High-risk intersections guide

DRAFT FOR CONSULTATION

NZ TRANSPORT AGENCY
WAKA KOTAHI

New Zealand Government

OUR PURPOSE

CREATING TRANSPORT SOLUTIONS FOR A THRIVING NEW ZEALAND

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The NZTA is part of, and contributes to, the Safer Journeys programme.
Safer Journeys is the government's strategy to guide improvements in road safety over the period 2010–2020. The strategy's vision is a safe road system increasingly free of death and serious injury. It is a coordinated effort across partner agencies to improve each aspect of road safety – better behaviours, a safer road environment, safer speeds and higher vehicle standards.

For more information visit **www.transport.govt.nz/saferjourneys**

Foreword

Intersections are among the most dangerous places on the New Zealand road network. During the last five years in urban areas 48% of fatal and serious injury crashes were at intersections. On rural roads, with speed limits of 80km/h or above, 17% of fatal and serious crashes were at intersections. Yet we spend only a tiny proportion of our travel time travelling through them.

The people, community and broader economic costs of crashes in intersections are high. The government's road safety strategy Safer Journeys signals that more must be done to improve safety on our high-risk intersections. The vision of Safer Journeys is 'a safe road system increasingly free of death and serious injury'. The strategy gives us a road map for focusing our efforts where the greatest gains can be made. Roads and roadsides are an area of great concern, and high-risk intersections are identified as requiring early action under the strategy.

Safer Journeys introduces the Safe System approach, which represents a fundamental shift in the way we think about, and act on, road safety. Human beings make mistakes and crashes are inevitable, but in a safe system they are less likely to result in death and serious injury. Our traditional approach to road safety has helped achieve our current good levels of road safety. We now need to add to this mix the Safe System approach, where road designers, transport and network managers and users share responsibility for a system to protect road users from death and serious injury.

This *High-risk intersections guide* follows in the footsteps of the *High-risk rural roads guide* which the NZTA launched in September 2011. Both guides are a flagship Safer Journeys initiative. They aim to be a practical guide for all road controlling authorities to help them make our roads safer.

This *High-risk intersections guide* is a draft guide and we are seeking your feedback to finalise it. The guide introduces a new way to identify high-risk intersections and, using the Safe System approach, provides best practice guidance on how to identify, prioritise and treat key road safety issues at high-risk intersections. This is a draft guide issued for consultation. Applying safe system concepts to intersections has been challenging. A number of the concepts in it are new.

The preparation of the draft has been assisted by a number of people outside the NZTA, including road safety engineers from several road controlling authorities. They have all made valuable suggestions and I would like to thank them for their contribution.

I encourage you to now consider how applying this *High-risk intersections guide* will change what you do and to send us your feedback on the guide using the forms provided on our website at www.nzta.govt.nz/consultation by Monday 14 May 2012.

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Geoff Dangerfield
Chief Executive
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Glossary of terms

3 Es	Engineering, education and enforcement
AADT	Annual average daily travel
ATP markings	Audio tactile profiled markings
EWS	Electronic warning sign(s)
EMP	Edge marker post(s)
DSi	Death or serious injury
F&S	Worst injury in crash was fatal or serious
HRIG	*High-risk intersection guide*
HRRRG	*High-risk rural roads guide*
IL	Investigation levels for skid resistance
KiwiRAP	The NZ Joint Agency Road Assessment Programme
LoSS	Level of safety service
MoT	Ministry of Transport
NZTA	NZ Transport Agency
OECD	Organisation for Economic Cooperation and Development
RCA	Road controlling authority
RoNs	Roads of national significance
RPS	Road protection score
SCRIM	Sideway-force coefficient routine investigation machine
TERNZ	Transport Engineering Research New Zealand
VMS	Variable message sign(s)

1 Introduction

1.1 Purpose

The *High-risk intersections guide* (HRIG) has been prepared by the NZ Transport Agency (NZTA) to provide guidance on the government's Safer Journeys 2020 strategy initiative to focus efforts on high-risk intersections. Although Safer Journeys specifies high-risk urban intersections, the significant number of rural intersection crashes and higher crash severity at them, means that it is sensible to address all intersections, both urban and rural, in one guide.

The objective of the HRIG is to provide practitioners with best practice guidance to identify, target and address key road safety issues at high-risk intersections. It is designed to accompany the *High-risk rural roads guide* (September 2011) and provides links to a number of road safety resources and guidance for planning, funding and evaluation of safety projects and programmes. Specifically, the HRIG is intended to provide:

- details of a Safe System approach to high-risk urban and rural intersections in New Zealand
- tools to assist in identifying and analysing high-risk intersections
- a range of countermeasures, for key crash movement types occurring at intersections, to assist in developing Safe System and best value remedial treatments, including changes to intersection form and control when appropriate
- guidance for developing, prioritising and funding road safety infrastructure programmes
- references to further resources and tools to undertake evaluation of implemented countermeasures.

This document has also been developed to provide national consistency regarding the identification of high-risk intersections and the application of proven countermeasures.

It provides a mechanism for road controlling authorities (RCAs) to manage the safety of intersections within their road networks. Although there are many ways in which high-risk intersections can be identified, regions will still need to identify and prioritise their own issues regardless of whether they conform to those identified within this document.

1.2 Scope

The HRIG incorporates references and direct links to the Austroads guides and to a number of appropriate policies, standards and guidelines applicable to New Zealand practice.

The guide supports and references:

- the New Zealand Ministry of Transport's (MoT) *Safer Journeys 2020, New Zealand's road safety strategy 2010–2020* (March 2010)
- the MoT's cross-agency *Safer Journeys implementation action plan* (May 2011)
- the NZTA's *Road safety strategic plan* (updated in April 2011)
- New Zealand legislation and, in particular, the Land Transport Act 1998 and rules made pursuant to that act, including the Land Transport (Road User) Rule, the Land Transport Rule: Traffic Control Devices and the Land Transport Rule: Setting of Speed Limits
- general polices contained in Austroads guides (guides to traffic management, road design, road safety) and Austroads technical reports
- New Zealand and, as appropriate, Australian standards codes of practice, guidelines
- published standards of various organisations and authorities.

