extend onto railway tracks. 	<ul style="list-style-type: none"> Positive protection against queues extending onto railway tracks.
Traffic signal coordination	<ul style="list-style-type: none"> Link intersection signals to railway signals to achieve safe and efficient operation (Commentary 26). [see Commentary 26] In urban areas railway crossing may be incorporated into the signal systems of adjacent intersections. 	<ul style="list-style-type: none"> Phasing can be arranged to ensure that particular problem movements are terminated during the train phase; others are able to run throughout the train phase. Signals at intersections adjacent to the rail crossing can be provided with progression and additional green time following termination of the train phase.
Road realignment	<ul style="list-style-type: none"> Undertaken to improve sight distance to the railway crossing and to improve sight triangles between approaching motor vehicle drivers and trains. 	<ul style="list-style-type: none"> Safer arrangement is achieved. Cost of realignment is high. Realignment may be impractical due to topography or other constraints.
Upgrade protection: <ul style="list-style-type: none"> passive to active protection improve active protection elements (install lights, bells, boom gates) 	<ul style="list-style-type: none"> Provide improved level of protection in accordance with AS 1742.7. 	<ul style="list-style-type: none"> Can provide most appropriate treatment through an investigation of existing site. Use ALCAM (Australian Level Crossing Assessment Model, see Section 7.6) to identify level of risk and to highlight characteristics that need attention. Examine site characteristics and use engineering judgement to determine appropriate treatment.
High intensity lights	<ul style="list-style-type: none"> Use where site characteristics require a more conspicuous signal. 	<ul style="list-style-type: none"> Effective where sun glare makes it difficult for motor vehicle drivers to see lights, or background to lights make it difficult for them to be seen. Provides a cost effective treatment of existing sites.
Train speed reduction	<ul style="list-style-type: none"> Would usually only be contemplated to ensure operational safety due to track deficiency. 	<ul style="list-style-type: none"> Could make existing crossing safer for motor vehicles. Is likely to reduce efficiency of train operations and adversely affect schedules.
Rail realignment	<ul style="list-style-type: none"> Is not usually practicable. Would only occur as part of a track upgrade for operational improvements. 	<ul style="list-style-type: none"> Works are costly and extensive. Disruption to rail traffic is necessary.
Sight line improvements	<ul style="list-style-type: none"> Removes barriers to motor vehicle drivers' vision within sight triangles. 	<ul style="list-style-type: none"> May require clearance/maintenance of vegetation and potentially clearing work on private property; buildings problematic. Must consider ongoing issue of access and maintenance.
Closure of the crossing	<ul style="list-style-type: none"> Is generally only suitable for crossings with low motor vehicle volumes. Alternative safe route must be available. Additional travel times for users and impacts should be considered. 	<ul style="list-style-type: none"> Eliminates a site of train/motor vehicle conflict. No maintenance is required at the location. Current users are directed to safer crossing. Additional travel and costs for current users.

Treatment option	Guidelines	Advantages/disadvantages
Grade separation	<ul style="list-style-type: none"> Economic analysis of operational and safety aspects demonstrates that grade separation is beneficial. 	<ul style="list-style-type: none"> Removes train/motor vehicle conflicts and train/pedestrian and cyclist conflicts. Level of service is improvement – reduced delay. Reduces transport costs and environmental impact. Requires high initial capital cost. Usually requires land acquisition.
Heavy vehicle ban	<ul style="list-style-type: none"> Generally only suitable if an alternate route is available. 	<ul style="list-style-type: none"> Minimises train/heavy vehicle conflicts which in the event of a crash are generally more severe.

7.3.5 Rail Level Crossings at or Near Road Intersections

Rail level crossings located in close proximity to major urban arterial road intersections are particularly problematic, as queues from the level crossing can block the intersection. Conversely, queues from the intersection can result in some vehicles inadvertently queuing on the crossing, even though it is illegal.

Urban rail crossings

For signalised intersections, queuing into the intersection may be managed by linking the intersection signals to the level crossing train signals by:

- installing inductive loops on the departure side of the intersection to detect a queue and hence an imminent blockage of the intersection
- terminating signal phases feeding the space between the level crossing and intersection when a queue is detected and reintroducing those phases only when the problem queue clears.

Queuing of road traffic across the rail level crossing may be managed by:

- linking the intersection signals to the level crossing to enable a special queue-clearing sequence to be initiated before the flashing red signals start to operate (*Guide to Traffic Management Part 9, Austroads 2016c*)
- installing pre-signals (i.e. traffic signals stopping vehicular traffic installed in advance of a level crossing)
- installing ‘yellow box’ pavement markings and fixed or variable message signs such as *keep tracks clear* (Figure 7.4)
- providing additional storage or an escape lane for those drivers who inadvertently queue on a crossing just prior to activation of the crossing traffic control devices.

Figure 7.4: *Keep tracks clear* sign for use with yellow box pavement marking



Source: AS 1742.7.

It is sometimes possible to include a rail crossing within an intersection conflict area. Where this occurs at a signalised intersection, the train movement is treated as a priority phase. The flashing red railway display should be provided as part of the intersection signal control. Special precautions may need to be taken to shield any green intersection signal from the view of drivers approaching or stopped by a flashing red railway signal.

Although the situation is not common, a railway or tramway crossing may be provided within a roundabout layout. In the case of a railway, or a tramway in a higher-speed environment (> 60 km/h), the appropriate active control devices should be provided. Tramway crossings in roundabouts generally occur only in low-speed urban situations and static or electronic signs are usually sufficient to advise drivers to give way to trams (*Part 10 of the Guide to Traffic Management*, Austroads 2016d).

Existing and proposed intersections in close proximity to railway crossings often require traffic analysis (*Part 3 of the Guide to Traffic Management*, Austroads 2013) and signal coordination.

For further guidance on interlinking traffic signals and level crossing train signals, refer to Section 7 of *Part 9 of the Guide to Traffic Management* (Austroads 2016c), *Part 10 of the Guide to Traffic Management* (Austroads 2016d), Institute of Transportation Engineers (2006), Roads and Traffic Authority (2010a, 2010b, 2010c) and VicRoads (2014).

Rural rail crossings

Rail crossings sometimes occur in close proximity to rural intersections. Traffic volumes at rural intersections are often relatively low and the number of trains using rural lines is also low (as noted in Section 7.3.3). The issue of queues extending between rural intersections and adjacent rail crossings is therefore rare. However, should such a situation occur, similar traffic analysis and traffic management techniques as those used in urban situations should be considered.

In rural situations where an arterial road runs parallel and close to an adjacent railway, the distance between the two facilities may create potential problems for:

- long, heavy vehicles crossing the railway track and approaching the arterial road where short stacking may be a concern
- motor vehicle drivers turning from an adjacent road and approaching the level crossing potentially being unaware of approaching trains.

Short stacking

Where there is limited distance between a railway level crossing and a downstream road intersection, preventing long-vehicles from occupying a rail level crossing whilst waiting to enter a road intersection (i.e. short stacking) should be considered.

Such a situation may occur where the road and rail were located many decades ago with limited separation (say 25 m). This causes problems for modern long-vehicles such as B-Doubles (B-Trains in New Zealand). Whilst there may be a very low probability of a train/truck conflict occurring under these circumstances at many locations, the costs (e.g. loss of rolling stock and production) and trauma associated with level crossing crashes is so great that every effort should be made to remove the potential for conflict. It may therefore be necessary to provide remedial treatments such as:

- widening and/or realignment of the parallel road to increase separation between the rail crossing and holding line
- provision of permanent or train actuated signals on the road parallel to the railway
- prohibit long-vehicles from using the crossing and deviate them to a suitable route that may also require some remedial works
- provision of an escape area in the verge between the railway and the road (generally not the preferred treatment due to subsequent difficulty for the long-vehicle in safely resuming its journey from a confined location).

The provision of signs to warn truck drivers of the situation is of limited value.

Awareness of approaching trains for turning traffic from a nearby intersection

Where vehicles turn at a road intersection and travel towards a railway level crossing which is a short distance downstream, drivers may have difficulty detecting an approaching train. This may be of particular concern where prior to turning at a road intersection, motorists travel parallel to the train line and in the same general direction as a train approaching the level crossing. These drivers may be unaware of a train if it is approaching from behind the vehicle. This may be a more prominent issue for drivers of vehicles which have restricted vision to the rear (e.g. trucks or vans).

In these circumstances, drivers are unlikely to be able to sight an approaching train until they have completed or substantially completed turning. This situation is generally more critical for a left-turning vehicle than a right-turning vehicle, although both movements require consideration.

At passive level crossings, this issue should be considered when determining the type of protection (e.g. *give way* or *stop* signs) and what, if any, other options are available or supporting measures should be implemented to minimise safety risk. For further guidance on sight distance and other road design considerations at railway level crossings, refer to *Part 4* of the *Guide to Road Design* (Austroads 2017a).

7.4 Path Crossings of Railways

7.4.1 Path Crossings – Pedestrian

Pedestrian crossings of suburban rail systems include the following types:

- grade separated pedestrian crossings
- pedestrian crossings at vehicular level crossings
- pedestrian crossings at stations remote from vehicular crossings
- pedestrian crossings remote from stations or vehicular level crossings.

Where facilities are to be provided for pedestrians at railway level crossings the treatment shall provide for people with disability or mobility difficulty, including people with ambulant, sight and hearing impairments (AS 1742.7).

Where pedestrians cross railway lines at-grade at a road/rail level crossing, a footway at the level of the top of the rail tracks will be required. This can be achieved in the form of a widening of the road or as a separate footway. Care needs to be taken in the details of the surface at the track crossing points. All pedestrian crossings must be easily negotiable and safe for all users, including wheelchair users and people pushing prams.

Signage, delineation and physical measures are required to define the intended path and direct pedestrians to the crossing and across the tracks. One or more of the following treatments may also be required:

- barriers and signage along the approach footways to ensure that pedestrians use the footway rather than the roadway or an alternate route
- pedestrian mazes to orientate pedestrians so that they can readily look for trains and cross at the correct location
- remotely controlled gates or boom barriers to prevent crossing when trains are approaching or proceeding through the crossing
- Don't Walk lights and audible warnings
- adequate lighting.

Signs commonly used at pedestrian crossings of railways are shown in Figure 7.5.

Figure 7.5: Examples of signs used at pedestrian and cyclist crossings of railways



Source: AS 1742.7.

7.4.2 Path Crossings – Shared

AS 1742.7 states that a *cyclists dismount sign* shall be used at crossings that are primarily used by pedestrians i.e. that are not part of a shared path, but may be used by cyclists. This requirement is intended to emphasise to cyclists that it would be safer for both pedestrians and cyclists if they were to dismount and not ride across the crossing.

The Standard includes an informative appendix of typical examples of pedestrian facilities at rail level crossings. The treatments include a minimum treatment, mazes, and gate enclosures. Treatments with passive and active control are illustrated. The *cyclists dismount sign* is shown in Figure 7.5.

AS 1742.7 does not provide warrants or guidelines to determine whether pedestrian or cyclist facilities are to be provided and, if so, which treatment is to be used. Road and rail authorities should work together to develop warrants taking into account pedestrian and cyclist volumes, train movement patterns, whether active control is provided for vehicular traffic and any other relevant risk factors.

Grade separated path crossings

In Australia, as in Europe and North America, grade separation of pedestrian movements is rarely provided, except across freeways or motorways and railways near busy railway stations, even though it provides the highest degree of protection from road traffic or trains. The general reasons for this include:

- high capital cost
- high cost of lighting
- difficulties experienced by the aged and physically impaired persons due to level differences
- the relatively excessive journey distance along ramps compared to a direct crossing of the road or railway.

Use of an underpass (with a smaller difference in level than an overpass) may reduce the road user difficulties of an overpass, especially for the elderly, although they may have other serious disadvantages such as:

- reduced personal security
- higher maintenance cost and lack of amenity due to vandalism
- seepage and flood risk.

The provision of a grade separation requires an evaluation, including consideration of:

- physical site suitability
- alternative traffic management treatments
- likely level of use
- likely benefits of increased safety and reduced delay
- engineering feasibility
- costs.

It is good practice for a footpath to be provided where a vehicular grade separation of a railway is constructed in an urban area (and also in generally rural areas where there is urban development near the grade separation). In such cases, and also in those cases where a separate pedestrian grade separation is provided, measures should be taken to ensure that pedestrians use the facility rather than a more direct, informal crossing of the railway. This may require the erection of barriers and provision of effective direction signs and connecting pathways.

In situations where a grade separation of a railway crossing forms part of a shared path, the structure must be designed to a standard that is safe for combined use by cyclists and pedestrians, including wheelchair users and people pushing prams. In particular:

- overpasses and underpasses should have an adequate width
- adequate vertical clearance is essential
- adequate sight distance must be available (particularly relevant to the entries and exits of underpasses)
- higher railings, designed not to snag bicycle pedals, are required on overpasses
- suitable gradients must be provided.

7.4.3 Impaired Persons

All pedestrian level crossings including the escape or bypass areas should be designed to allow convenient and safe passage by all pedestrians, including people who have a vision, mobility or hearing impairment and/or are elderly. The design principles that apply are similar to those that apply for other road users. The specific aspects of a crossing design, construction and maintenance to achieve this objective are summarised in Table 7.5.

Table 7.5: Design features at path level crossings to assist impaired and aged persons

Design feature	Comments
Surfaces	<ul style="list-style-type: none"> • Must be smooth and even. • Uneven surfaces and flangeway gaps (where rails intersect paths) can cause the small wheels of wheelchairs to become entrapped, or cause loss of control or tipping of the wheelchair. • Vision impaired or aged persons can stumble and fall due to relatively minor level differences.
Manoeuvring space	<ul style="list-style-type: none"> • Crossing layouts and entry treatments (e.g. mazes) should be designed so that the movement of larger wheelchairs and scooters is not too restricted. • Crossing pathway should be of adequate width (AS 1742.7).
Warnings of trains approaching	<ul style="list-style-type: none"> • Warning times must be adequate to cater for slower pedestrians and wheelchair users to safely cross and clear the crossing.
Visual, audible and tactile warnings	<ul style="list-style-type: none"> • Users may have a range of disabilities and/or mobility difficulties. • Crossings should desirably provide visual, audible and tactile warning systems for pedestrians who have poor hearing and/or vision. • The use of crossings is made easier for vision impaired persons by the use of appropriate tactile and contrasting visual cues, in addition to warning devices.
Alignment of crossings	<ul style="list-style-type: none"> • Should be at right-angles to tracks wherever practical to do so. • Crossings that are not aligned at right-angles to the rails may increase the risk of wheelchairs becoming entrapped and can create navigational problems for the vision impaired.
Approaches to crossings	<ul style="list-style-type: none"> • The design of crossings should include consideration of approaches to ensure that well designed and maintained paths connect each crossing to the local footpath network.

Whilst AS 1428 *Design for Access and Mobility* provides considerable advice on treatment of pedestrian crossings at intersections for people with disability or mobility difficulty, specifically in relation to tactile ground surface indicators (TGSIs), no corresponding standard exists for the design and control of pedestrian crossings of railways.

7.5 Lighting at Rail Crossings

Lighting can improve the safety of rail crossings, including those in rural areas by increasing the conspicuity of the crossing area. In urban areas, as well as highlighting the presence of the crossing, lighting can provide both reflected light from trains and back lighting of trains that are on a crossing. Lighting schemes should be designed in accordance with AS/NZS 1158 *Lighting for Roads and Public Spaces* and *Part 6B of the Guide to Road Design* (Austroads 2015f). Given that the railway crossing is an intersection, this will ensure that adequate lighting is provided for pedestrians and all other road users. Additional guidance on this topic may also be found in the *Guideline: Lighting for Railway Crossings* (Roads and Maritime Services 2013a).

7.6 Selection of Treatment (ALCAM)

The Australian Level Crossing Assessment Model (ALCAM) is a safety assessment tool used to assist in the prioritisation of railway level crossings according to their comparative safety risk (ALCAM 2016). It supports decision making for road and pedestrian level crossings as well as providing a method to help determine the optimum safety improvements for individual sites.

At the May 2003 Australian Transport Council (ATC) meeting, all state and territory transport ministers agreed to adopt this innovative method of risk assessment. ALCAM is currently applied across New Zealand and all Australian states and is overseen by a committee of representatives from these jurisdictions to ensure its consistency of development and implementation.

ALCAM provides a road and pedestrian model. The ALCAM road model includes three elements (the Infrastructure model, Exposure model and Consequence model) which are multiplied to produce a risk score for each crossing. The ALCAM pedestrian model has a similar (although simpler) form to the road model:

- the 'Infrastructure Factor' considers each site's physical properties (characteristics and controls) including consideration of the related common human behaviours
- the 'Exposure Factor' accounts for vehicle, pedestrian and train volumes
- the 'Consequence Factor' reflects the expected outcome in the event of a collision.

The ALCAM Risk Score enables comparison of the relative scores across level crossings within a given jurisdiction as well as highlighting where specific risks exist. It is important to note that whilst ALCAM assists with safety assessment of level crossings, this does not preclude the need for sound engineering judgment. Consideration should also be given to consideration of other elements such as social and economic impacts, international best practice, stakeholder inputs, local knowledge as well as site-specific safety factors.

ALCAM should be applied by road and railway engineers or other similar professionally qualified staff who have been trained in the proper application of ALCAM.

The ALCAM process, model structure and other guidance is provided in *ALCAM in Detail* (ALCAM 2016).

8. Pedestrian and Cyclist Crossings

8.1 Introduction

8.1.1 Types of Crossings

This section discusses treatments available to assist pedestrians and cyclists crossing of roads at midblock locations as well as at intersections. Typically these crossings are needed to provide continuous and connected bicycle routes for cyclists and to improve access for pedestrians.

8.1.2 Basics of Crossings

An important purpose behind creating crossing points is to concentrate the movements to selected locations where:

- pedestrian and cyclist networks exist or are being developed to improve the safety, amenity of the environment, and accessibility provided for pedestrians and cyclists
- pedestrians and cyclists are provided with a safe place to cross the road through the use of treatments and devices that effectively manage conflicts between pedestrians/cyclists and motorised traffic
- motorists would expect the presence of pedestrians and cyclists
- the crossing can be readily identified by all road users as a point of crossing (this may include delineation, coloured pavement or other devices)
- pedestrians with limited vision or mobility can be provided with non-visual cues and/or physical aids
- regulatory traffic control devices can be installed.

The Australian Standard *AS 1428.1 Design for Access and Mobility: General Requirements for Access: New Building Work* specifies requirements, with particular attention to paths of travel, access and facilities for people with ambulant and sensory disabilities and those who use wheelchairs. From the design perspective, additional guidance is given in the *Austrroads Guide to Road Design Part 4* (Austrroads 2017a), *4A* (Austrroads 2017b) and *6A* (Austrroads 2017c), and in the *New Zealand Pedestrian Planning and Design Guide* (NZTA 2009).

An exception to concentrating non-motorised movements to a specific location is the integrated facility where all road users share the same road space under a controlled environment.

It is important that pedestrian and cyclist crossings be considered as part of continuous networks. The *Guide to Traffic Management Part 4* (Austrroads 2016b) provides guidance on network management, including planning processes for balancing and prioritising the needs of different road users and specific guidance applicable to cyclist and pedestrian networks.

8.2 Mid-block Crossings

8.2.1 General Considerations for All Road Users

Mid-block crossings can be classified into four categories which reflect the various levels of safety, amenity and cost. The objectives and general priority, applications, treatment options, and treatment considerations that may apply for different categories of crossing facilities are shown for:

- general facilities (Table 8.1)
- traffic controlled (time separation) facilities (Table 8.2)
- grade separated (space separation) facilities (Table 8.3)
- integrated facilities (Table 8.4)
- Table 8.5 provides a guide to the appropriate use of a treatment for particular road classifications.

The selection of appropriate pedestrian crossing facilities should be made on the basis of safety performance and network operation objectives (through application of a NOP), and in particular the level of service provided to pedestrians. The Austroads *Pedestrian Crossing Facility Selection Tool* (available from Austroads 2016f) can assist in the selection of the most appropriate pedestrian crossing type. ‘The online tool assesses the viability of different types of pedestrian crossing facilities according to the physical and operational parameters of a site and its safety performance’.

Mid-block crossings should also be designed to enable the safe and convenient passage of cyclists travelling along or turning into and from the intersecting road. The guidance and treatments in Section 2.4 and Section 5.4 may be considered for unsignalised and signalised crossings respectively.

Table 8.1: Benefits of treatments – general crossing facilities

Objectives and priority	Application	Treatment	Benefits and considerations ⁽¹⁾
<p>To increase the safety of pedestrians and cyclists by the use of physical aids within the roadway so as to:</p> <ul style="list-style-type: none"> • reduce conflict between vehicles and both pedestrians and cyclists • simplify the decisions which drivers, pedestrians and cyclists have to make. <p>Motorist has priority; non-motorised traffic must select an appropriate gap.</p>	<p>There are moderate volumes of crossing traffic.</p> <p>Pronounced desire line or cycle path route⁽²⁾.</p> <p>There is difficulty crossing full width of road in one stage due to:</p> <ul style="list-style-type: none"> • long delays or unsafe gap selection • long crossing length or multiple lanes • high vehicle flows or speed • insufficient sight distance to enable a crossing length of both directions of traffic. <p>Need exists to cater for people with disability or mobility difficulty.</p> <p>Pedestrian or cyclist crossings are not expected by motorist.</p> <p>There are poor crossing options at other locations, or best location to cross is unclear.</p> <p>There are crossings at numerous locations along short section of road.</p>	Refuge island median	<ul style="list-style-type: none"> • Improves accessibility for pedestrians and cyclists. • Users cross one direction of traffic at a time making gap selection easier. • Provides physical protection from vehicles.
		Kerb extension	<ul style="list-style-type: none"> • Can safely store multiple users at part crossing distance. • Provides an alternative to refuge if people feel unsafe standing in middle of road.
		Road narrowing	<ul style="list-style-type: none"> • Can be used frequently along a length of road.
		Indented parking	<ul style="list-style-type: none"> • Parking controls may be necessary to provide adequate sight distance to pedestrians and cyclists. • Relatively low cost if road width is available. • Reduces crossing width. • Improves conspicuity and sight distance. • Delineate and protect parking, can reduce number of bays. • Can contribute to speed control. • Can create a squeeze point for cyclists.
		Staggered pedestrian crossing	<ul style="list-style-type: none"> • Consider staggered pedestrian crossing arrangement on multilane roads as this can provide for more effective two-way traffic signal coordination and provide the opportunity to double cycle the pedestrian crossing. Staggered crossings near roundabouts provide the opportunity for both safety and operational benefits compared to a non-staggered crossing.
		Fence	<ul style="list-style-type: none"> • Redirects pedestrians and cyclists to crossing point. • Controls movements outside hotels. • Prevents direct crossing access from lane or pathway. • Can limit access to parked vehicles.
Speed control device	<ul style="list-style-type: none"> • Manages speed in the vicinity of untreated crossing points. 		

1 See Part 4 of the Guide to Road Design (Austroads 2017a), AS 1742.9, AS 1742.10, NZTA (2009) and NZTA (2008b).

2 A desire line is the route naturally taken by pedestrians or cyclists, determined from a worn surface or observation.

Table 8.2: Benefits of treatments – traffic controlled (time separation) facilities

Objectives and priority	Application	Treatment	Benefits and considerations ⁽¹⁾
<p>To minimise conflict between pedestrians and cyclists crossing the road and vehicles travelling along the road.</p> <p>This is done by allotting short time periods for use of a section of road by pedestrians and cyclists crossing the road, and also for vehicles travelling along the road.</p> <p>Pedestrians and cyclists have priority according to device type and applicable road rule.</p> <p>Cyclists must dismount except at signalised treatments that have bicycle lanterns erected (i.e. bicycle crossing or shared use crossing). Improves accessibility for pedestrians and cyclists.</p>	<p>Regular crossings used by young or older pedestrians. May have pronounced peak crossing demand.</p> <p>Used for lower speed zones (e.g. ≤ 40 km/h).</p> <p>Is suitable for crossing two-lane two-way, low-speed roads that have high-volumes or insufficient gaps, and high entry angle left-turn slip lanes at arterial road intersections.</p> <p>Is not suitable on multilane roads (e.g. four-lane undivided or high-speed roads).</p>	<p>Pedestrian (Zebra) crossing</p>	<ul style="list-style-type: none"> • Not suitable for multilane or arterial roads. • Crossing zone is well defined. • Safety is improved with kerb extensions. • Good sight distance and conspicuity are required. • Cost-effective, may create short delays to motorists at many locations – depends on pedestrian demand. • Suits all users. • Less suitable when crossing numbers are small.
		<p>Children’s crossing</p>	<ul style="list-style-type: none"> • Part-time operation, crossing priority only when flags (or school patrol and signs in NZ) are in position. • Specific for children and youths, may be supervised. • Requires undertaking to manage flags. • Reverts to a crossing point where motorists have priority – possible reduced crossing width.
	<p>Applicable for higher speed zones.</p>	<p>Pedestrian traffic signals⁽²⁾ Pelican Puffin</p>	<ul style="list-style-type: none"> • Provides greater guarantee of priority control. • Allows provision of audio and tactile cues. • Can be used where limited sight distance exists. • Pelican/Puffin provides reduced delay to motorists and reduced cycle time. • Pelican has onus on motorists to remain stopped until pedestrian crossing completed. • Puffin has positive control over priority for full period of crossing. • Consider bicycle detection and hand rails.
	<p>Applicable at locations with:</p> <ul style="list-style-type: none"> • one-way or two-lane roads • existing low-speed and low volumes • a need to reduce or control speeds • LATM schemes • high crossing use • good sight distance. 	<p>Pedestrian (Wombat) crossing</p>	<ul style="list-style-type: none"> • Increases conspicuity. • Provides positive speed control. • Provides a low cost, permits landscaping. • Should form part of a traffic calming scheme. • May increase noise. <p>Note: Wombat crossings are Pedestrian (Zebra) crossings placed on raised platforms of similar design to road humps.</p>
<p>Applicable at locations with:</p> <ul style="list-style-type: none"> • very low-volume local streets intersecting frequently with cycle paths • proportion of commercial traffic low • low-speed environment, no more than two lanes • good visibility and away from intersections. 	<p>Low-volume street crossing</p>	<ul style="list-style-type: none"> • Is intended where exclusive bicycle path crosses minor road. • Provides an improved level of service to cyclists through continuity of paths. • Cyclists are not required to dismount. • Is not suitable where significant numbers of primary school children cross. 	

¹ See Section 4, Part 9 of the Guide to Traffic Management (Austroads 2016c), Part 4 of the Guide to Road Design (Austroads 2017a), AS 1742.9, AS 1742.10, AS 1742.14, NZTA (2009) and NZTA (2008b).

² For recent developments in the use of crossings at signalised facilities, see Section 8.2.3.

Table 8.3: Benefits of treatments – grade separated (space separation) facilities

Objectives and priority	Application	Treatment	Benefits and considerations ⁽¹⁾
To increase the safety of pedestrians and cyclists by eliminating physical conflict between them, and motorised traffic. Removes priority considerations.	Applicable at locations with: <ul style="list-style-type: none"> high posted speed high-volumes of motorised and crossing traffic multiple lanes cycle path continuity. 	Overpass, underpass	<ul style="list-style-type: none"> May require high capital cost. Grade difference of an overpass is less preferred for vision or mobility impaired persons, aged persons, and cyclists. Underpass has problems with security, lighting and vandalism. Infrequent location may not cover desire lines causing increased journey distance, fencing may be required.
	Applicable at locations with: <ul style="list-style-type: none"> high-volumes of pedestrians and/or cyclists continuous crossings along road commercial or recreational activity a need for very limited motorised access to properties. 	Mall	<ul style="list-style-type: none"> Road becomes thoroughfare for pedestrians. Cycling may be prohibited in malls. If cycling is allowed together with high pedestrian flows, specific space may have to be allocated for cycling. Permits streetscaping options. Vehicle access may be provided through permit system.

¹ See Section 4, Part 8 of the Guide to Traffic Management (Austroads 2016g), Part 4 of the Guide to Road Design (Austroads 2017a), AS 1742.9, AS 1742.10, AS 1742.13, NZTA (2009) and NZTA (2008b).

Table 8.4: Benefits of treatments – integrated facilities

Objectives and priority	Application	Treatment	Benefits and considerations ⁽¹⁾
To create an environment in which all road users may share existing road space in a largely unsupervised manner. Motorists and cyclists must give way to pedestrians in a shared zone.	Applicable at locations with: <ul style="list-style-type: none"> high-volume pedestrian demand crossing demand along length of road lack of footpath space where other forms of crossing would be ineffective low motorised traffic volumes no requirement for a through route. 	Shared zone ⁽²⁾	<ul style="list-style-type: none"> Environment is adapted for low-speed. Image of street changed to increase awareness of different conditions. Improves safety and amenity for pedestrians and cyclists without affecting access. Pedestrians have legal priority. Provides for flexible parking arrangements. Usually restricts vehicle type. High cost, motorists may not observe speed restrictions during periods of low pedestrian and cyclist use.
		Shared space ⁽²⁾	<ul style="list-style-type: none"> Removal, or at least reduction, in traffic control devices. Reduction or removal of separation between vehicles and pedestrians. Vehicle-pedestrian interaction increases as level of demarcation is reduced. Improves pedestrian movement and comfort by reducing dominance of motor vehicles. Normal priorities apply, but design encourages sharing. Department for Transport (2011) provides guidance on how physical features can influence the level of sharing.

Objectives and priority	Application	Treatment	Benefits and considerations ⁽¹⁾
School zone and LATM schemes generally maintain motorist priority.	Applicable at locations with: <ul style="list-style-type: none"> high or peak pedestrian and cyclist user demand associated with school or adjacent route to school high drop-off/pick-up activity. 	School zone	<ul style="list-style-type: none"> Speed control through signage and visual aids. May be implemented by time-of-day.
		Local Area Traffic Management schemes	<ul style="list-style-type: none"> Speed control through use of devices in a systematic way throughout a local area.

1 See Section 4, Part 8 of the Guide to Traffic Management (Austroads 2016g), Part 4 of the Guide to Road Design (Austroads 2017a), AS 1742.9, AS 1742.10, AS 1742.13 and NZTA (2009).

2 For further guidance on shared zones and shared space, see Commentary 3 of the Guide to Traffic Management Part 7: Traffic Management in Activity Centres (Austroads 2015l).

Table 8.5: Guideline for selection of facilities according to road classification

Facility	Freeway/motorway	Primary arterial urban/(rural)	Secondary arterial	Collector road	Local street
Refuge/traffic island, median	X	O	O	A	A
Kerb extension	X	X/(O) ⁽³⁾	O	A	A
Road narrowing, indented parking	X	X	X	A	A
Pedestrian fencing ⁽¹⁾	X ⁽²⁾	O	O	O	X
Speed control device	X	X	X	O	A
Pedestrian (Zebra) crossing	X	X	O	O	A
Children's crossing	X	X	X	O	A
Pedestrian traffic signals	X	A/(X)	A	O	X
Grade separated	A	O	O	X	X
Mall	X	X	X	O	O
Integrated	X	X	X	X	O

1 Pedestrian fencing in the context of this table is an enhancement to a facility provided to guide pedestrians to away from an unsafe crossing location.

2 Pedestrian fence located within the road reservation is inappropriate on freeways or motorways because pedestrians are not generally present. However, boundary fences are normally erected along urban freeways or motorways to prevent access between interchanges, including pedestrian access.

3 Kerb extensions are not usually provided on urban primary arterial roads as road capacity and traffic efficiency are most important. However, a kerb extension at an appropriate set back from the edge of traffic lane may be appropriate on the approaches to a rural village as a form of 'gateway' treatment, the objective being to encourage drivers to reduce speed.

Notes:

A = Most likely to be an appropriate treatment.

O = May be an appropriate treatment.

X = Usually an inappropriate treatment.

X/(O) = Represents urban/(rural).