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The HRIG provides suggested approaches to improve safety at high-risk intersections. However, practitioners must always apply sound judgement in the identification and installation of any countermeasures to ensure the best possible safety outcomes. Any departures from recommended practice must be supported by documentation of the principles behind the departures.

1.3 Target audience

The principles presented in the guide are relevant to both state highway and territorial local authority (TA) transport networks. The HRIG is intended to provide guidance to a range of technical practitioners, including:

- those from RCAs
- state highway and TA engineers
- planners
- funders.

It may also be useful for other industry practitioners, developers and private landowners where identification of road safety risks at intersections and development of appropriate risk reducing measures may be desirable.

1.4 Risk management

The objective of this guide is to reduce fatal and serious injuries at the New Zealand intersections. The term 'high-risk intersection' takes into account both consequence and likelihood of fatal and serious crashes occurring.

It is important to note that communication and consultation is one of the most important components of risk management and should be considered at all stages of the process. For example, in using the high-risk intersection definitions (which use reported, estimated and predicted fatal and serious crash risk) further risk identification may be through public feedback, the Road Transport Association, the AA, emergency services and other stakeholders. This feedback should determine whether the level of perceived risk matches the actual or potential risk through the use of crash and road data. Once specific intersections have been identified for treatment, further consultation can be undertaken with the community and road user groups on better understanding the risks, and the best methods of addressing these. This is explained further in sections 5 and 7.

It is useful to document the identification, analysis, treatment and monitoring process for high-risk intersections. This is an important means of recording the right level of information for the decision maker and the person responsible for taking action.

Further information on risk management, communication and consultation and recording the risk management process can be sourced from AS/NZA ISO31000: 2009 *Risk management: Principles and guidelines* and chapters 3 and 9 of SAA/SNZ HB 436: 2004 *Risk management guidelines*.

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1.5 Definitions

- An intersection[1] is:
  - where two or more streets or roads join or cross, or
  - where a major public driveway joins a street or road and is constructed as an intersection.
- An intersection crash is any crash occurring within a 50m radius from the centre of the intersection.
- An urban road is any road with a speed limit of 70km/h or less.
- A rural road is any road with a speed limit of 80km/h or more.
- A high-risk intersection is classified as:
  - an intersection where the reported, estimated or predicted number of F&S crashes (collective risk) or the reported, estimated or predicted number of F&S crashes relative to the volume of traffic passing through an intersection (personal risk) is classified as high or medium−high compared with other intersections.

1.6 Structure of the document

The guide is divided into six main sections:

Section 2	**Strategic context**	Outlines various strategies and priorities of government. It includes descriptions and background information on Safer Journeys and the Safe System approach.
Section 3	**Crash priorities strategic context**	Provides an overview of crashes at intersections in New Zealand. It includes a summary of the most common crash movement types for a variety of intersection forms and speed environments.
Section 4	**Identifying high-risk intersections**	Describes how high-risk intersections are identified in the New Zealand context. It includes guidance on assigning risk ratings and prioritising intersections for investigation within a limited funding base. Guidance on the most appropriate treatment strategy for an intersection based on the calculated risk metrics is also provided.
Section 5	**Understanding the issues**	Provides guidance on how crash data should be analysed in detail to understand the issues.
Section 6	**Safer intersection countermeasures**	Provides an overview of different safety countermeasures, evaluates the appropriateness of a variety of countermeasures and describes best practice approaches.

[1] Intersections include entrances and exits to and from supermarkets, petrol stations and other public parking areas such as airports and hospitals.

2 Strategic context

2.1 Safer Journeys: Road safety strategy 2010–2020

The New Zealand Government released its Safer Journeys: Road safety strategy in March 2010. Safer Journeys is a national strategy to guide improvements in road safety over the period 2010 to 2020. The strategy sets out a long-term vision for New Zealand of 'a safe road system increasingly free of death and serious injury'.

To support the vision, Safer Journeys introduces, for the first time in New Zealand, a Safe System approach to road safety (section 2.2).

Safer Journeys also lists a number of key initiatives that have been identified as having the greatest impact on road trauma. These initiatives will be implemented through a series of action plans relating to safe roads and roadsides, safe speeds, safe road use and safe vehicles.

2.2 Safe System

2.2.1 Safe System principles

A Safe System approach to road safety represents a fundamental shift in the way New Zealanders think about road safety. The Safe System approach is about acknowledging that:

1. Human beings make mistakes and crashes are inevitable.	However, the consequences of those mistakes should not result in a fatality or severe injury. A Safe System aims to reduce the likelihood of crashes with a focus on removing the potential for death or serious injury.
2. The human body has a limited ability to withstand crash forces.	The human body has a limited tolerance to crash forces. A Safe System aims to manage the magnitude of crash forces on the human body to remove the potential for death or serious injury. Refer to figure 2-1.
3. System designers and system users must all share responsibility for managing crash forces to a level that does not result in death or serious injury.	The aim of the system designer is to deliver a predictable (self explaining) road environment to the road user that minimises the risk of a crash while also being forgiving of mistakes. The Safe System relies on the principle of shared responsibility between system designers and road users. System designers include planners, engineers, policy makers, educators, enforcement officers, vehicle importers, suppliers, utility providers, insurers, etc.
4. It will take a whole–of–system approach to implement the Safe System in New Zealand.	Everyone plays a part in providing a safe transport system. Road designers will design safe roads and roadsides that will encourage safe behaviour and be forgiving of human error. Vehicle technology (safe vehicles) will vastly improve communication with the road environment to ensure appropriate speeds that respond to real–time conditions (safe speeds). Road users need to understand and play their part in the system, including an acceptance of the skills required to get a driver licence as well as maintaining their vehicles to appropriate standards.

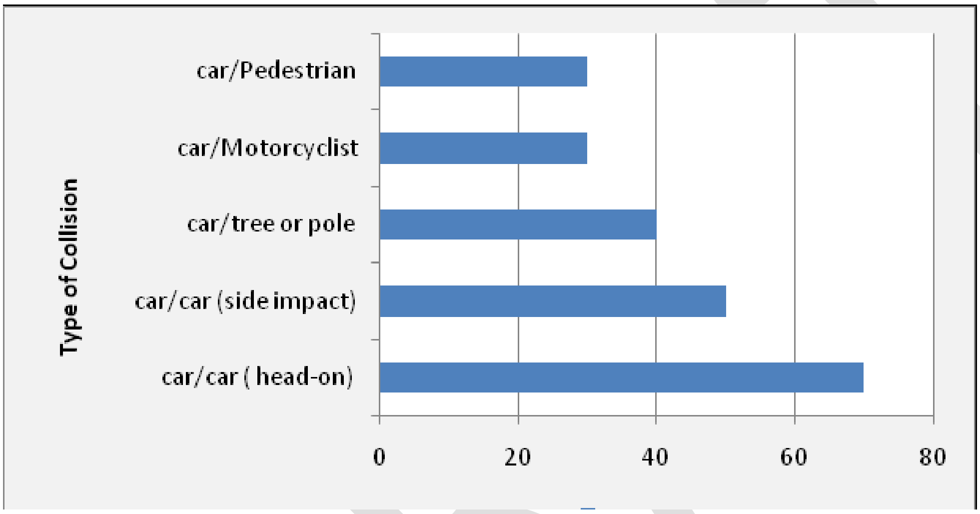
Scandinavian research [4] indicates that even if all road users complied with all road rules, fatalities would only fall by around 50% and serious crashes by 30%. Putting this in a New Zealand context, if everybody obeyed all the road rules, there would still be around 200 road deaths each year (based on fatalities in recent years).

The traditional 3 Es approach to road safety – engineering, education and enforcement – has proved useful in achieving current levels of road safety and these elements remain important. However, the 3 Es approach has a tendency towards blaming and trying to correct the road user. Continuing with this approach will not achieve the desired gains in road safety in New Zealand. A Safe System approach recognises the need for shared responsibility between system designers and road users with the ultimate aim of protecting road users from death and serious injury.

2.2.2 Human tolerance to physical force

The fundamental principle of a Safe System is the relationship between road users, vehicles, speeds and road infrastructure, and how much force the human body can withstand when each of these four elements interact in the event of a crash. The OECD [5] states that 'the human body's tolerance to physical force is at the centre of the Safe System approach'. This principle is illustrated in figure 2-1 and figure 2-2, which show survivable impact speeds for a number of crash scenarios, and the F&S crash risk curve for car drivers in side impacts with other cars respectively.

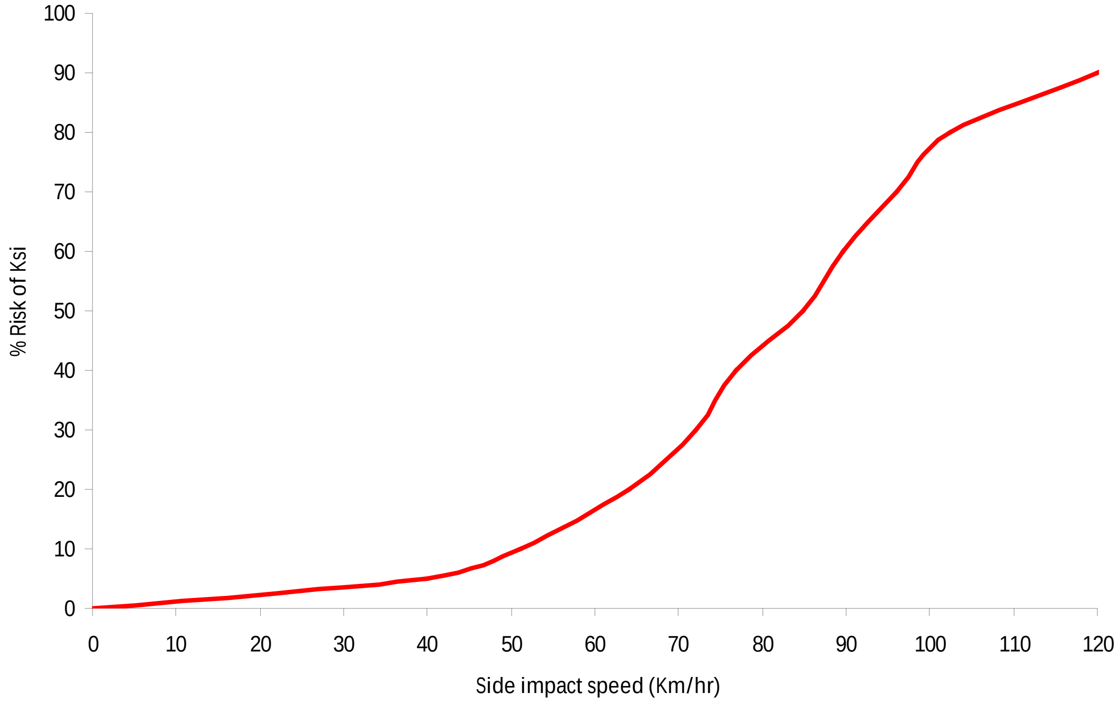
Figure 2-1: Survivable speeds for different scenarios



Source: Australian Transport Council (2006)

Figure 2-2 shows that the risk of a side impact collision being a F&S crash is approximately 10% where side impact speeds are limited to 50 km/h compared to 80% where side impact speeds are 100 km/h. Side impact collisions are one of the most likely impact types at intersections.

Figure 2-2: F&S crash risk relationship for car v car side impact speeds



Source: adapted from TRL 2009, Richards, D. and Cuerden R. *The relationship between speed and car driver injury severity*. Road safety web report 9, Transport Research laboratory, April 2009.

It should be noted that figure 2-2 is based on data where vehicles were struck on the same side as the injured occupant who was wearing a seat belt. The original source used the instantaneous change in speed of the struck vehicle. This has been converted to impact speed by doubling the value.