8.2.2 Bicycle Path Terminal Treatments at Road Crossings

Where a path crosses a road, in most instances it is unnecessary to use restrictive devices to slow cyclists down before they cross a road. The preferred treatment is a connection without the use of other devices. Where there is a safety issue identified that cannot be overcome by other means, it may be necessary to add special termination treatments designed to slow cyclists (Refer also to the *Guide to Road Design Part 6A*, Austroads 2017c).

Where it has been found that a treatment is required, the treatment should:

- provide safe and convenient access for all path users, including pedestrians with disability and/or mobility difficulty
- enhance the safety of cyclists accounting for factors such as gradient, proximity of roads, path alignment and anticipated category of users
- allow passage of bicycles without the need for cyclists to dismount
- allow passage of other types of bicycle (e.g. tandem bicycles and bicycles with trailers to transport infants)
- provide smooth and correctly orientated ramps, and well placed holding rails where appropriate.

If not appropriately designed, terminal treatments can be hazardous to cyclists who will circumvent them if the treatment is too restrictive. Well-designed treatments may involve narrowing of the path or deviation of the cyclists a short distance in advance of the crossing, together with landscaping or other physical barriers to prevent cyclists from travelling around the treatment. On paths that carry high-volumes of cyclists provision of a narrow median in the path may be beneficial in managing and separating opposing cyclist flows near the crossing (AS 1742.9, Section 3.7).

8.2.3 Crossings at Signalised Facilities

Pelican and Puffin crossings

Pelican and Puffin (Pedestrian User-Friendly Intelligent) crossings are pedestrian operated signals with operational modifications. Pelican crossings have a flashing yellow phase that enables drivers to proceed once pedestrians have cleared the crossing. Puffin crossings have additional detectors to monitor the progress of pedestrians on the crossing allowing the crossing time to be reduced when a pedestrian has crossed quickly, or extended for slow-moving pedestrians. See Section 4, *Part 9* of the *Guide to Traffic Management* (Austroads 2016c) and the *Guide to Road Design Part 4* (Austroads 2017a). See also AS 1742.9, AS 1742.10, AS 1742.14 and NZTA (2009).

An evaluation of a Puffin pedestrian crossing installation with nearside displays for pedestrians in New Zealand found that Puffin crossings offered advantages over normal signalised midblock crossings and that the nearside displays gave rise to better user compliance than did the usual farside displays (Murray & Walton 2009).

Pedestrian countdown timers

Pedestrian countdown timers (PCT), provide users with information on the available crossing time remaining. They are used widely in some European countries and are mandated for use in the United States for all new traffic signal installations.

Trials in Australia and New Zealand (ARRB Group 2010a, ARRB Group 2010b, ARRB Group 2011, ARRB Group 2015, Blake 2013 and Wanty & Wilkie 2010) have found mixed results in relation to pedestrian safety and compliance, although PCT were associated with increased pedestrian amenity due to reduced delay at the crossings. A trial undertaken in Sydney (ARRB Group 2015) found that the PCT were most beneficial where there was an exclusive pedestrian phase operated, while safety risks were higher at sites with parallel pedestrian and vehicle phasing. Evaluations undertaken in Canada and the USA (Camden et al. 2012; Richmond et al. 2014; Kapoor & Magesan 2014; Pulugurtha et al. 2010; Huitema et al. 2014) also found mixed results.

Surveys during trials have found pedestrians were in favour of the PCTs and that they often perceive PCTs to be safer. Although trial results have been mixed, most Australian jurisdictions have installed PCTs, typically at CBD intersections that experience high pedestrian volumes.

In some countries, a different type of PCT that provides a countdown of pedestrian waiting time (i.e. until the start of a pedestrian Walk interval) has been used. However, a limitation of their use is that they are incompatible where signals have adaptive traffic control.

8.2.4 Road Crossings by Off-road Bicycle Paths in Rural and Outer Urban Areas

Off-road paths and rail trails (constructed along disused or abandoned railway corridors) in rural and outer urban areas often cross roads carrying low to medium volumes of traffic at higher speeds. Drivers using these roads do not expect to encounter a crossing or give way to pedestrians or cyclists and typically the treatment is to provide physical aids where trail users are required to give way. Advanced warning signs should be provided and the crossing should have a high level of conspicuity. It is most important that drivers approaching the crossing have adequate stopping sight distance to the crossing point and to all trail users approaching the crossing. For further guidance, refer to *Parts 4A and 6A of the Guide to Road Design* (Austroads 2017b, 2017c) and AS 1742.7.

8.2.5 Road Crossings Used by Horse Riders

Trails in rural and outer urban areas may also be used by horse riders as well as pedestrians and cyclists. In such cases it is important that road crossings are designed to enable horse riders to manoeuvre the horse into a position where they can safely await gaps in road traffic and cross the road. Should a crossing be signalled a second pedestrian button should be provided at a height where it can be safely and conveniently operated by riders.

8.3 Bicycle Treatments at Intersections

Where a bicycle lane exists or is planned on roads leading up to an intersection the design should assist the safe passage of cyclists through the intersection. In rural areas this may simply require an adequate clearance between the islands and left edge of the road to provide continuity of shoulders through the intersection. In urban areas it will often involve a bicycle lane marked through the intersection. In some jurisdictions, cyclists are permitted to use footpaths and therefore share crossing facilities. In catering for the needs of cyclists at intersections designs should conform to the standard approach and principles of traffic engineering design for all road users. This practice seeks to provide traffic facilities which clearly indicate the nature and extent of traffic movements and the potential conflicts. All road users, including cyclists, will benefit from a traffic environment which assists the road user to anticipate potential conflicts and encourages traffic awareness and predictable behaviour.

The types of lanes that may have to be incorporated into traffic routes, and therefore intersections, include bicycle lanes, bicycle/car parking lanes and wide kerbside lanes. These and other types of bicycle lanes are discussed in the *Guide to Road Design Part 3* (Austroads 2016e) and *Guide to Traffic Management Part 4* (Austroads 2016b). Because of the wide range of ages and ability of cyclists (Section 2.4.2), off-road paths may be considered to accommodate for young and/or inexperienced cyclists or competent but more risk averse ('interested but concerned') cyclists within intersection layouts (*Cycling Aspects of the Austroads Guides*, Austroads 2017d).

Bicycle lanes (simple delineation or a green surface treatment) through intersections can:

- increase awareness of cyclists
- reduce conflict by providing dedicated space for cyclists
- improve cyclist comfort
- improve continuity and connectivity for cyclists (if the facility connects to other cycling lanes or paths)
- assist cyclists perform right-turn manoeuvres more safely (by providing space to wait and undertake such manoeuvres).

Some agencies have developed warrants for provision of the green surface treatment for bicycle lanes, for example TMR (2016c) *TRUM Volume 1 Part 10* or ACT *Design Standards for Urban Infrastructure* (ACT Government 2007).

8.3.1 Unsignalised Intersections

At unsignalised intersections, bicycle lanes should:

- be continuous through the intersection
- be well delineated as a space for cyclists by appropriate placement of pavement logos
- have green surfacing, particularly in complex or high-risk situations.

Continuing bicycle lanes or cycle tracks through intersections provide cyclists priority at the intersections while bicycle paths generally do not have priority at intersections (Section 2.4.2).

A bicycle lane through an unsignalised intersection may also be provided where the geometric design elements of the intersection (catering to motor vehicle requirements) result in risks for cyclists. 'A short, marked bicycle lane through an intersection may provide safety advantages to cyclists provided that its termination point does not lead cyclists into an unsafe situation' (*Cycling Aspects of Austroads Guides*, Austroads 2017d). A risk and site assessment of the intersection should inform the extent of the lane & whether it should be coloured. Austroads (2017d) notes that 'terminating at a sealed shoulder or in a wide kerbside lane would normally deliver adequate safety'.

Further information and examples on the integration of bicycle facilities into unsignalised intersections is provided in the *Guide to Road Design 4A* (Austroads 2017b):

- basic and channelised turn treatments
- refuge within an unsignalised intersection.

8.3.2 Signalised Intersections

As noted in Section 2.4.2, commuter cyclists often choose to ride on the major roads because the trip length and travel time is less than on alternative routes including paths.

Wherever practicable, traffic routes and signalised intersections should provide the space and operational conditions to support cycling as a viable alternative mode of transport. The needs of cyclists should be considered in relation to detection, signal phasing and timing, and road space. Off-road paths are often provided for non-commuter cyclists (e.g. the young and novice cyclists) and these paths often have to be incorporated into the functional layouts of signalised intersections.

The operation of traffic signals to accommodate cyclists is discussed in GTM 9 and traffic signal displays for cyclists in GTM 10. (Cycling Aspects of Austroads Guides, Austroads 2017d)

The report *Effectiveness and Selection of Treatments for Cyclists at Signalised Intersections* (Austroads 2011) examined the safety impacts of providing cycling facilities, in combination with other features, at signalised intersections. Key findings of this study included:

- The substantial benefit of coloured cycle facilities
- The worst lane configuration for cyclists is a shared left and through lane. Exclusive left-turn lanes (CHL) are around four times safer, because the conflict with left turning vehicles at the diverge is much safer for cyclists than at the intersection.
- For safety, having enough space was more important than whether cycle lanes were marked (but marked lanes are more attractive). Wider cycle lanes built to high standards were safer, while narrow ones were worse.

Cyclist requirements for signalised approaches are outlined in Table 4.3 (arterial roads) and Table 4.4 (local roads). In order to maximise cyclist safety at signalised intersections, bicycle lanes should be provided on the approach and departure of the intersection and enhanced with green coloured pavement marking where possible. Cyclist treatments and facilities at signalised intersections are described in the *Guide to Road Design Part 4* (Austroads 2017a), including:

- exclusive right-turn lanes and hook turns for cyclists
- bicycle lanes marked at signalised intersections
- head-start and expanded storage areas
- left turn treatments
- cyclist bypass lanes at signalised T-intersections.

8.4 Intersections of Paths with Paths

Intersections between paths, bicycle paths, separated or shared paths can be relatively basic but do require the same consideration of factors as those applied to road intersections. Some specific considerations are:

- appropriate sight distance, low gradients, adjacent areas clear of obstacles
- speed control and priority allocation where volumes are elevated
- cross-intersections which allow high-speed conflicts should not be provided
- provision of holding rails where main path volumes are high.

On shared paths and their intersections, the potential for conflict between cyclists, pedestrians and other users should be considered and, as far as possible, be minimised through traffic management and design measures.

Key conflict issues between pedestrians and cyclists on shared paths and footpaths are identified and described in Austroads (2006), and guidance on key conflict minimisation strategies and options are presented. Summary information on these conflicts is provided in the (Austroads 2006).

For further guidance on intersections of paths with paths, refer to Section 6 of *Part 6A* of the *Guide to Road Design* (Austroads 2017c) and AS 1742.9.

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Appendix A Signalised Intersection Guidance

Guidance on signalised intersections and traffic signals is provided in other parts of the *Guide to Traffic Management* and the *Guide to Road Design*. Key sections are shown in Table A 1.

Table A 1: Key Austroads guidance relating to signalised intersections and traffic signals

Guide	Title	Edition ⁽¹⁾	Section	Signalised intersection related topics
Guide to Traffic Management Part 2	Traffic Theory	2015j	4	Queuing
			7.4	Platoon dispersion
Guide to Traffic Management Part 3	Traffic Studies and Analysis	2013	6.4	Capacity analysis, intersection performance and other analysis procedures pertaining to signalised intersections
Guide to Traffic Management Part 9	Traffic Operations	2016c	6.2	Traffic signal techniques and network operation planning
			6.3	Traffic signal system overview
			6.4	Movements and phases
			6.5	Signal groups
			6.6	Traffic signal controllers
			6.7	Traffic detection
			6.8	Coordination of traffic signals
			6.9	Benefits of adaptive traffic signal control
			6.10	Active transit signal priority
			6.11	Complex signalised intersection situations
			6.12	Implementation
			6.13	System monitoring and maintenance
			6.14	Signal equipment maintenance
6.15	Emergency vehicle priority			
Guide to Traffic Management Part 10	Traffic Control and Communication Devices	2016d	8.1	Types of traffic signal displays and their meanings
			8.2	Signal face layouts
			8.3	Display sequences
			8.4	Location of signal faces
			8.5	Special traffic signal applications and facilities
Guide to Traffic Management Part 13	Road Environment Safety	2015k	5.2.7	Road safety considerations at traffic signals
Guide to Road Design Part 4	Intersections and Crossings – General	2017a	Appendix B2	Geometric layout and the operation of signalised intersections
			Appendix B3	Signalised intersection layouts
			Appendix B4	Traffic lanes, pedestrian and cyclist treatments
Guide to Road Design Part 4A	Unsignalised and Signalised Intersections	2017b	9.2	Sight distances

¹ The sections identified refer to the latest editions of the *Guide to Traffic Management* and *Guide to Road Design* at the time of writing. However, sections may change in future updates. See the Austroads website for more up-to-date information.

Appendix B Safe System Assessment Framework Summary

The Safe System Assessment Framework (SSAF) is a practitioner assessment tool for measuring how well a particular design or concept aligns with the Safe System objective of minimising severe injury. It can be used to highlight areas of residual severe injury risk, and to assist in identifying design improvements to achieve the Safe System objective. The SSAF approach is documented in *Safe System Assessment Framework* report (Austroads 2016a).

The SSAF has been adopted by a number of state road agencies to assess the alignment of projects with Safe System objectives. It has been found to be particularly useful in identifying key safety risks, including at concept design stage.

Safe System assessment typically involves:

- identifying the objectives for the assessment, including its purpose (Appendix B.1)
- deciding on the scale and depth of the assessment (Appendix B.2)
- setting the context, including identifying the function of the road, relevant speed environment, main road user types, and likely vehicle composition (Appendix B.3)
- applying the 'Safe System Matrix' where major crash types are assessed in relation to key sources of risk: exposure (traffic and vulnerable road user volumes), crash likelihood and severity (Appendix B.4).

A case study illustrating the application of the SSAF may be found in the *Safe System Assessment Framework* report (Austroads 2016a). The example provided in this Appendix is for illustration purposes only.

B.1 Assessment Objectives

The first step is to identify and document the objective of the assessment. The framework can be used for a number of different objectives, for instance:

- identifying whether a project or solution will produce a Safe System outcome
- identifying the level of Safe System alignment
- identify and document Safe System-relevant issues that mean the project will not be aligned (i.e. severe injury risks)
- suggesting solutions that would move the project closer towards, or in full alignment with Safe System objectives
- develop and compare alternative project options.

B.2 Scale and Depth of Assessment

The desired depth of assessment needs to be identified, for instance:

- at high level at the planning stage (key issues only, broad level of alignment, areas for improvement)
- in more detail for individual project components (quantitative level of Safe System alignment, identify specific problems and solutions)

Where a high degree of precision is required, the subjective assessment proposed in the framework can be replaced by more detailed quantitative information. For example, information could be added using the Australian National Risk Assessment Model (ANRAM) or the Extended Kinetic Energy Management Model (X-KEMM-X). Having this objective in mind will help to focus the assessment on the overall objectives.

B.3 Setting the Context

The prompts in Table B 1 below provide guidance on considerations when setting the context.

Table B 1: Template for setting the project context

Prompts
<ul style="list-style-type: none"> • What is the reason for the project? Is there a specific crash type risk? Is it addressing specific issues such as poor speed limit compliance, road access, congestion, future traffic growth, freight movement, amenity concerns from the community, maintenance/asset renewal, etc. • What is the function of the road? Consider location, roadside land use, area type, speed limit, intersection type, presence of parking, public transport services and vehicle flows. What traffic features exist nearby (e.g. upstream and downstream)? What alternative routes exist? • What is the speed environment? What is the current speed limit? Has it changed recently? Is it similar to other roads of this type? How does it compare to Safe System speeds? What is the acceptability of lowering the speed limit at this location? • What road users are present? Consider the presence of elderly, schoolchildren and cyclists. Also, note what facilities are available to vulnerable road users (e.g. signalised crossings, bicycle lanes, school zone speed limits, etc.). • What is the vehicle composition? Consider the presence of heavy vehicles (and what type), motorcyclists and other vehicles using the roadway.

Source: Austroads (2016a).

B.4 Applying the ‘Safe System Matrix’

B.4.1 Safe Roads and Roadsides and Speeds

The main part of SSAF is the application of the Safe System Matrix focussed on the contribution of road infrastructure design and speeds to severe injury risk. The purpose of the matrix is to assess different major crash types that have been identified from research as the predominant contributors to fatal and serious crash outcomes. These are run-off-road, head-on, intersection, other (typically rear-end and side-swipe), pedestrian, cyclists and motorcyclist crashes. Different elements of the matrix, along with examples of road attributes associated with risk generators, are shown in Table B 2.

As part of the assessment, a score is allocated to each cell of the matrix based on available information. This is typically based on subjective assessment by teams of road safety experts. Scores of between zero (0) and four (4) are provided at each cell. A score of zero (0) indicates a full alignment with the Safe System vision for that component of risk of a given crash type. The higher the score, the further the project is from a Safe System condition – a score four (4) would be for the most unfavourable safety condition for the given context. Scores should be allocated considering the factors of interest shown in Table B 2 and the scoring guidance provided in Table B 3.

Table B 2: Safe System Assessment Framework for infrastructure projects

	Run-off-road	Head-on	Intersection	Other	Pedestrian	Cyclist	Motorcyclist
Exposure	AADT; length of road segment	AADT; length of road segment	AADT for each approach; intersection size	AADT; length of road segment	AADT; pedestrian numbers; crossing width; length of road segment	AADT; cyclist numbers; pedestrians	AADT; motorcycle numbers; length of road segment
Likelihood	Speed; geometry; shoulders; barriers; hazard offset; guidance and delineation	Geometry; separation; guidance and delineation; speed	Type of control; speed; design, visibility; conflict points	Speed; sight distance; number of lanes; surface friction	Design of facilities; separation; number of conflicting directions; speed	Design of facilities; separation; speed	Design of facilities; separation; speed
Severity	Speed; roadside features and design (e.g. flexible barriers)	Speed	Impact angles; speed	Speed	Speed	Speed	Speed

Note: When undertaking SSAF assessment for intersections, all legs and access points should be included. The length of each approach (leg) should be determined by features that influence the safety performance of the intersection (e.g. start of turning lane, parking limit, sight distance, geometric elements, etc.).

Source: Adapted from Austroads (2016a).

Table B 3: Safe System matrix scoring system

Road user exposure	Crash likelihood	Crash Severity
0 = there is no exposure to a certain crash type. This might mean there is no side flow or intersecting roads, no cyclists, no pedestrians, or motorcyclists).	0 = there is only minimal chance that a given crash type can occur for an individual road user given the infrastructure in place. Only extreme behaviour or substantial vehicle failure could lead to a crash. This may mean, for example, that two traffic streams do not cross at grade, or that pedestrians do not cross the road.	0 = should a crash occur, there is only minimal chance that it will result in a fatality or serious injury to the relevant road user involved. This might mean that kinetic energies transferred during the crash are low enough not to cause a fatal or serious injury (FSI), or that excessive kinetic energies are effectively redirected/dissipated before being transferred to the road user. Users may refer to Safe System-critical impact speeds for different crash types, while considering impact angles, and types of roadside hazards/barriers present.
1 = volumes of vehicles that may be involved in a particular crash type are particularly low, and therefore exposure is low. For run-of-road, head-on, intersection and 'other' crash types, AADT is < 1 000 per day. For cyclist, pedestrian and motorcycle crash types, volumes are < 10 units per day.	1 = it is highly unlikely that a given crash type will occur.	1 = should a crash occur, it is highly unlikely that it will result in a fatality or serious injury to any road user involved. Kinetic energies must be fairly low during a crash, or the majority is effectively dissipated before reaching the road user.

Road user exposure	Crash likelihood	Crash Severity
<p>2 = volumes of vehicles that may be involved in a particular crash type are moderate, and therefore exposure is moderate.</p> <p>For run-of-road, head-on, intersection and 'other' crash types, AADT is between 1 000 and 5 000 per day.</p> <p>For cyclist, pedestrian and motorcycle crash types, volumes are 10–50 units per day.</p>	<p>2 = it is unlikely that a given crash type will occur.</p>	<p>2 = should a crash occur, it is unlikely that it will result in a fatality or serious injury to any road user involved. Kinetic energies are moderate, and the majority of the time they are effectively dissipated before reaching the road user.</p>
<p>3 = volumes of vehicles that may be involved in a particular crash type are high, and therefore exposure is high.</p> <p>For run-of-road, head-on, intersection and 'other' crash types, AADT is between 5 000 and 10 000 per day.</p> <p>For cyclist, pedestrian and motorcycle crash types, volumes are 50–100 units per day.</p>	<p>3 = it is likely that a given crash type will occur.</p>	<p>3 = should a crash occur, it is likely that it will result in a fatality or serious injury to any road user involved. Kinetic energies are moderate, but are not effectively dissipated and therefore may or may not result in an FSI.</p>
<p>4 = volumes of vehicles that may be involved in a particular crash type are very high, or the road is very long, and therefore exposure is very high.</p> <p>For run-of-road, head-on, intersection and 'other' crash types, AADT is > 10 000 per day.</p> <p>For cyclist, pedestrian and motorcycle crash types, volumes are > 100 units per day.</p>	<p>4 = the likelihood of individual road user errors leading to a crash is high given the infrastructure in place (e.g. high approach speed to a sharp curve, priority movement control, filtering right turn across several opposing lanes, high speed).</p>	<p>4 = should a crash occur, it is highly likely that it will result in a fatality or serious injury to any road user involved. Kinetic energies are high enough to cause an FSI crash, and it is unlikely that the forces will be dissipated before reaching the road user.</p>

Source: Austroads (2016a).

In addition to the score, comments are provided relating to each of the cells. This helps to record the rationale for the score, and to identify the specific issues of concern. This is very helpful in resolving the key residual risk factors for each project.

Once a score is provided in each cell for the exposure, likelihood and severity rows, the product of each column is calculated and entered in the final row, labelled 'product'. The purpose of this multiplicative approach is that if a score of zero (0) has been given for any component of a crash type (i.e. exposure, likelihood or severity), that crash type receives a total of zero (0) and is eliminated from the score (as it has reached a Safe System condition). The maximum score for each crash type column is 64. Table B 4 shows an example assessment to illustrate the approach (note the example in this Appendix is for illustration purposes only, in order to demonstrate application of the framework and does not represent final designs).

As an approximation, a design with the crash type score of less than 16 can be considered highly-aligned with Safe System for that crash type (e.g. run-off-road or head-on scores in Table B 4). A design can be considered moderately-aligned between 16 and 32, and poorly-aligned above 32. The SSAF is a subjective tool and scores are indicative of Safe System alignment.

Table B 4: An example of a Safe System Assessment

	Run-off-road	Head-on	Intersection	Other	Pedestrian	Cyclist	Motorcyclist
Exposure	4	4	4	4	4	1	4
Likelihood	1	1	3	3	3	4	3
Severity	2	2	3	1	4	4	4
Product	8 / 64	8 / 64	36 / 64	12 / 64	48 / 64	16 / 64	48 / 64
Total SSAF Score							176 / 448

The sum of the scores for each crash type is then added to calculate the ‘Total SSAF Score’. This score is out of a possible 448 and represents the Safe Speeds and Safe Roads and Roadside pillars’ contribution to Safe System for the project. The closer the total score is to zero (0), the more the project in question is aligned with the Safe System objective. Attention to minimising individual crash type scores is still needed.

As a rule-of-thumb, total SSAF scores of less than 112 can be considered highly-aligned with Safe System, 112 to 224 moderately-aligned, and above 224 poorly-aligned. Consistency of Safe System alignment across all crash types needs to be considered. For example, a project can be qualified well-aligned with Safe System for passenger and heavy vehicles, but poorly aligned for vulnerable road users.

As noted previously, SSAF scores are indicative of Safe System alignment. SSAF scores should not be compared between different locations, or used for site prioritisation, as the values are influenced by site conditions beyond practitioners’ control (e.g. AADT, speed environment). Scores can be compared for alternative design options for the same project in order to develop and select the option which is most Safe System-aligned.

B.4.2 Other Pillars

Along with the infrastructure- and speed-related assessment, broader issues are also assessed as part of this process. The Safe System approach demands that each pillar of the system must work together to help produce Safe System outcomes. The system comprises safe roads, safe speed, safe vehicles, safe road users and safe post-crash care. Although safe roads and speeds are typically included in safety reviews for infrastructure projects, the other elements are seldom considered.

In many circumstances these other pillars will have strong bearing on safety outcomes, and it is often the case that designers will have some ability to influence these to produce safer travel outcomes. This synergy is important to account for as it may reduce capital costs and improve overall project effectiveness.

For these reasons, the remaining pillars need to be assessed when reviewing projects. Table B 5 provides some prompts for additional issues considered during the assessment.

Table B 5: Additional Safe System components for consideration in infrastructure projects

Pillar	Prompts
Safe Road Users	<ul style="list-style-type: none"> • Are road users likely to be alert and compliant? Are there factors that might influence this? • What are the expected compliance and enforcement levels (alcohol/drugs, speed, road rules, and driving hours)? What is the likelihood of driver fatigue? Can enforcement of these issues be conducted safely? • Are there special road uses (e.g. entertainment precincts, elderly, children, people with disability or mobility difficulty, on-road activities, motorcyclist route), distraction by environmental factors (e.g. commerce, tourism), or risk-taking behaviours?
Safe Vehicles	<ul style="list-style-type: none"> • What level of alignment is there with the ideal of safe vehicles? • Are there factors that might attract large numbers of unsafe vehicles (e.g. farm machinery)? Is the percentage of heavy vehicles too high for the proposed/existing road design? Do recreational motorcyclists use this route? • Are there enforcement resources in the area to detect non-roadworthy, overloaded or unregistered vehicles and thus remove them from the network? Can enforcement of these issues be conducted safely? • Has vehicle breakdown been catered for?
Post-crash care	<ul style="list-style-type: none"> • Are there issues that might influence safe and efficient post-crash care in the event of a severe injury (e.g. congestion, access-stopping space)? • Do emergency and medical services operate as efficiently and rapidly as possible? • Are other road users and emergency response teams protected during a crash event? Are drivers provided the correct information to address travelling speeds on the approach and adjacent to the incident? Is there reliable information available via radio, VMS etc.? • Is there provision for e-safety (i.e. safety systems based on modern information and communication technologies, C-ITS)?

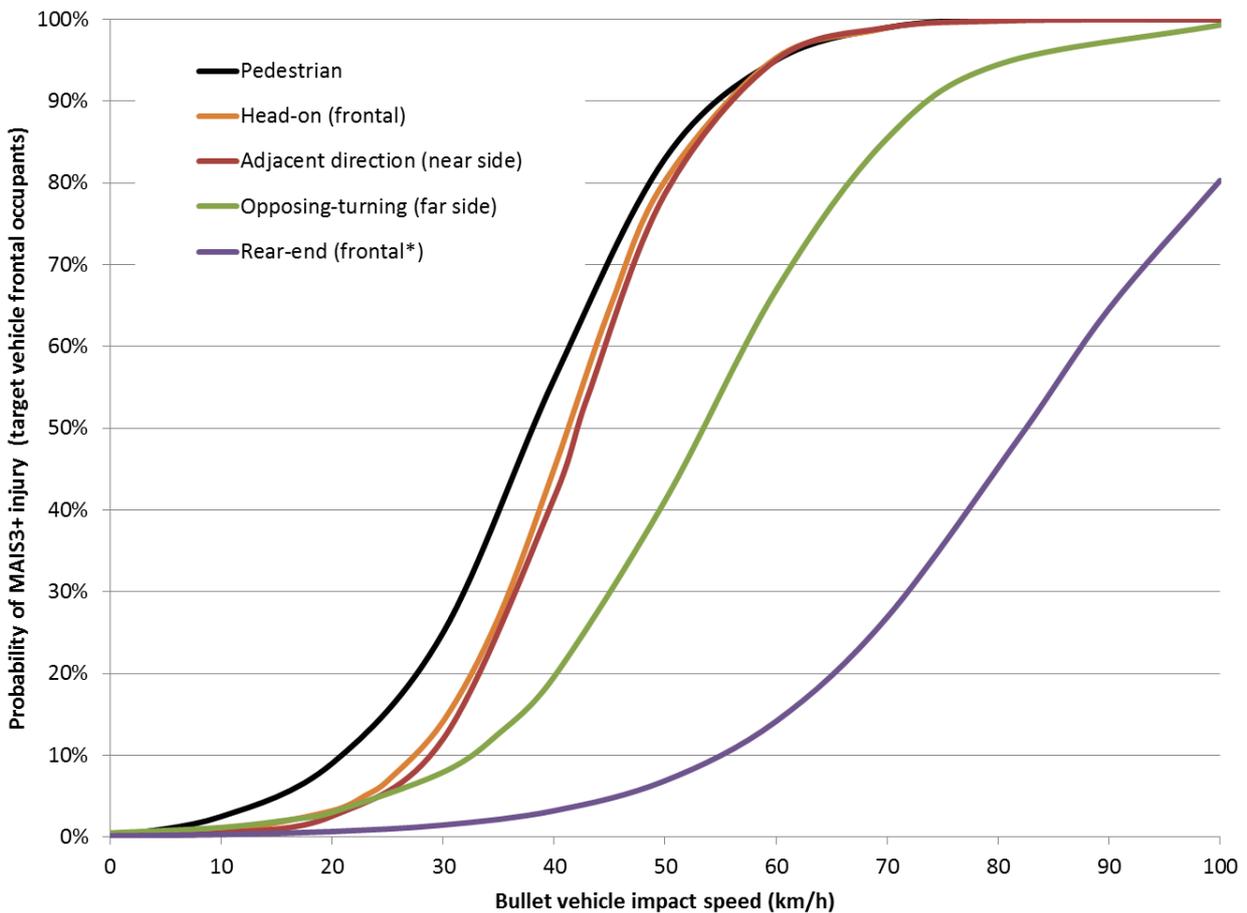
Source: Adapted from Austroads (2016a).

Commentary 1 Relationship Between Vehicle Speeds and Likelihood of Severe Injury

Improving the Performance of Safe System Infrastructure (Austroads 2015d) reported Safe System critical impact speeds for five major crash types, based on a small sample of speed measurements. This research indicated that, for crashes involving vulnerable road users, collision speeds of < 30 km/h, and moving towards 20 km/h, reduced the likelihood of serious injuries (Figure C1 1). Further investigation is needed to provide guidance on appropriate design speeds at intersections.

A geometric analysis presented in Bicycle Safety at Roundabouts (Austroads 2017e) indicated that vehicle speeds through urban local road roundabouts could be higher than the Safe System target speed (< 30 km/h) when vehicles and vulnerable road users mix. This is determined using the methods outlined in the *Guide to Road Design Part 3* (Austroads 2016e). If this translates to other similar roundabouts, the threshold speed of 30 km/h may be too high. In view of this, a speed of less than 30 km/h may be needed to reduce the likelihood of serious injuries.

Figure C1 1: Proposed model of severe injury probability vs bullet vehicle impact speeds in different crash types



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

Notes:

The bullet speed is the speed of a vehicle that collides into another vehicle.
 MAIS3+ is widely considered the serious injury threshold and includes fatality.
 Source: Austroads (2015d), based on Bahouth et al. (2014), Davis (2001).

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Commentary 2 **Turn Treatment Research Findings**

Arndt (2004) found that:

- Some BAR turn treatments (and AUR treatments) in the study included a narrow median. The rear-end major vehicle crash rate was found to decrease substantially with median width, regardless of the type of median (painted, raised or depressed). The median enables the right-turning vehicle to be positioned further away from the point of conflict in the through lane, lowering the probability of the vehicle being struck.
- Providing a median at a BAR turn treatment is unlikely to be a practical design consideration in many cases. However, there may be scope at some existing BAR treatments to consider introducing such a median by reducing the shoulder width. This may be a low-cost option of achieving a reduction in the rear-end major vehicle crash rate.
- MNR turn treatments record the highest rear-end-major vehicle crash rate of all the turn treatments (100 times higher than CHR turn treatments). This result likely reflects the fact that MNR turn treatments, unlike any other turn treatment, provide no specific facilities for through traffic to avoid turning traffic.
- Type AUR turn treatments record a rear-end major vehicle crash rate 30 times higher than do CHR [and CHR(S)] turn treatments.