The OECD (2008) recognises that safe speeds are paramount in achieving a Safe System. The likely impact speeds for which a collision is survivable are shown in table 2-1. In urban environments in particular, where there is vehicular interaction with unprotected road users, safe speeds through intersections should be no more than 30-40km/h. Intersections with possible side-on impacts between vehicles should have speeds through them of no more than 50km/h (including likely impact speeds at rural intersections).

Table 2-1: Safe speed thresholds [7]

Road types combined with allowed road users	Safe speed (km/h)
Roads with possible conflicts between vehicles and unprotected users	30–40
Intersections with possible side-on conflicts between vehicles	50
Roads with possible frontal conflicts between vehicles	70
Roads with no likelihood of frontal or side-on conflicts between road users	≥100

On high speed rural roads, reducing travel speeds through intersections to 70-80km/h is likely to reduce the likelihood of a serious or fatal crash due to the decrease in stopping distance and the reduced speed (and therefore energy) at impact.

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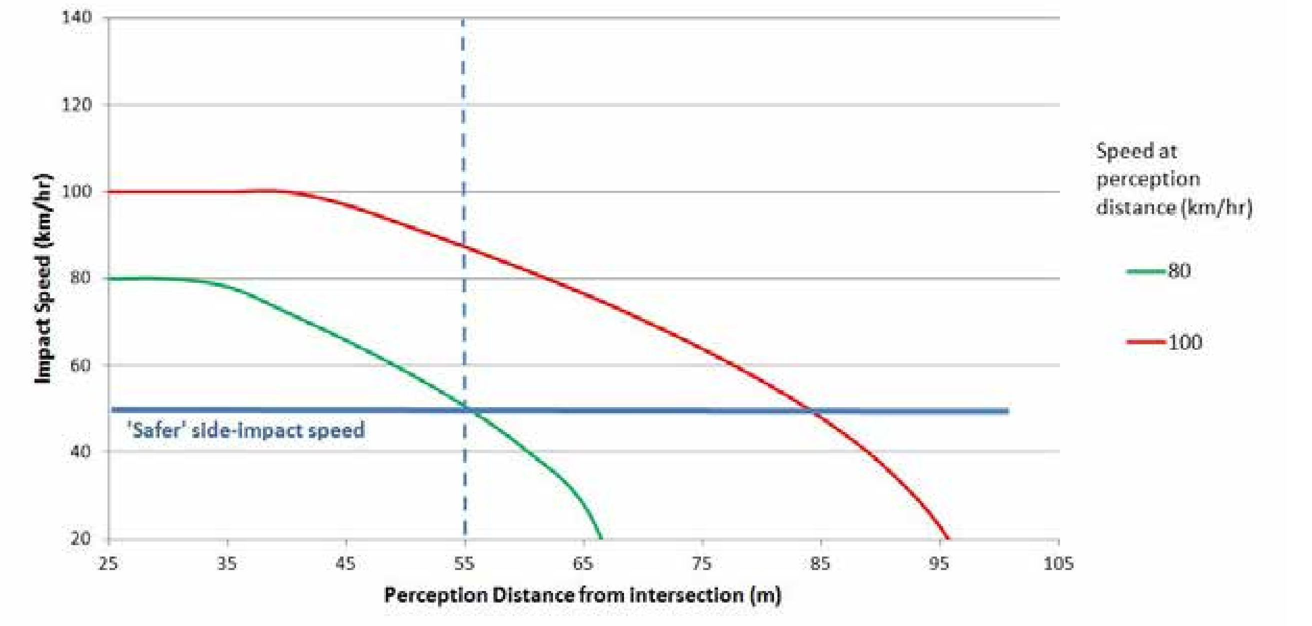
Figure 2-3 shows that the effects of various travel speeds on eventual impact speed is significant. In a side impact situation where braking starts 55m from the point of collision, a travel speed of 100km/h is likely to result in serious harm whereas a travel speed of 80km/h is much less likely to result in serious injury or death (Mackie, 2011). Where Safe System treatments such as rural roundabouts are not practical, other speed reducing measures, such as active warning signs on approaches may be appropriate.

For both urban and rural intersections, managing approach speeds by managing speed on the mid-block sections preceding intersections should be a key principle in providing inherently safer intersections.

Figure 2-3: Relationship between intersection approach speed, perception distance and impact speed (Mackie, 2011)



Note: A reaction time of 1.5 seconds and deceleration of 0.7g have been used for this example.

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2.2.3 Safe System components

Under a Safe System, designers create and operate a transport system where road users that are alert and compliant are protected from death and serious injury. The four key components of a Safe System are illustrated in figure 2-4 and include:

- **safe roads and roadsides** that are predictable and forgiving of mistakes – their design should encourage appropriate road user behaviour and speeds
- **safe speeds** that suit the function and level of safety of the road – road users understand and comply with speed limits and drive to the conditions
- **safe vehicles** that help prevent crashes and protect road users from crash forces that cause death and serious injury
- **safe road use** ensuring that road users are skilled, competent, alert and unimpaired, and that people comply with road rules, choose safer vehicles, take steps to improve safety and demand safety improvements.

Figure 2-4: The Safe System

At intersections the Safe System approach means that:

- the physical layout is simple, self explaining and forgiving of user error
- high severity conflicts are avoided
- any impact forces are managed to avoid serious harm
- road users are aware and compliant.

2.3 Key Safer Journeys initiatives

The Safer Journeys strategy contains road safety initiatives across the four Safe System cornerstones. This guide provides direction on how to implement a number of key initiatives for safer roads and roadsides and safe speeds at intersections. Specifically, the guide provides information and guidance on the following actions:

- Focus safety improvement programmes on high-risk rural roads and high-risk intersections.
- Create speed limits that reflect a Safe System.