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Commentary 3 **Research findings on Minor Road Stand-up Lanes at Unsignalised Intersections**

Arndt (2004) showed that the angle-minor vehicle crash rate at unsignalised intersections with two stand-up lanes on the minor road is significantly higher than for one stand-up lane. A free left-turn lane did not constitute an additional stand-up lane. The higher crash rate can be attributed to vehicles in the offside stand-up lane blocking visibility for drivers of vehicles in the nearside lane, and vice versa as illustrated in Figure 3.4 in the body of this guide.

The angle-minor vehicle crash rate was found to be 1.5 times higher for those conflict points where there was an adjacent minor road stand-up lane in the direction of the relevant oncoming major road vehicles.

At T-intersections, this may not be a major problem because angle-minor vehicle crash rates for the various conflicts are generally low (except for one conflict type which is not affected by the visibility restrictions due to adjacent vehicles).

At cross-intersections, however, visibility restrictions due to adjacent vehicles will substantially increase an already high angle-minor vehicle crash rate for conflicts involving through movements from the minor road.

For the above reasons, only one stand-up lane should be provided on minor road approaches at unsignalised intersections, particularly at four-leg intersections with heavy through movements from the minor legs. Where two lanes are required for capacity reasons, installation of a left-turn slip lane or signalisation of the intersection should be considered.

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Commentary 4 **Additional Guidance on Service Lanes**

Service roads should not generally be carried through signalised intersections because they cause a reduction in:

- road safety due to the greater number of conflict points, the larger conflict area and the difficulty for right-turning drivers to select appropriate gaps in opposing traffic on two carriageways
- capacity because of increased pedestrian and vehicle clearance times.

Where there is insufficient separation between a major carriageway and a service road, two-way service roads cause operational issues at intersections with minor roads that also intersect with the major carriageway, for example:

- insufficient space for turning vehicles
- turning manoeuvres interlock
- queues at the major carriageways block through movement on the service road.

In addition, narrow outer separators cannot be satisfactorily treated to avoid glare and confusion that may arise from the headlights of vehicles travelling along the service road in the opposite direction to the traffic flow on the major carriageway and to the left of it.

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Commentary 5 **Staggered T-intersections Research Findings**

The realignment of minor road approaches at a staggered T-intersection requires drivers travelling through from a minor leg to initially turn onto the major road followed by turning onto the opposite minor road leg. Staggered T-intersections are deemed to be safer than four-way unsignalised intersections with aligned minor legs. Arndt (2004) found that four-way unsignalised intersections tend to experience higher crash rates than staggered T-intersections.

At four-way intersections where the minor legs are fully aligned, drivers can overlook the presence of the intersection and can perceive the minor road continuing straight ahead. This can be especially true in a rural setting.

Arndt (2004) and Chia, Jurewicz and Turner (2013) suggest that a left-right stagger may have a lower crash risk than right-left stagger, due to less hazardous conflict points being generated.

Chia, Jurewicz and Turner (2013) in *Road Geometry Study for Improved Rural Safety* (Austroads 2015i) recommended that staggered T-intersections should have:

- low major road traffic volumes (< 2000 veh/day)
- no significant curvature of the minor road approaches
- left-right stagger type
- stagger distance \geq 15 m
- advance warning signs on the major road.

Chia, Jurewicz and Turner (2013) concluded that a rural staggered T-intersection 'should not be provided where traffic analysis indicates the likelihood of operation at or near capacity within its design life'... and that 'if excessive delays are anticipated, then other intersection solutions should be considered' (Austroads 2015i).

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Commentary 6 Unconventional and Innovative Intersection Designs

The separation of conflicts in space has been investigated in a number of less conventional or innovative designs of intersection not common in Australia or New Zealand. Some designs are considered ‘unconventional’ due to their lack of use in a particular road network. However, in many cases they have been in existence for some time and used in other parts of the world. A number of emerging and innovative designs are also included, which include relatively new designs that may not yet be fully evaluated.

Most unconventional signalised intersection designs are based on the theory of repositioning the right-turn movement in order to:

- reduce the delays experienced by turning-traffic signal phases
- reduce the number of conflict points through separation.

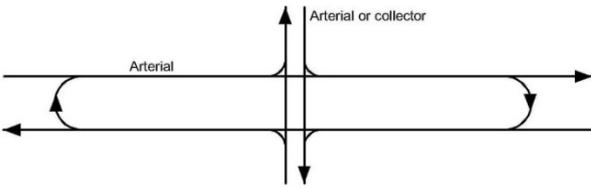
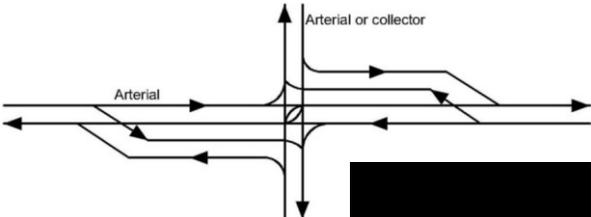
The benefits of various unconventional designs are dependent on site-specific characteristics such as road reserve width and traffic volumes. Unconventional designs have been found to be beneficial in a number of instances (Austroads 2007). However, their implementation has been limited to site-specific studies balancing considerations of right-of-way and local roads. Driver confusion may also be an issue, especially during the early stages of operation, due to unfamiliarity with uncommon intersection configurations.

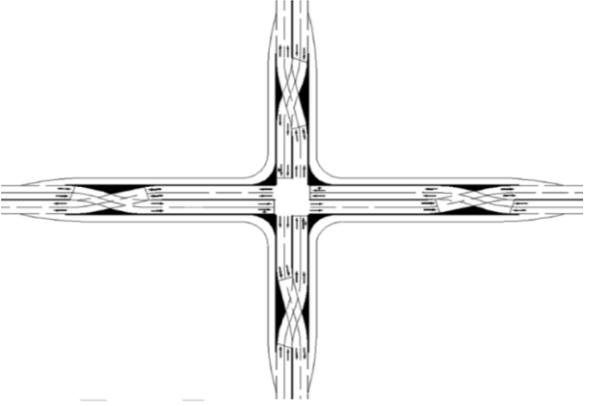
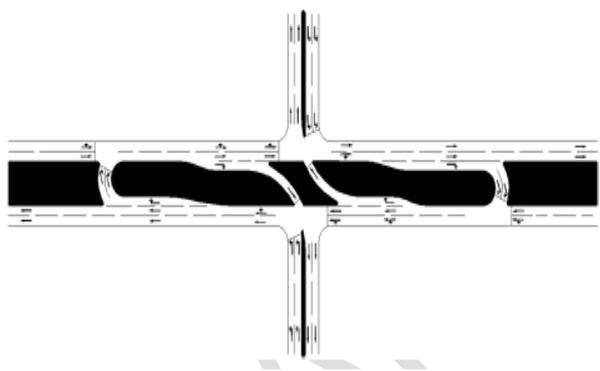
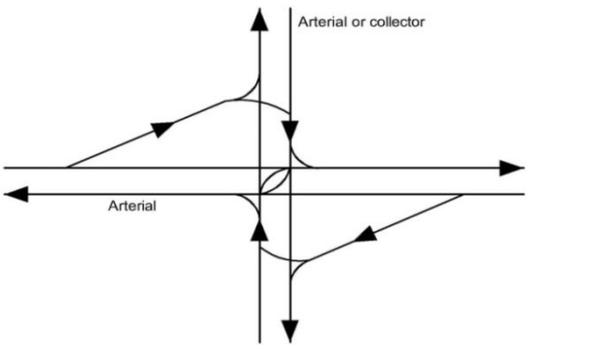
The safety performance of a number of innovative intersection designs were evaluated as part of a recent Austroads project (in press). Some of these have been used successfully internationally, but often not in Australia and/or New Zealand. Innovative designs that were assessed as having a low probability of a FSI crash included:

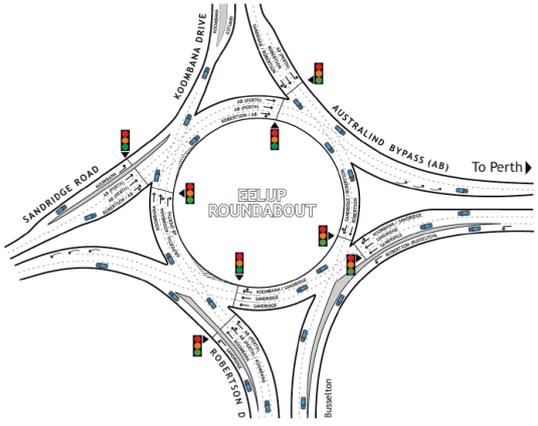
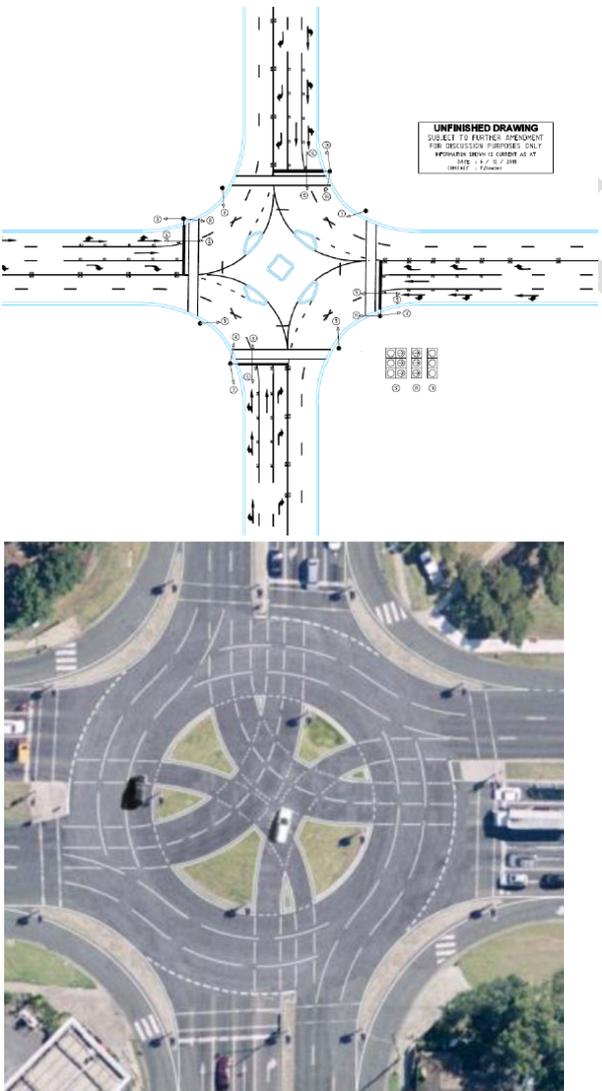
- signalised – signalised 3-leg roundabout, cut-through roundabout, divided arterial with speed humps
- unsignalised – flower roundabout, two-lane roundabout (3 or 4 leg).

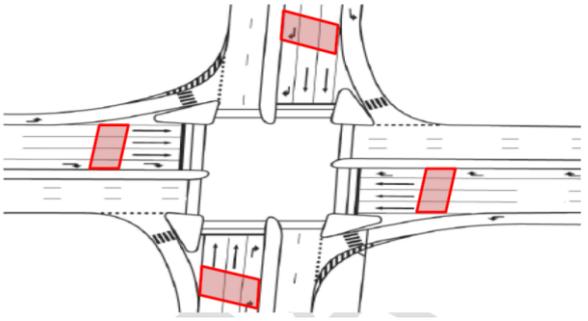
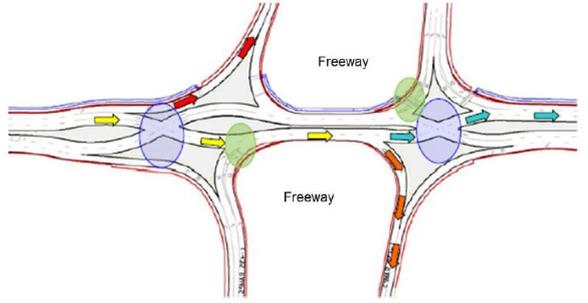
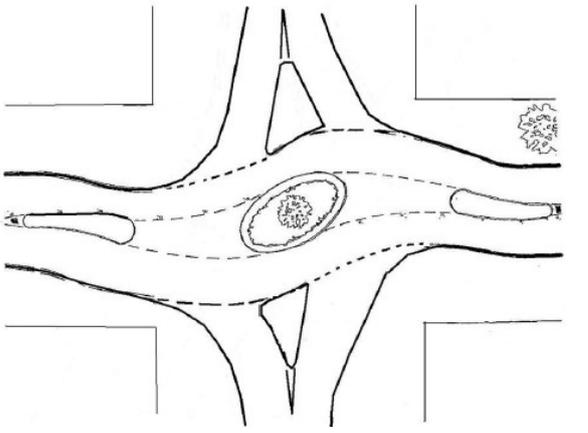
Unconventional and/or innovative intersection designs include those described in Table C6 1 . For further guidance on these and other unconventional intersection designs and overseas applications refer to Austroads (2007), Arup (2004), Hughes et al. (2010), Austroads (2015d) (*Improving the Performance of Safe System Infrastructure*) and Austroads (in press).

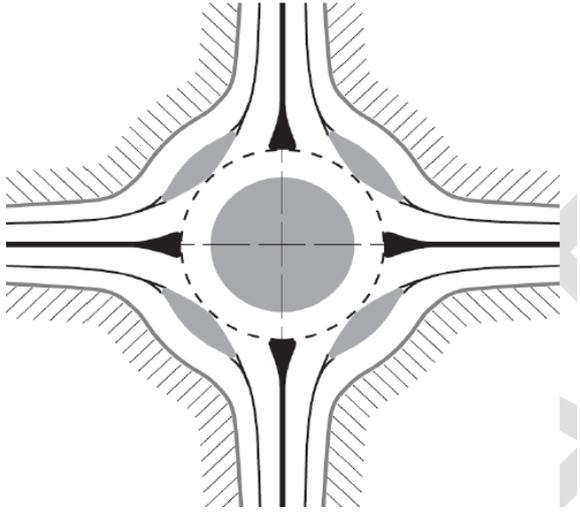
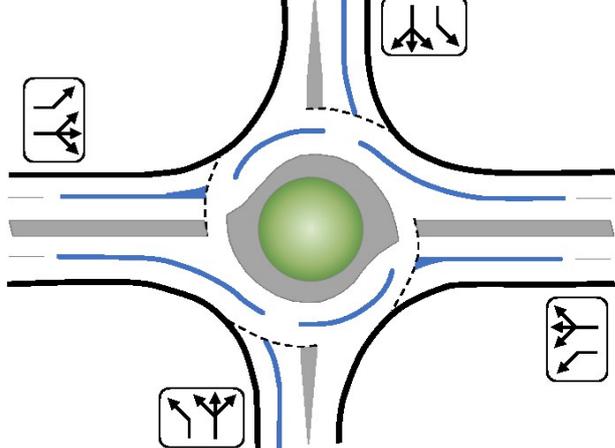
Table C6 1: Types of unconventional intersection designs