Another Safer Journeys strategy that is expected to have a positive influence on safety at intersections is the change to the give way rule at intersections, which comes into effect on 25 March 2012. It is anticipated that changing the give way rules will greatly simplify the complex demands placed on road users at intersections and reduce the number of give way related crashes at intersections by around 7%. Investment framework

The *Government policy statement on land transport funding 2012* (GPS), covering the period 2012/13 to 2021/22, has a strong safety focus, with its three priorities being road safety, value for money and economic growth and productivity improvement. While no specific safety funding activity class has been created, there is an expectation that the level of safety investment is to be made transparent and the NZTA will be required to report on how it has been used to improve road safety. Safety expenditure includes the safety proportions of RoNS, safety improvements such as barriers and realignments, minor safety works, efforts on high-risk rural roads and high-risk intersections, motorcycle black routes, demonstration projects, road safety education and a safety component of maintenance and renewals.

The NZTA's Investment and Revenue Strategy (IRS) gives effect to the GPS 2012. The IRS has a focus on reductions in deaths and serious injuries and the adoption of a Safe System approach in line with Safer Journeys. The high strategic fit assessment of the IRS includes the 'potential to significantly reduce the number of crashes involving death and serious injuries in line with Safer Journeys on a high-risk rural road and a high-risk urban intersection'. High-risk rural roads include rural intersections. However, at this stage, for a high strategic fit, the IRS has a requirement to address actual crash risk only based on crash history. A predicted crash rate based on crash prediction models will be assigned a medium strategic fit. For more details on applying this criteria when developing programmes, refer to the NZTA's Planning and investment knowledge base http://www.nzta.govt.nz/resources/planning-and-investment-knowledge-base/ .

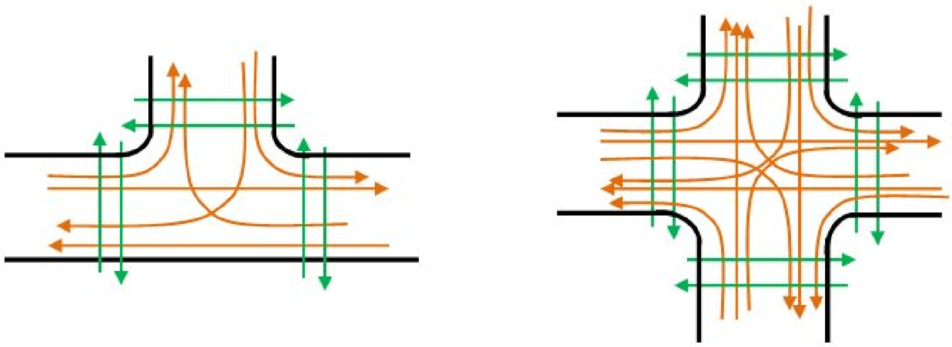
This investment focus combined with this HRIG is aimed at strongly encouraging RCAs to focus their efforts on the Safer Journeys priorities and actions,

3 Crash priorities

Intersections are places on the road network where road user's paths cross, increasing the risk of a crash. Despite the relatively short time spent travelling through intersections on most journeys, a high proportion of crashes occur at them.

Conflict at intersections is managed with the help of controls such as markings, signs, signals and roundabouts. The number of potential conflict points increase as the number of arms on the intersection increase (figure 3-1). As an intersection becomes busy, the complexity of decision making increases as several of these conflicts can happen at the same time.

Figure 3-1: Maximum possible travel directions for vehicles (orange) and for formal pedestrian movements (green) at intersections of three and four arms



Understanding the mechanisms of intersection crashes and appropriate treatments will often be more complex than mid-block examples. However, developing a clear and consistent approach to intersection safety is essential if New Zealand is to implement a Safe System approach to high-risk intersections.

Prioritising safety improvement measures for high-risk intersections requires a focus on reducing the number of fatal and serious crashes and casualties. This involves specifically focusing on the key high-risk crash movement types at intersections.

At rural intersections, speed and driver awareness are the main factors that can affect crash risk and severity (figure 3-2). At urban intersections, busy environments can place significant demands on road users (figure 3-3) and pedestrians and cyclists are at particular risk of higher severity crashes.

Figure 3-2: A typical priority controlled rural intersection

Figure 3-3: A typical stop controlled urban intersection

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Details of crash severity, intersection form and key crash movement types within the New Zealand context are further described in this section.

3.1 Crash severity at New Zealand intersections

Intersection crashes accounted for 38% of all injury crashes on New Zealand roads between 2006 and 2010. Furthermore, 17% of all reported injury crashes at intersections were F&S crashes.

Of the 22,012 injury crashes at intersections that occurred between 2006 and 2010, 18,314 (or 82%) occurred at urban intersections (speed limit of 50–70km/h). Despite the majority of injury crashes occurring at urban intersections, there were more fatal crashes at rural intersections (speed limit of 80–100km/h) between 2006 and 2010 than at urban intersections. The significant influence speed has on crash severity is shown in figure 3-4.

Figure 3-4: Severity of injury crashes at intersections in New Zealand by speed limit