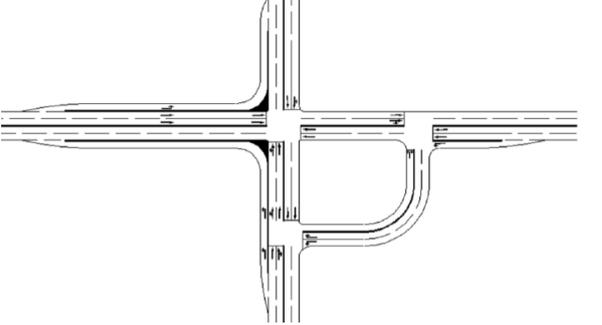
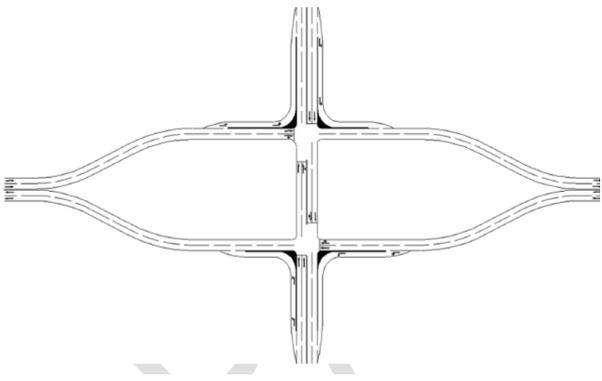
Intersection type	Comments	
Median U-turn intersection	Eliminates right-turns at an intersection by requiring motorists to continue straight through an intersection, use a downstream median U-turn to reverse direction, then return to intersection and make a left-turn.	 <p>Source: Adapted from Arup (2004).</p>
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.	 <p>Source: Adapted from Arup (2004).</p>

Intersection type	Comments	
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.	 <p>Source: Austroads (in press).</p>
Superstreet intersection	<p>Similar to a median U-turn intersection, but applied to minor street traffic (e.g. collector) turning right.</p> <p>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.</p>	 <p>Source: Austroads (in press).</p>
Jughandle intersection	Motorists making a right-turn must first exit left upstream from an intersection and then turn right onto minor road.	 <p>Source: Adapted from Arup (2004).</p>
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.	 <p>Source: Turner and Brown (2013) in Austroads (2015d).</p>

Intersection type	Comments	
<p>High-speed signalised roundabout</p>	<p>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).</p>	 <p>The diagram shows the Felup Roundabout, a large circular intersection with multiple lanes. It features traffic lights at each approach. The roads shown include Sandridge Road, Koombana Drive, Australind Bypass (AB), and Foreston. A sign indicates the direction 'To Perth'.</p> <p>Source: Main Roads Western Australia (2012) in Austroads (2015d).</p>
<p>Horizontal deflections on signalised intersection approaches</p>	<p>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.</p>	 <p>The top part of the image is a technical drawing of a signalised intersection with horizontal deflections. It shows a four-way intersection with various lane markings and traffic flow directions. A box in the drawing states: 'UNFINISHED DRAWING SUBJECT TO FURTHER AMENDMENT FOR SUCCESSFUL PROPOSALS ONLY INFORMATION GIVEN IS CURRENT AS AT DATE 14.02.2016 (2016) 1.2.2016'. Below the drawing is an aerial photograph of a similar intersection, showing the physical layout of the roads and the deflected approaches.</p> <p>Source: Austroads (in press).</p>

Intersection type	Comments	
<p>Vertical deflections at intersections and/or on approaches</p>	<p>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 be 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.</p>	 <p>Source: Austroads (in press).</p>
<p>Diverging Diamond Interchange (DDI)/Double Crossover Diamond interchange (DCD))</p>	<p>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.</p>	 <p>Source: FHWA (2010) in Austroads (2015d).</p>
<p>Turbine (local roads)</p>	<p>Employs horizontal deflections to manage speeds through intersection.</p>	 <p>Source: Austroads (in press).</p>

Intersection type	Comments	
Flower roundabout	Features a divided left-turn lane to eliminate weaving conflicts within the roundabout.	 <p>Source: Austroads (in press).</p>
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.	
Tennis ball interchange	A grade separated freeway interchange, similar to roundabout under signal control however right-turn traffic movements cut through the roundabout to and from the freeway ramps. This configuration reduces conflicts between vehicles and reduces approach speeds, and also reduces queueing and delays.	 <p>Source: Austroads (in press).</p>

Intersection type	Comments	
<p>Quadrant roadway intersection</p>	<p>Intended to reduce right-turn movements at the main intersection by relocating these movements to supplementary intersections</p>	 <p>Source: Austroads (in press).</p>
<p>Split intersection</p>	<p>Intersection split to separate right-turning movements</p>	 <p>Source: Austroads (in press).</p>
<p>Mini roundabout</p>	<p>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.</p>	 <p>L.G.H. Department for Transport in Austroads (2015d).</p>

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Commentary 7 **Considerations for Trucks at roundabouts**

Signalised intersections are generally preferred to roundabouts on roads that carry a significant volume of trucks. At roundabouts, trucks reduce speed, perform a relatively tortuous movement and then accelerate away from a roundabout. This may be acceptable at some roundabouts, as an effective measure to help manage speed, while at other locations may lead to unacceptable inefficiencies for freight movement while being taxing on truck drivers. In some instances the reverse curves through roundabouts, combined with high loads, a slightly excessive approach speed and human factors, have led to trucks rolling over whilst passing through roundabouts. This, combined with other factors may result in roundabouts not being favoured at some locations on freight routes (Table 2.8).

While trucks at times will encounter the inconvenience of coming to a complete stop at a red signal at signalised intersections, they are often able to continue through a green signal. This is generally preferred to the inconvenience associated with negotiating a roundabout.

While signalised intersections may also present some problems for trucks, there is potential to do more for them through timing and phasing measures (Ogden 1996).

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Commentary 8 **Considerations for Signals at Staggered T-intersections**

In general, signals would only be installed at existing staggered T-intersections (Figure 5.1) where there would be limited options to improve the layout. At such sites the signal operation can be complex. Inadequate storage in the internal approaches, including for the through movement, can lead to excess queuing and blockage of other movements and can introduce inefficient signal operation. This is exacerbated by heavy right-turn flows from the major road or between the minor roads on left-right configurations or heavy right-turn flows from the minor roads on right-left configurations. Care needs to be taken to ensure any see-through effect does not increase the risk of crashes.

Unequal lane utilisation may occur due to origin – destination movements and the location of pedestrian crossings needs careful consideration for safety and efficiency reasons.

If the stagger distance is very large, the intersection may require two traffic signal controllers linked for coordinated operation.

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Commentary 9 **Warrants for Unsignalised Intersection Turn Treatments**

This section briefly discusses the development of warrants for turn treatments on the major road at unsignalised intersections (excluding roundabouts and seagull treatments) as detailed in Arndt and Troutbeck (2006). The warrants are for both urban and rural roads.

C9.1 Development of the Warrants

According to Arndt and Troutbeck (2006) the warrants were created to:

- improve the limitations and ambiguity of previous warrants
- base the warrants directly on the measured safety performance of each turn type
- ensure that higher-order turn treatments are not warranted until higher traffic volumes occur on lower-speed roads, as turn treatments on lower speed roads record far fewer rear-end-major vehicle crashes (generally rear-end type crashes resulting from a through driver colliding with a driver turning right from the major road than do turn treatments on high speed roads
- ensure that higher-order right-turn treatments are provided at lower traffic volumes than for higher-order left-turn treatments, as lower-order right-turn treatments record far more rear-end-major vehicle crashes than lower-order left-turn treatments
- incorporate CHR and AUL turn treatments with short length right-turn slots as such treatments have significant safety benefits over lower-order turn treatments.

The warrants have been produced by identifying the location at which the benefits of providing a higher-level treatment (the reduction in estimated crash costs) are made equal to a proportion of the additional construction costs. This proportion is the benefit cost ratio (BCR) and applies for an assumed design life. The benefits and costs of a higher-level treatment are compared to the base case (the minimum turn treatment).

For the right-turn treatments, a design life of 10 years and a BCR equal to one is assumed in the calculations. For the left-turn treatments, however, using BCR values of one with a design life as high as 50 years, the warrants produced are such that traffic flows, on even the busiest roads, would never be high enough to justify using higher-level left-turn treatments. Omitting higher-level left-turn treatments in all circumstances would not meet driver expectation and would cause operational problems, especially on the busier roads. Therefore, an alternative method of determining warrants for left-turn treatments was developed.

For the left-turn warrants, the curves produced for the right-turn treatments are adopted. As the major road traffic volume on the X-axis of the warrants is based on all relevant major road traffic flows, higher-order right-turn treatments are required at lower traffic volumes than for higher-order left-turn treatments. This process ensures that these warrants reasonably match driver expectations set through the previous warrants.

The warrants show that it is not beneficial to provide AUR turn treatments. Instead, channelised right-turn treatments with reduced length of right-turn slots [CHR(S)] are the preferred treatment. Basically, CHR(S) treatments offer significantly better value for money (in terms of the safety benefits versus the construction costs) than do AUR turn treatments.

C9.2 Application of the Warrants

The warrants are based on the construction of intersections on new roads (i.e. Greenfield sites). Therefore, their most appropriate application is to the selection of turn types for intersections on new roads. However, the warrants may also be used:

- as a reference for the construction of new intersections on existing roads
- as a reference for intervention levels when upgrading existing intersection turn treatments
- although not intended for direct application to accesses and driveways, they may be used as a reference for such. [\[Back to body text\]](#)

Commentary 10 **Cyclist Types**

It is important to understand that cyclists include people with a very wide range of skill, from novices to experts, and also people who travel for a variety of reasons which can involve a specific trip purpose or a recreational experience. The broad groups of cyclists are:

- Primary school children – the cognitive skills of young children are not fully developed and they also have little understanding of traffic laws and traffic behaviour.
- Secondary school children – the skill of this group varies greatly and the majority of cycling for those over 14 years of age takes place on the road.
- Recreational cyclists – generally ride for the enjoyment of the ride and companionship. The skill of this group also varies greatly as does the trip purpose. They generally ride at low to moderate speeds and often prefer not to ride on the road. Some are likely to travel on paths for a leisurely ride whereas others will travel at relatively high-speed for physical training purposes. Some commuter cyclists may also use paths and mix with those riding for recreation. Family groups including children are common on weekends.
- Commuter cyclists – ride for transport to work or other destinations. Many commuter cyclists are highly skilled and able to cope with a variety of traffic conditions. They generally ride at moderate to high speeds, often travel relatively long distances and choose to ride on the major roads to minimise trip length and travel time. However, some prefer to use paths for part of their journey in order to escape the stress associated with riding in traffic even though the journey time may be longer than an alternative on-road route.
- Utility cyclists are those who travel for specific local trip purposes such as shopping and other trips. They may use any part of the network, often using low stress local routes.
- Touring cyclists may undertake extensive long distance journeys on rural roads or shorter trips around local areas of tourist significance. They may travel solo or in groups and are usually very experienced.
- Sporting cyclists travel extensive distances on both rural and urban arterial roads while training for the various events in which they compete. They may train solo or in pairs but often train in substantial groups.

In addition to the types of cyclists, there are two main focuses on providing infrastructure for cyclists:

- developing infrastructure to improve safety and/or accommodate those who currently cycle
- developing infrastructure to encourage people who don't currently cycle to cycle. This requires the development of safe separated facilities in busy areas that might connect to bicycle friendly residential streets (or shared streets, shared zones or bicycle boulevards) and off-road paths for instance.

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Commentary 11 **Cycle Tracks**

At some locations, where it is suitable and practicable, consideration may be given to providing separated bicycle facilities within the road corridor that have priority for cyclists at intersections (known as a *cycle track* in some agencies). A cycle track is a physically separated dedicated bicycle facility within the road corridor that has clear bicycle priority at intersections. 'The key features of cycle track are the priority crossing through unsignalised intersections and specialised controls at signals. These intersection features maintain the directness and level of service expected of a cycle track.' For more information refer to TMR (2015b).

Figure C11 2: Example of a cycle track showing cyclist priority through intersection



Source: TMR (2015b), Figure 37.

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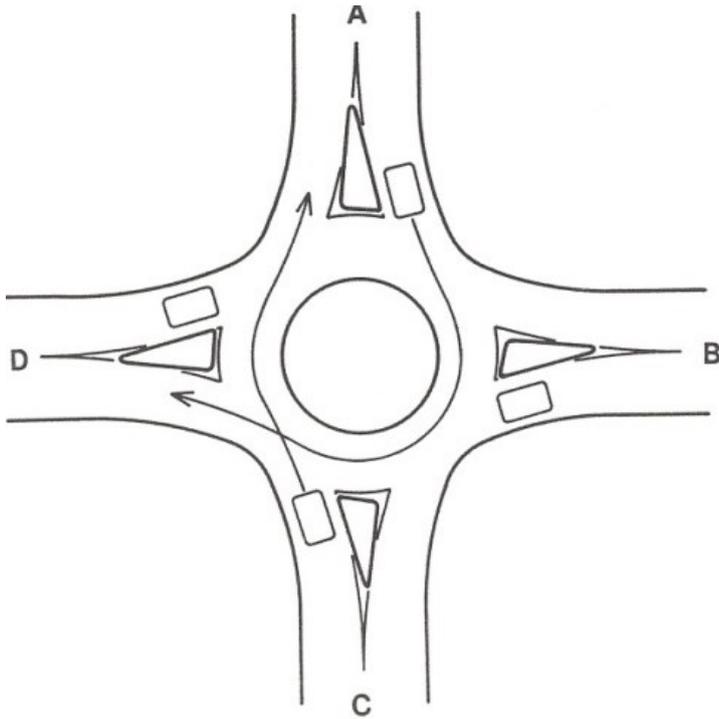
Commentary 12 Additional Guidance on Site Characteristics for Roundabouts

Table C12 1 and Table C12 2 provide additional information on appropriate and inappropriate sites for roundabouts.

Table C12 1: Appropriate sites for roundabouts

Site characteristics	Corresponding notes
<p>At intersections where traffic volumes on the intersecting roads are such that:</p> <ul style="list-style-type: none"> • Stop or give way signs or the T-junction rule result in unacceptable delays for the minor road traffic. • Traffic signals would result in greater delays than a roundabout. 	<ul style="list-style-type: none"> • Stop or give way signs: roundabouts would decrease delays to minor road traffic, but increase delays to the major road traffic. • Traffic signals: in many situations roundabouts provide a similar capacity to signals, but may operate with lower delays and better safety, particularly in off-peak periods.
<p>At intersections where there are high proportions of right-turning traffic.</p>	<p>Unlike most other intersection treatments, roundabouts can operate efficiently with high-volumes of right-turning traffic.</p> <p>However, satisfactory operation is dependent on the entering flows being balanced so that a heavy right-turn does not cause excessive delay on subsequent entries.</p> <p>Right-turning traffic contribute to good roundabout operation because they create opportunities for drivers on other approaches to enter the roundabout (Figure C12 1).</p>
<p>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 convenient and effective treatment.</p>	<ul style="list-style-type: none"> • With stop or give way signs, it is often not practical to define priorities adequately. • Signals may be less efficient due to the large number of phases required (resulting in a high proportion of lost time). • Two-lane roundabouts with more than four legs may cause operational problems and should be avoided.
<p>At rural cross-intersections (including those in high-speed areas) at which there is a crash problem involving crossing or right-turn (vs opposing) traffic.</p>	<p>If the traffic flow on the lower-volume road is less than about 200 vehicles per day, consideration could be given to using a staggered T treatment.</p>
<p>At intersections of arterial roads in outer urban areas where traffic speeds are high and right-turning traffic flows are high.</p>	<p>A well designed roundabout could have an advantage over traffic signals in reducing right-turn opposed type crashes and overall delays.</p>
<p>At T- or cross-intersections where the major traffic route turns through a right-angle. This often occurs on highways in country towns. At other T or skewed T intersections where a high proportion of right-turning traffic exists.</p>	<p>In these situations the major movements within the intersection are turning movements which are accommodated efficiently and safely at roundabouts.</p>
<p>At locations where traffic growth is expected to be high and where future traffic patterns are uncertain or changeable.</p>	<p>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.</p>
<p>At intersections of local roads where it is desirable not to give priority to either road.</p>	
<p>At arterial and collector road intersections in outer urban areas and country towns, where only short periods of congestion occur.</p>	<p>In such situations control by traffic signals would be relatively inefficient and costly from a maintenance and operation point of view.</p>
<p>Strip shopping centres in urban areas and rural townships where a roundabout at both ends reduces vehicle speeds through the centre, improving safety and amenity.</p>	

Figure C12 1: Effect of turning vehicles on roundabout operation



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.