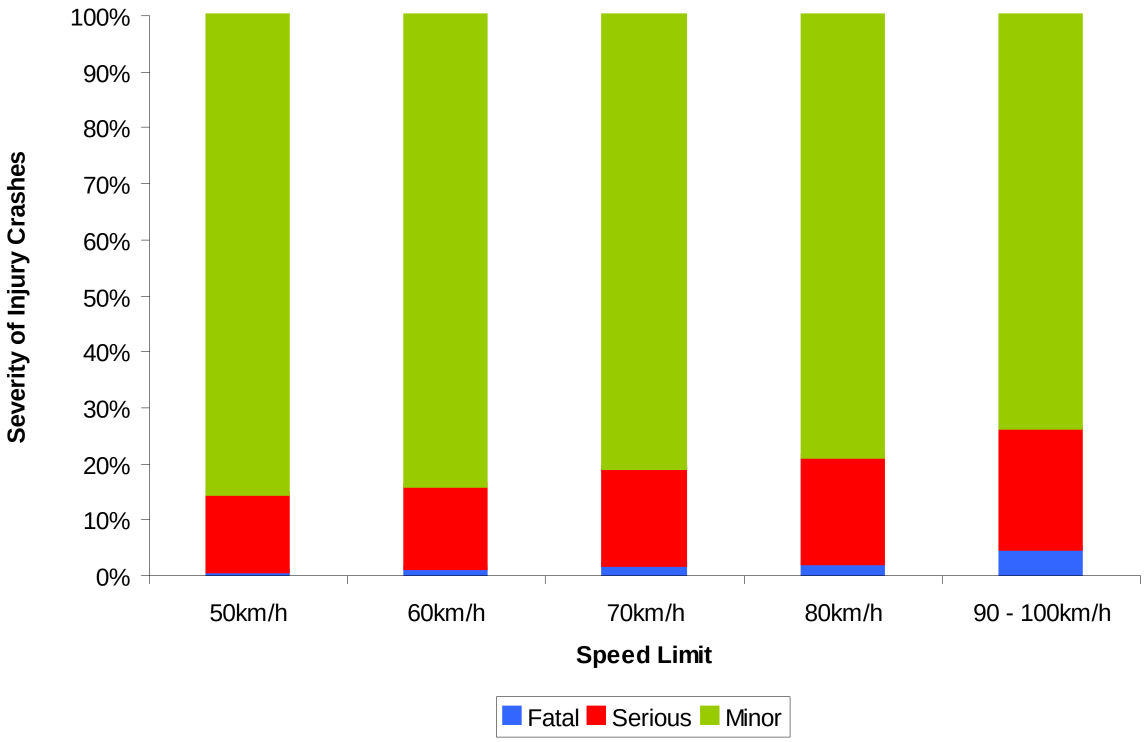

Figure 3-4 shows that the risk of a crash at an intersection being a F&S crash increases as the speed limit increases.

The proportion of injury crashes by severity occurring at intersections in urban and rural environments is shown in figure 3-5.Figure 3-5: Intersection crashes by severity and speed environment

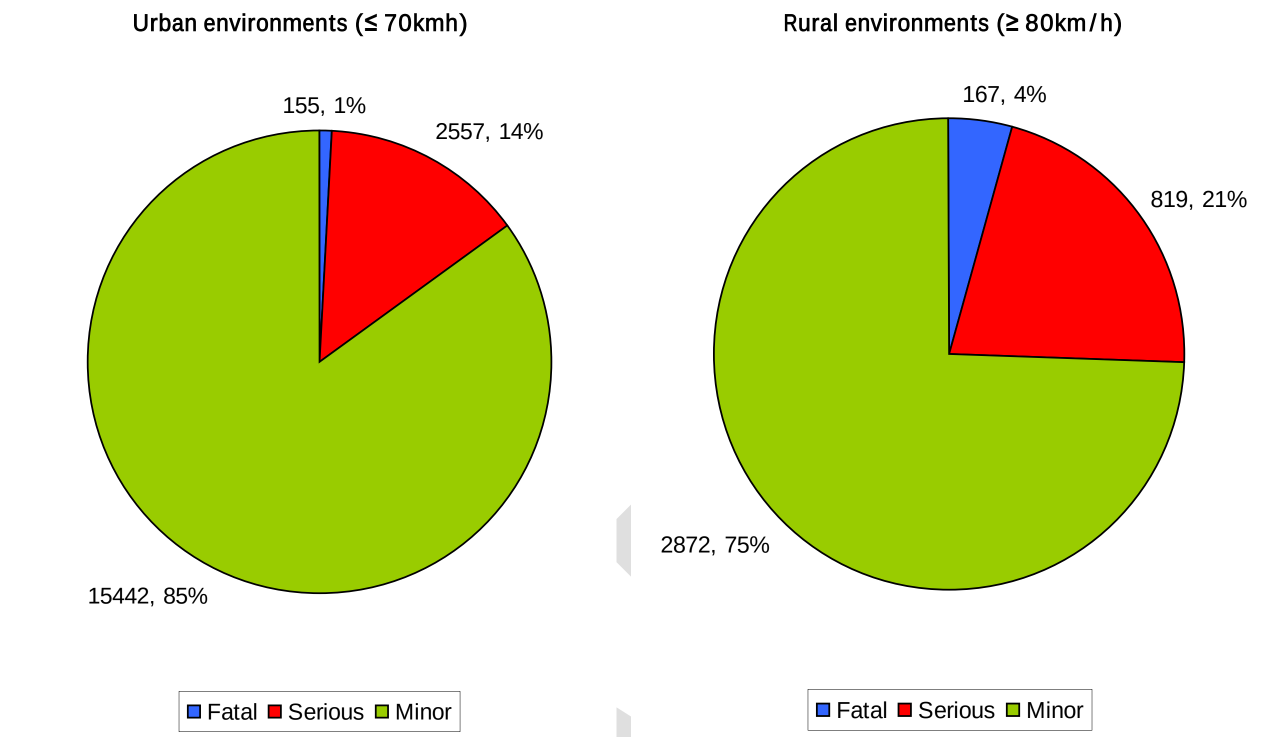

Figure 3-5 shows that the proportion of F&S crashes increases with the speed limit. In urban environments the proportion of F&S crashes of all injury crashes is 15% compared with 25% in rural environments. Overall the majority of F&S crashes occur in the urban environment.

3.2 Key F&S crash movement types by environment

This analysis concentrates on the key crash movement types for F&S crashes and Death and Serious (DSi) casualties. The DSi casualty analysis explores the extent to which certain crash movement types in different speed environments affect the likelihood of more than one death or serious injury in a crash. This level of analysis is important as reducing the number of deaths and serious injuries on New Zealand's roads is the main focus of Safer Journeys.

The proportions of key crash movement types for F&S crashes and DSi casualties at urban and rural intersections are shown in figure 3-6. The full list of CAS crash movement codes is provided in Appendix 1.

Generally the proportions of deaths and serious injured casualties are very similar to the proportions of fatal and serious crashes.