Table C12 2: Inappropriate sites for roundabouts

Site characteristics	Corresponding notes
Where a satisfactory geometric design cannot be provided due to insufficient space or unfavourable topography or unacceptably high cost of construction.	<ul style="list-style-type: none"> • Satisfactory deflection, entry layouts or sight distances may not be possible. • The cost of including property acquisition, service relocations etc. May be prohibitive.
Where traffic flows are unbalanced with high-volumes on one or more approaches, and some drivers would experience long delays.	This is especially true for roundabouts on high-speed, high-volume rural roads which intersect a very low-volume road. In these cases, the number of single vehicle crashes generated by the roundabout can substantially exceed the number of multiple vehicle crashes generated by a conventional unsignalised at-grade intersection.
Where a major road intersects a minor road and a roundabout would result in unacceptable delay to the major road traffic.	A roundabout causes delay and deflection to all traffic, whereas control by <i>stop</i> or <i>give way</i> signs or the T-junction rule would result in delays to only the minor road traffic.
Where there is considerable pedestrian activity and due to high traffic volumes it would be difficult for pedestrians to cross either road. It is noted that under Australian Road Rules, right-turning drivers, when departing a roundabout, are not obliged to give way to pedestrians.	In this case traffic signals are preferred to assist pedestrians to cross the road safely. The pedestrian warrants for signalisation shown in Section 2.3.4 may be used as a guide.
Where the intersection is located on a major on road cycle route.	Studies have demonstrated that cyclists are many times more likely to be involved in a crash at roundabouts than motor vehicles, and are less likely to be involved in a crash at traffic signals than at a roundabout. Multilane roundabouts are complex and problematic for cyclists.

Site characteristics	Corresponding notes
At an isolated intersection in a network of linked traffic signals.	In this situation a signalised intersection linked to the others or a conventional unsignalised at-grade intersection would generally provide a better level of service.
Where peak period reversible lanes may be required.	The form of a roundabout and its splitter islands result in reversible flow options being impracticable.
Where large combination vehicles or over-dimensional vehicles frequently use the intersection and insufficient space is available to provide for the required geometric layout.	In some cases roundabouts have been constructed to enable over-dimensional vehicles to drive straight through the central island.
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 need not be completely discounted, but they are generally found to be less effective than adopting a signalised intersection treatment.
A tram service or railway passes through the intersection.	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.

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Commentary 13 Provision of Double Roundabouts

Situations where double roundabouts may be considered include (Brown 1995):

- at existing cross-roads where the pair of roundabouts separates opposing right-turning movements, allowing them to pass as they would in a normal diamond turn
- at overloaded single roundabouts where, by reducing the circulating flow past critical entries, capacity is increased
- at junctions with more than four entries, a double roundabout achieves better capacity with acceptable safety characteristics in conjunction with more efficient use of space, whereas a large roundabout can generate high circulatory speeds with consequent loss of capacity and safety
- the improvement of an existing staggered junction where it avoids the need to realign one of the approach roads, and achieves considerable construction cost saving
- at unusual or asymmetrical junctions such as a ‘scissors’ junction where the installation of a single roundabout would require extensive realignment of the approaches or excessive land acquisition
- the joining of two parallel routes separated by a feature such as a river, railway line or motorway
- as a grade separated ‘dumbbell’ arrangement at freeway interchanges (Figure C13 1).

The signage and road markings associated with closely spaced roundabouts must be carefully considered.

Figure C13 1: Closely spaced pair of roundabouts (Grade separated 'dumbbell' roundabout)



Source: © Western Australian Land Information Authority (Landgate) (2017).

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Commentary 14 **Research Findings on Cyclist Crashes at Roundabouts**

Allot and Lomax Consulting Engineers (1993) found cyclist crash rates at roundabouts were up to 15 times those for cars and two to three times those for cyclists at traffic signals. A study (Jordan 1985) of cyclist casualty crashes which occurred at roundabouts revealed that 74% were right-angle crashes where a cyclist on a roundabout was struck by an entering motor vehicle and that 17% of cyclist crashes at roundabouts were at the exits.

Robinson (1998), in a study of reported crashes at roundabouts in New South Wales, confirmed the roundabout entry problem involving cyclists with the finding that 70% of 'two-party' incidents resulting in injury involved circulating cyclists or motorcyclists being hit by entering motorists. He also found that:

- 6% of those injured at cross-intersections were cyclists compared with 18% at roundabouts
- at non-metropolitan roundabouts, 32% of those injured in two-party crashes were cyclists
- cyclists were responsible for 16% of the crashes in which they were involved.

These studies confirm that motorists often do not see cyclists approaching in the roundabout or at least misjudge their speed and relative position.

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Commentary 15 **Geometric Features of Roundabouts and Crashes**

Arndt (1998) provided a comprehensive study to determine how the geometric features of roundabouts affect the types and numbers of crashes occurring at roundabouts. The report was a continuation from a previous report of the same title (Arndt 1994). Models were developed to predict the different types of crashes that occur at roundabouts, namely:

- rear end crashes, predominantly on the approach (18.3%)
- entering/circulating crashes in the vicinity of the holding lines (50.8%)
- single vehicle crashes through loss of control, mainly in the roundabout (18.3%)
- exiting/circulating crashes near the exit (6.5%)
- side swipe crashes throughout the roundabout, half in circulating road (3.7%)
- other low frequency crashes (2.4%).

The percentages of crash categories reported by Arndt (1998) are shown in brackets and based on a study of 492 crashes at roundabouts in Queensland.

Based on the research, Arndt (1998) also provided advice on roundabout design to minimise crash rates. Key aspects that influence safety were considered to be:

- **The number of roundabout legs and the angle between legs:** It is preferable that roundabout legs be aligned at approximately 90° angles and that there are only four legs provided, particularly at multilane roundabouts.
- **Roundabout diameter:** Generally larger diameter roundabouts enable better geometry that results in lower conflict angle at the entries and greater speed reduction.
- **Approach geometry:** Alignments that enable high entry speeds and relatively high angles of conflict at entries are less safe and undesirable. Successive reverse curves are considered to be effective, it being recommended that the 85th percentile approach speed be limited to 60 km/h, and the decrease in speed between successive curves be limited to 20 km/h.
- **Deflection through the roundabout:** The study confirmed that deflection is an important parameter but suggests that if the approach speed is limited to 60 km/h the need to consider deflection is reduced. The reason offered for this was that the slowing of drivers prior to the roundabout through approach curvature usually obtains the required deflection and also results in lower overall crash rates than is achieved through speed reduction using deflection alone.
- **Separation between legs:** It is preferable to design the entry and exit curves tangential to the roundabout inscribed circle diameter as this provides good separation and a low angle of conflict. Closely spaced entries and sharp corner radii lead to higher conflict angles between entering and circulating traffic.

Whilst roundabouts are a safe treatment for motor vehicle occupants there is concern in sections of the community as to their suitability for pedestrians and cyclists. Arndt (1998) reported that of the 492 crashes recorded in the study, only one involved a pedestrian, and considered it difficult to make any conclusions about the effect of roundabout design on pedestrian safety. However, cyclists accounted for 13% of the entering/circulating crashes in the study, indicating once again that they were well over-represented in these crashes. It is suggested that design in accordance with the key aspects described above would also improve safety for cyclists at roundabouts.

Arndt (2001) and (Queensland Department of Main Roads 2016b) discuss the program ARNDT – ‘A Roundabout Numerical Design Tool’ that enables designers to predict crash rates and costs for new and existing roundabouts (It should be noted that this tool does not model pedestrian and cyclist crashes, although TMR (2015c) *Technical note 136* includes a cyclist crash prediction model). It is suggested that it is a useful tool for determining the potential safety performance of roundabouts by identifying potentially hazardous geometry. It can be used to determine the likely saving in crash costs by adoption of particular geometric characteristics. Other programs may also be considered for use.

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Commentary 16 **Cyclist Paths at Roundabouts**

The results of various studies have indicated that a separated cycle path, located outside of the circulating roadway, was the safest design in the presence of large vehicle flows (Bruede & Larsson 1996). CROW (1993) indicates off-road cycleways should be constructed at roundabouts with a traffic volume in excess of 10 000 vehicles per day and also at all large (central island diameter in excess of 25 m) roundabouts, primarily due to speed considerations.

Separate cycle paths have been found to be safer than a bicycle lane within the road roadway, particularly at highly trafficked roundabouts (Bruede & Larsson 1996, Van Minnen 1996).

Overseas research has also demonstrated that:

- cyclist crash rates are higher where cyclists (using separated perimeter paths) have right of way over motorists at roundabouts
- low cyclist crash rates have occurred at roundabouts with an approach traffic volume of 8000 to 10 000 vehicles per day
- roundabouts with a low cyclist volume and high traffic volume have been found to be less safe for cyclists.

This is pertinent to conditions in Australia where cyclists are relatively few in number, although cyclist numbers are increasing.

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Commentary 17 **The European Compact Radial Roundabout Design**

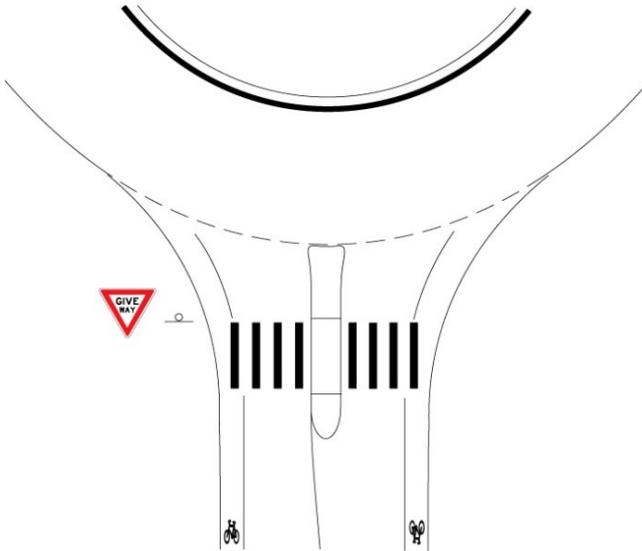
The compact radial European (also referred to as continental) design used in urban situations reduces the curvature on approaches and aligns the approach so that it is directed at a relatively large central island. As illustrated in Figure C17 1, this form of design 'tightens up' the entry and lowers entry speeds. This should enable more time for drivers to scan the roundabout and detect the presence of cyclists, while the lower vehicle speeds should promote improved road safety for all road users.

The layout design uses a large central island, single-lane entry and exits of minimum width and minimal flaring of entries and exits. Where a multilane roundabout needs to be considered, due to high traffic volumes, a separated cycle path should be provided (Fowler 2016). The needs of trucks and buses must also be considered.

Care needs to be taken in the design and application of a radial design roundabout to ensure that lower speeds are achieved. Some concerns exist that a poor design could lead to the potential for higher entry speeds may lead to an increase in the likelihood of off-path crash frequency and severity. This requires further investigation. There are examples of such a design in Australia and New Zealand which could be used for comparison of Safety performance with Austroads designs.

Fowler (2016) summarises German guidance on compact radial roundabouts that may be applicable in Australia and New Zealand.

Figure C17 1: European roundabout entry design



Source: VicRoads (2005).

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Commentary 18 Lane Choice at Roundabouts

Lane choice at roundabouts is relatively straightforward if legs are at 90° (Figure C18 1), but more difficult if they are not (Figure C18 2).

Figure C18 1: Appropriate lane choice is relatively straight forward at a multilane roundabout where legs are aligned at 90°

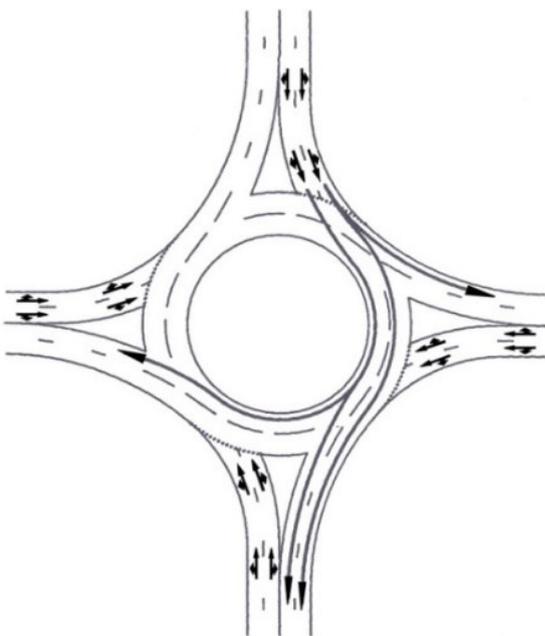
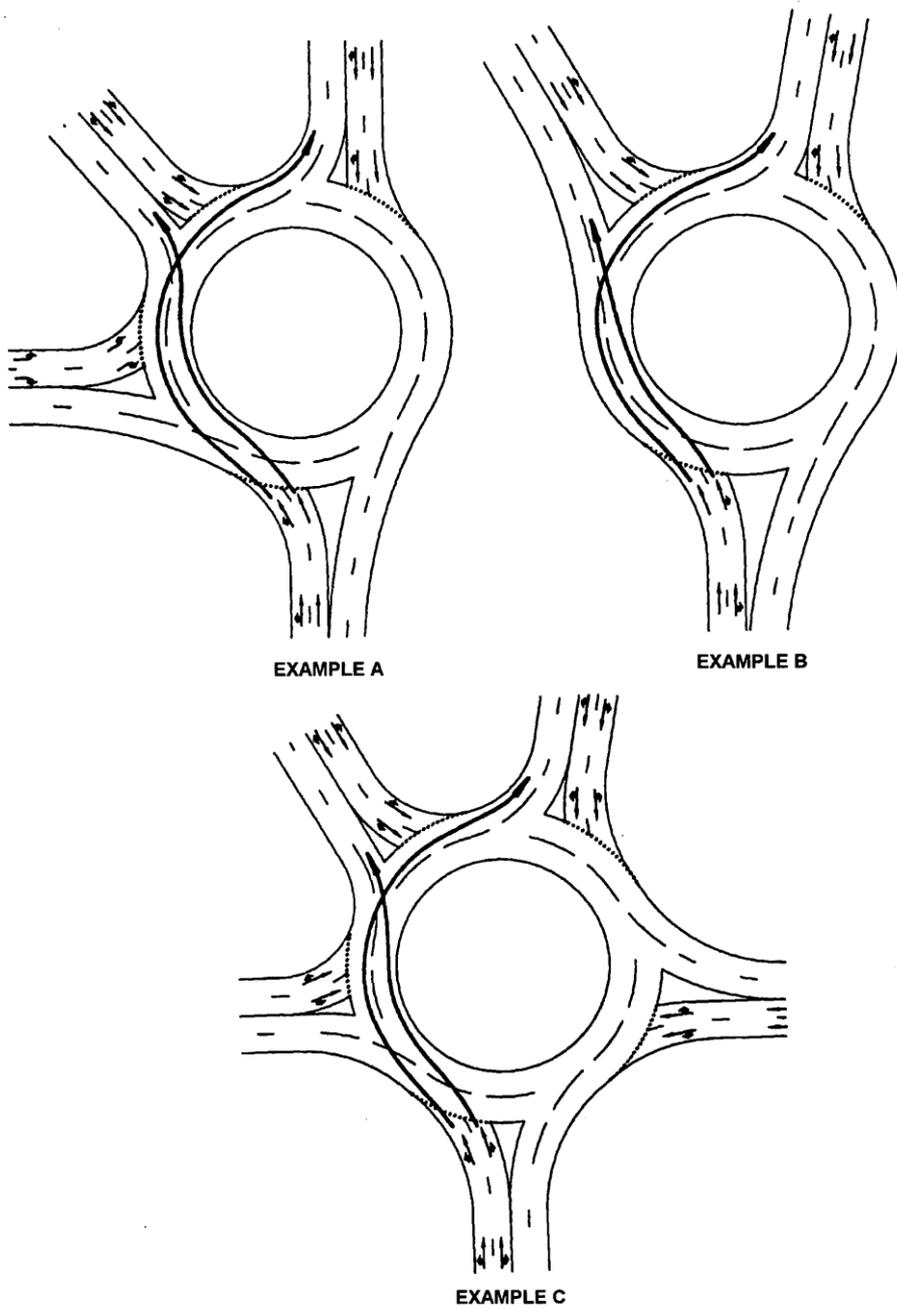


Figure C18 2: Appropriate lane choice can be difficult to anticipate at multilane roundabouts with some or all legs aligned at angles other than 90°



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Commentary 19 **Additional Guidance on Signalising Roundabouts**

Recent research (Austroads 2015d) observed 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.