Figure 3-6: F&S intersection crashes and casualities by crash movement type and speed environment

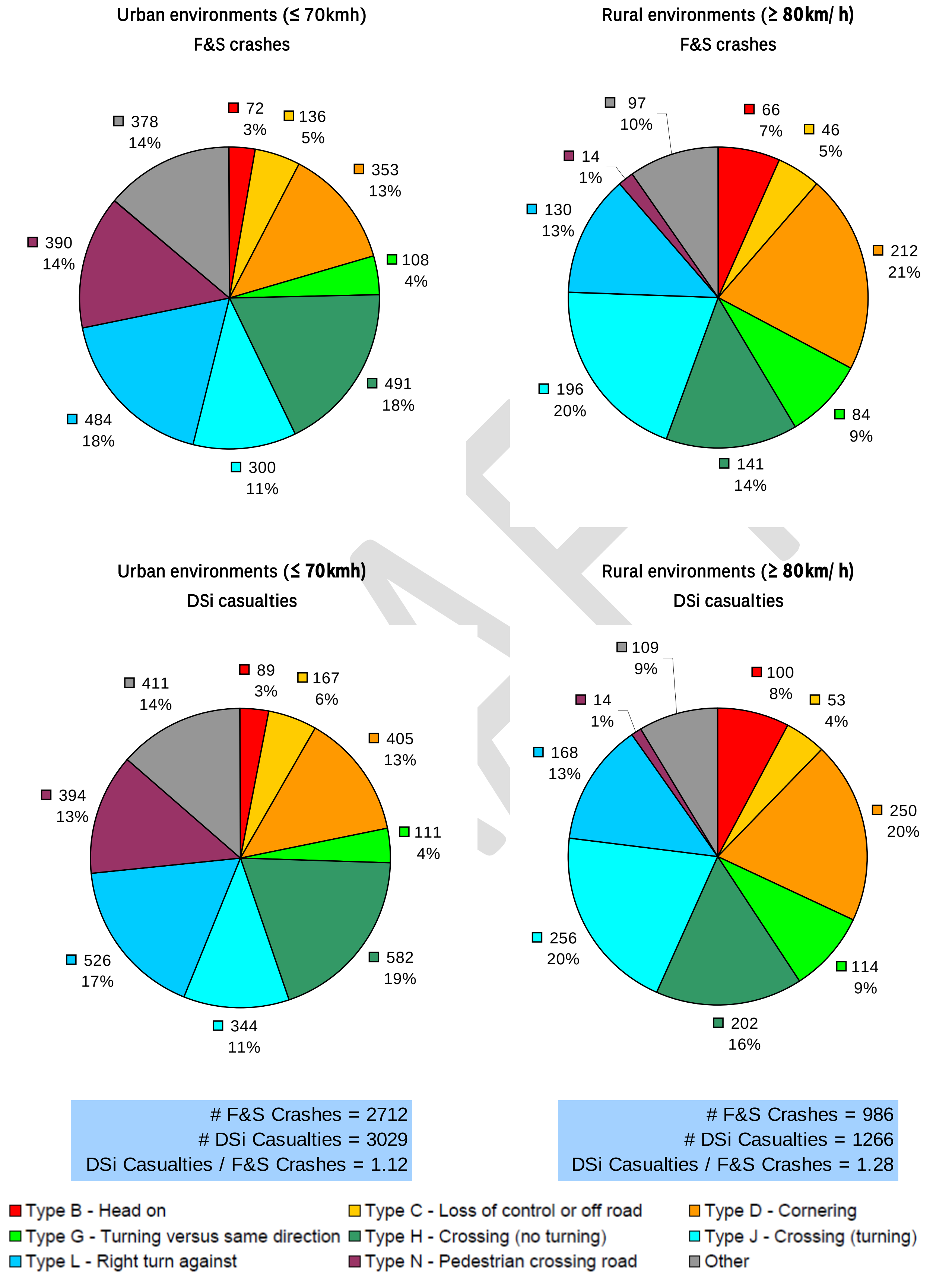

Figure 3-6 shows the main crash movement codes at intersections in urban and rural environments. It also shows which crash movement types have historically resulted in more than one death or serious casualty in a crash.

3.2.1 Urban intersections

In urban environments the main F&S crash movement types (more than 10% of all F&S) are Type H – crossing (no turning), Type L – right turn against, Type N – pedestrian crossing road, Type D – cornering and Type J – crossing (turning). Type H and Type J crash movement types can be broadly grouped as crossing type crashes. These crashes involve a vehicle entering an intersection from a minor (side) leg of an intersection colliding with a vehicle travelling through the intersection on the major leg.

The ratio of DSi casualties to F&S crashes is 1.12 at urban intersections. In the period from 2006 to 2010, a total of 243 F&S crashes (9%) resulted in more than one death or serious casualty at urban intersections. Type B, Type C and Type H crashes were most likely to result in multiple DSi casualties. However, Type B and Type C crashes combined only account for less than 10% of all DSi casualties at urban intersections.

This analysis indicates that the key crash movement types that should be focussed on at urban intersections are:

Crossing

- Type H – crossing (no turning)
- Type J – crossing (turning)

Type L – right turn against

Type N – pedestrian crossing road

Type D – cornering

3.2.2 Rural intersections

In rural environments the main F&S crash movement types (more than 10% of all KSi) are Type D – cornering, Type J – crossing (turning), Type H – crossing (no turning) and Type L – right turn against.

The ratio of DSi casualties to F&S crashes is 1.28 at rural intersections. This is significantly higher than the ratio at urban intersections. In the period from 2006 to 2010, a total of 202 F&S crashes (20%) resulted in more than one death or serious casualty at rural intersections. Type B and Type H crashes were most likely to result in there being multiple DSi casualties.

This analysis indicates that the key crash movement types that should be focussed on at rural intersections are:

Type D – cornering

Crossing

- Type H – crossing (no turning)
- Type J – crossing (turning)

Type L – right turn against

3.3 Key DSi casualty movement types by intersection form

The composition of the key crash movement types at for the main intersection form and speed environment combinations has been analysed. The five major intersection forms are signalised intersections, roundabouts, give way/stop (priority) controlled X, T and Y intersections and uncontrolled intersections.

Summary results of this analysis are presented in table 3.1 for urban environments and table 3.2 for rural environments. More detailed analysis is provided in Appendix 2.