As noted in Section 3.3.1, unsignalised roundabouts generally have a good safety record when compared to other types of intersections. However, the UK Department for Transport (2009) noted that, in some instances, converting to signalised roundabouts may lead to improved safety. Crash types identified that may benefit from roundabout signalisation included crashes caused by poor judgement of gaps in traffic by drivers entering the circulating carriageway travelling at high-speed and rear-end collisions involving vehicles waiting at the entrances to roundabouts.

Signalising roundabouts were also noted as aiding cyclists by better managing the speed of traffic on the circulating carriageway. Pedestrians (including those with a vision, mobility or hearing impairment) and cyclists may also benefit from signalised crossings. Signalised roundabouts may enable other treatments to assist cyclists, such as a bicycle leading interval (*Guide to Traffic Management Part 9*, Austroads 2016c).

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Commentary 20 **Reducing Sight Distance on Intersection Approaches**

In order to reduce risk taking by drivers and encourage slower approach speeds at rural intersections, limiting or reducing drivers' view of traffic approaching a rural intersection from other directions, through use of screens or hedges, has been trialled. The treatment aims to prevent drivers risk taking associated with anticipating gaps that may not still be present when the traffic arrives at the intersection. The treatment is also intended to encourage drivers to slow down in case they need to stop at the intersection. It should be noted that the minimum sight distance is still required at the intersection. The reduced sight distance applies to drivers view available in advance of the intersection. *Methods for Reducing Speeds on Rural Roads: Compendium of Good Practice* (Austroads 2014a) notes a speed reduction of up to 18 km/h and a crash reduction of 40% associated with this treatment, although it is also noted that the treatment is relatively untested in Australia or New Zealand, and therefore a detailed assessment should be undertaken at any potential sites before being used. Following installation, close monitoring should also be undertaken.

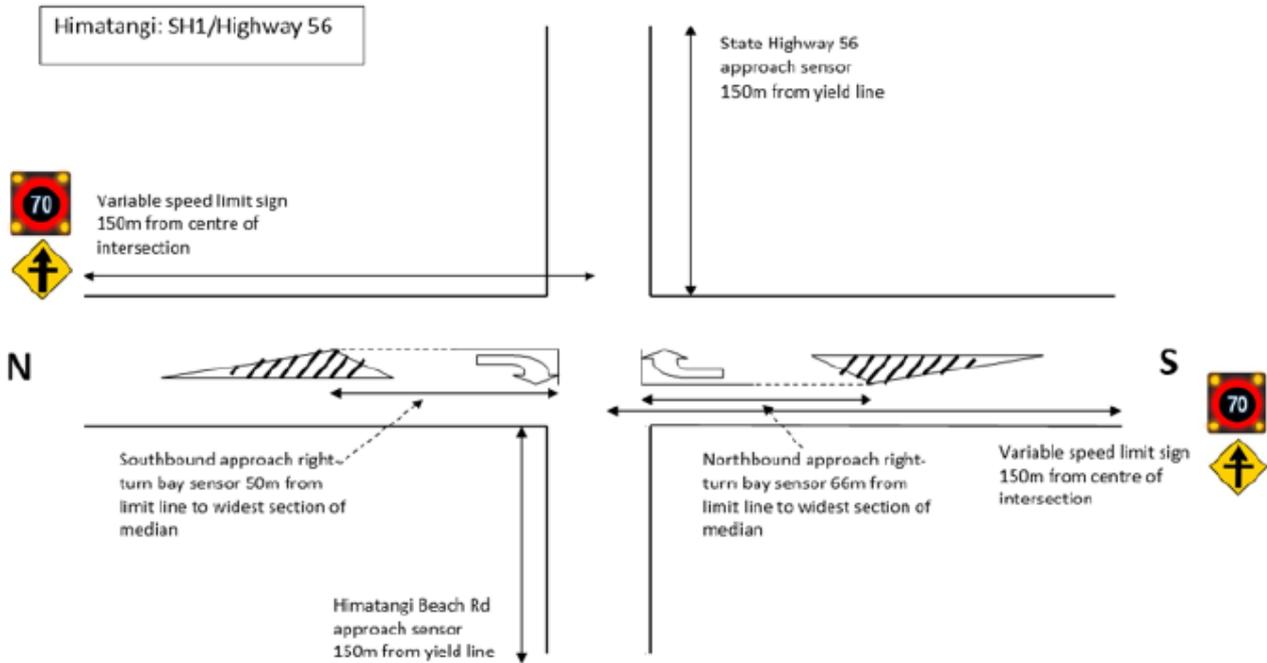
At roundabouts, a similar approach with the application of Sight Distance Criterion 3 is outlined in *Part 4B* of the *Guide to Road Design* (Austroads 2015c). Criterion 3 relates to provision of a 'sight triangle to allow recognition of potential conflict' while recognising some concerns exist that a 'larger sight triangle may lead to higher entry speeds'.

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Commentary 21 Rural Intersection Active Warning System

The rural intersection active warning system (RIAWS) was trialled at ten sites in New Zealand. The system 'is designed to slow major road through traffic on approaches to an intersection when a potential collision risk exists. Electronic signs (variable speed limit or 'Slow Down') on the intersections approaches are triggered by the presence of vehicles at the minor road or waiting to turn right.' (Mackie Research & Consulting Ltd 2015). The figure below illustrates the basic setup for a RIAWS site, including sensors at the minor roads and right-turn bays, as well as variable speed signs supported by warning signs.

Figure C21 1: Basic outline of RIAWS componentry



Source: Mackie Research and Consulting Ltd (2015).

An evaluation of the trial (undertaken when RIAWS has been operating for approximately two years at two of the trial sites) found that (Mackie Research & Consulting Ltd 2015):

- the RIAWS system operated reliably
- significant reductions in vehicle speeds through the intersections were achieved when the system was activated (Modal traffic speeds at the 70 km/h VSL intersections typically range from 68–72 km/h compared to speeds of 80-95 km/h)
- speed limit signs were more effective in reducing speeds than 'slow down' signs in the RIAWS system
- the RIAWS system was positively received by road users (based on a survey)
- a preliminary crash analysis found a reduction in FSI and total crashes was experienced at the trial sites (based on crashes at six RIAWS sites; other sites were not included due to insufficient post installation period for crash assessment).

A subsequent evaluation (Mackie Research & Consulting Ltd 2016) was undertaken in order to assess the 'longer-term performance of the ten RIAWS trial sites in terms of crash and speed performance'. This subsequent evaluation used post installation data between 11 and 36 months at the RIAWS trial sites. The findings from the initial evaluation were supported, including:

- a reduction in FSI and total crashes (FSI: 89% reduction from 0.035 crashes per month to 0.004 crashes per month; total: 72% reduction from 0.32 crashes per month down to 0.09 crashes per month)
- reductions in vehicle speeds were sustained.

The evaluation of the longer-term performance of the RIAWS sites also found that compliance with the 70 km/h VSL was generally maintained, however that compliance with a 60 km/h VSL trial site appeared to have diminished over time.

Mackie Research and Consulting Ltd (2015) found that:

- RIAWS has the potential to reduce fatal and serious casualties at rural intersections by:
 - slowing motorists on major road intersection approaches and thus reducing crash likelihood (effectively increasing available stopping distance) and severity (less energy on impact)
 - increasing driver state awareness and therefore preparing motorists for a possible event (effectively reducing reaction time)
 - increasing the gaps between potentially colliding vehicles
- RIAWS is feasible, operates well, effective, perceived positively by the motoring public, has shown preliminary safety benefits and produces outcomes that are consistent with the Safe System approach.

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Commentary 22 **Additional Guidance on Cyclist Paths at Interchanges**

High ramp volumes on an existing freeway may, in the absence of feasible alternative routes through or around the interchange, indicate that the freeway itself, or a segment of it, is unsuitable for cycling. An alternative route off the freeway may be required.

In order for cyclists to be able to cross a ramp at the nose, the volume and approach pattern of motor vehicles using the ramp must be such that adequate gaps occur in the traffic stream to enable a safe and convenient crossing of the ramp to be made by cyclists. This method requires a cyclist to turn from the shoulder/breakdown lane and cross the ramp at right-angles.

It is estimated that a cyclist requires a gap of seven seconds in order to cross the ramp safely (Ove Arup & Partners 1989). This gap was determined using the assumption that both the bicycle length and the car width are 2.0 metres. Assuming that the speed of the bicycle is 5 km/h (1.4 metres per second), at the crossing it will take almost three seconds for the bicycle to pass in front of the motor vehicle. If it is further assumed that at least two seconds clearance is required after the passage of the first vehicle and also before passage of the second vehicle it follows that a minimum gap of seven seconds is required.

If the ramp is an off-ramp or the on-ramp is not controlled by traffic signals it may be reasonable to assume that vehicles using the ramp arrive at random and gap acceptance theory should be used to estimate the delay likely to be suffered by cyclists in crossing these ramps. If analysis indicates that the average delay to a cyclist is greater than 15 seconds (beyond which they are assumed to accept unsafe gaps of less than seven seconds), then cyclists should be directed to use the exit ramp, cross the intersecting road at-grade, and re-enter the freeway via the on-ramp, or a grade separation of the ramp for cyclists should be evaluated. If an on-ramp is controlled by traffic signals then the ability of cyclists to cross the ramp must be evaluated in relation to the signal cycle and phasing and other traffic movements which may not be controlled by signals.

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Commentary 23 **Additional Guidance on Ramp Types and Selection**

C23.1 Left-turn Movements

Possible free-flow left-turn movements are shown in Figure 6.25a. For all median widths, the direct left-turn outer connector ramp is usually the least expensive. If one or both medians are wide then semi-direct left-turns may be used to avoid a design control or to reduce weaving while maintaining directionality at the next diverge.

C23.1.1 Semi-direct Ramps

The two types of semi-direct ramps (A and B) for left-turns are shown in Figure 6.25. Semi-direct A requires a right hand exit and the semi-direct B requires a right hand merge. Neither type is favoured, as they contravene the principles of consistency of operation.

C23.1.2 Outer Connectors

Outer connectors are the predominant treatment for left-turn movements and are exclusively for one left-turn movement. These ramps provide the most direct left-turn connection between two roadways. Outer connector diverge geometry must meet the criteria provided in road design guidelines (*Parts 3 and 4 of the Guide to Road Design, Austroads 2016d, 2017a*) for high-volume movements and low-volume movements.

C23.2 Right-turn Movements

In general, direct or semi-direct ramps should be provided for high-volume right-turning movements (e.g. where more than 50% of total traffic on a road turns right) provided route continuity considerations do not dictate otherwise. These ramps usually result in additional grade separation structures and multiple levels within an interchange, or loop roads that result in longer structures.

At-grade intersections with local roads or traffic routes should generally not be provided on direct or semi-direct ramps, as the safety and operation of the ramp will be compromised. Access to local roads should be via the minor road at service interchanges.

The five possible free-flow right-turn movements are illustrated in Figure 6.25b. Right hand exits and entries may be used for direct, semi-direct A and semi-direct B movements where wide medians permit their construction and an additional lane is provided, provided traffic volumes and route continuity considerations warrant their use. These cases should be treated as a major fork or branch connection (Sections 6.6.7 and 6.6.8).

C23.2.1 Direct Ramps

Direct ramps cater exclusively for one right-turn movement. These ramps provide the most direct right-turn connection between two roadways, for example see Figure 6.25b.

C23.2.2 Semi-direct Ramps

The three types of semi-direct ramps (A, B and C) for right-turns are shown in Figure 6.25b. Semi-direct ramps normally cater exclusively for only one right-turn movement. Type B is acceptable for high-volume right-turning movements where the right-turning volume is greater than 50% of the total traffic, provided that route continuity considerations are not paramount, however it does have the undesirable feature of a right hand diverge from the median lane. Type A has the undesirable feature that a forced right hand merge occurs on the road that traffic is entering and this type should be avoided if possible. Type C is the most desirable ramp type if major fork or branch connection conditions do not exist.

C23.2.3 Loop Ramps

The use of loop ramps depends on the types of roads that are intersecting. Loop ramps should only be used at interchanges between two freeways or motorways where:

- there is a high turning volume and it is impracticable or uneconomical to provide a more direct connection
- low turning volume will use the loop.

At freeway/freeway (or motorway/motorway) interchanges, loops constitute a low-speed element between two high-speed facilities and this can result in safety issues due to the large speed decrement, particularly with respect to heavy vehicle stability. This issue is more likely to arise where the traffic volume is high and a large number of heavy vehicles are using the loop. At these interchanges the loop caters for only one turning movement.

Loop ramps are suitable for use at interchanges between freeways and non-freeway roads, as either entry ramps or exit ramps, where the loop will carry a low to moderate traffic volume. In such cases, the loop can provide for both right and left-turning movements at its intersection with the non-freeway facility. At these interchanges it is particularly important to design the freeway exit or entrance so that the speed differential between the loop and freeway traffic streams is managed safely and efficiently.

C23.2.4 Diagonal Ramps

Diagonal ramps leave the freeway at an angle and terminate at an intersecting road (i.e. non-freeway). This type of ramp is typically used at diamond interchanges. They can be either exit ramps or entrance ramps, and generally cater for all turning movements. The alignment and detailed layout of all ramps should be developed in accordance with road design guidelines (*Parts 3 and 4 of the Guide to Road Design, Austroads 2016e, 2017a*).

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Commentary 24 Provision of a Second Entry Ramp Lane

The guiding principle for the provision of a second entry ramp lane is that a second lane should be added when there is a significant probability of slow-moving trucks on the entry ramp impeding the entry of traffic in general.

Part 4A of the Guide to Road Design (Austroads 2017b) includes guidance for the design of acceleration lanes for trucks. It notes that in order to avoid undue disruption to traffic flow, it is preferable that heavy vehicles 'have sufficient length to accelerate to a speed no less than 20 km/h below the mean free speed of the through road'. It also notes that on upgrades, 'it is seldom practical to provide an acceleration lane' (or, in this case, ramp) of sufficient length to enable trucks to accelerate to the design speed of the through roadway.

For more information on heavy vehicle acceleration lanes, refer to *Part 4A of the Guide to Road Design (Austroads 2017b)*. See also *Part 4 of the Guide to Road Design (Austroads 2017a)*.

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Commentary 25 **Closure of Railway Level Crossings**

Grade separation of a rail crossing can be used to justify the closure of adjacent level crossings. Eliminating redundant and unnecessary crossings should consider the balance of public necessity, convenience and safety.

Whenever a crossing is closed, it is important to consider whether the diversion of road traffic may be sufficient to change the type or level of traffic control needed at other crossings. The surrounding street system should be examined to assess the effects of diverted traffic. The Federal Highway Administration (2002) suggests that coupling a closure with the installation of an adjacent grade separated crossing can be an effective means of mitigating resistance to the closure.

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Commentary 26 **Linking of Intersection and Railway Signals**

The signal requirements should be determined in consultation with the appropriate railway authority. If linking of road signals with the railway level crossing is justified, track switches should be provided by the railway authority to enable the special queue-clearing sequence to be initiated before the flashing red signals start to operate or at the time they start flashing.

The road signal sequence should be arranged so that after the queue-clearing phase has terminated, no phases or turning movements can be introduced for traffic that needs to cross the rail tracks until the train has cleared. The railway track switches should provide an indication when the train has cleared the level crossing. In the case of a rail crossing provided with manually operated gates, no special provision is generally required. When the level crossing opens to road traffic, the normal phase sequence is restored and some compensation can be given to the waiting traffic.

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Austrroads' Guide to Traffic Management consists of 13 parts and provides comprehensive coverage of traffic management guidance for practitioners involved in traffic engineering, road design and road safety.

Guide to Traffic Management Part 6: Intersections, Interchanges and Crossings is concerned with traffic management at all types of intersections where road users must join or cross another stream of traffic. It describes the appropriate use of various intersection types and techniques to provide efficient and safe intersections to all road users.

Guide to Traffic Management Part 6



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