Table 3-1: Composition of key crash movement types by intersection form in urban speed environments

	Type B	Type C	Type D	Type G	Type H	Type J	Type L	Type N	Other
Traffic signals									
Roundabout									
Priority crossroads									
Priority T&Y intersections									
Uncontrolled									

Key

Less than 5%

5 to 14%

15 to 24%

25 to 34%

35% or more

Table 3.1 shows that with the exception of uncontrolled intersections, one crash movement type stands out as the major contributor of DSi casualties at each urban intersection form. Notwithstanding this, there are a number of other crash movement types that have not insignificant contribution and cannot be overlooked from analysis.

Table 3-2: Composition of key crash movement types by intersection form in rural speed environments

	Type B	Type C	Type D	Type G	Type H	Type J	Type L	Type N	Other
Traffic signals									
Roundabout									
Priority crossroads									
Priority T&Y intersections									
Uncontrolled									

Table 3.2 shows that with the exception of signalised intersections, one crash movement type stands out as the major contributor of DSi casualties at each rural intersection form. The proportion of DSi casualties caused by the dominant crash movement type is more marked at rural intersections than urban intersections, thus making the process of targeting specific crash movement types much simpler than urban situations.

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4 Identifying high-risk intersections

A number of inter-related factors associated with road design, speed, vehicles and road use contribute to the likelihood and severity of intersection crashes. Understanding the mechanisms of intersection crashes and appropriate treatments will often be more complex than mid-block examples. However, developing a clear and consistent approach to intersection safety is essential if New Zealand is to implement a Safe System approach to high-risk intersections.

This section defines and provides risk metrics for what constitutes a high-risk intersection and outlines how the various risk metrics that make up the definition of a high-risk intersection are derived. Guidance has also been provided on how these metrics can be used to determine an appropriate treatment strategy, together with some examples of the process.

4.1 Different approaches

High-risk intersections are intersections with a higher than normal risk that someone will die or be seriously injured in the future. This HRIG generally uses fatal and serious crashes as the risk measure because the number of deaths and serious injuries in intersection crashes is usually similar to the number fatal and serious crashes. (The main exception is for some crash types at rural priority junctions as shown in appendix 3.) It is important that high risk intersections are identified because they are where targeted safety improvements are most likely to prevent deaths and serious injuries thereby fulfilling the long-term vision of Safer Journeys.

However until we have investigated such intersections, identified the preventable risk factors and developed effective targeted improvements that reduce the risk, we do not have an intersection that meets all the funding criteria for a high-risk intersection.

Turning this concept into a reliable and practical method of identifying high-risk intersections is difficult.

There are various ways of defining intersections that are likely to be high-risk, none of which are sufficiently reliable on their own. Instead, the various methods can be used to draw up a list of likely sites for further investigation, but further analysis will be required to confirm that the sites are truly high-risk.

Risk can be assessed using two main methods:

- The risk can be estimated using the recent history of crashes. (called actual crash risk in the NZTA investment criteria)
- The risk can be predicted using the physical and operational characteristics of an intersection that are known to affect the risk (called predicted crash risk in NZTA investment criteria).

4.1.1 Using crash history

Traditionally unsafe intersections were identified when the reported injury crash record of the past five years exceeded a threshold. This tended to place a strong emphasis on crashes with minor injury, as minor injury crashes account for 85% of all injury crashes in urban areas and 72% of injury crashes in rural areas. A better alternative was to rank sites by the social cost of crashes – but this placed an undue weight on fatal crashes, which are rare events.

(a) Using reported fatal and serious crashes (F&S crashes)

Under a Safe System approach, it is appropriate to focus on the number of fatal and serious crashes. However, few intersections in New Zealand have three or more fatal and serious crashes in a five-year period. Using these crashes alone can be fraught with the risk of reaching false conclusions about crash risk based on small numbers. It can easily result in road controlling authorities chasing randomly occurring crashes around the network.

To improve the reliability of estimates based on crash history we can increase the number of years of crash data used. However, this approach is only truly valid if the crash risk has not significantly changed. So care must be taken to identify any changes to the site conditions that would affect crash risk. Also, caution is advised at sites where the majority of crashes are in the distant past. The trend in all injury crashes may assist to confirm a consistent pattern over time. Of course the same issues can arise for known changes within the last five years.

(b) Using all injury crashes

By using all injury crashes instead of just F&S crashes, there is significantly more data available for analysis – around six to seven times more at urban intersections and three to four times more at rural intersections. We can use this extra data to estimate the risk of F&S crashes occurring. We do so by applying our knowledge of crash severity to estimate the likelihood that any crash will result in fatal or serious injury.

We know that some intersection crash movement types are more severe than others. For instance, drivers turning right out of side roads are particularly vulnerable to being hit in the driver's door from the right, which is particularly severe. However, rear-end collisions rarely result in a F&S crash. Different intersection forms and controls also have different typical severities – roundabouts in particular are designed to reduce crash severity, but crashes at traffic signals are also less severe than priority controls, because many of the conflicts involve road users who have stopped at the signals. This method is better at estimating future F&S crashes than just the prior F&S crash history alone.

This method is described, including a worked example in Appendix 3.

4.1.2 Using crash risk prediction models

The predicted crash risk can also be assessed by crash risk prediction models. Models have been developed in NZTA research projects, some of which have been included in the *Economic evaluation manual* (EEM). A wide variety of models exist, ranging from simple approach flow only models through to conflicting flow models for different road user types. The models take the characteristics of a site into account to predict the typical crash rate for the intersection.

While the more complex models provide better crash prediction estimates, there is no dataset with this information consistently available for all but a small number of intersections across the country. So it is not currently possible to use this method to identify likely high-risk intersection sites on a nationwide basis. However, traffic volume data is consistently available throughout the country for the more generalised flow only models to be used.

The approach entry flow models are most useful for comparing the crash history of a site with that expected for a similar intersection with similar traffic volumes. The difference between the crash history and the modelled rate is a measure of the crash performance of an intersection and can be used to indicate the likely potential for crash reduction at sites where the crash history exceeds the modelled crash prediction. This is the basis of the level of safety service assessment described in section 4.3.1.

High risk intersections identified only by crash prediction models are not eliglible for high strategic fit under the NZTA investment criteria.

4.2 High-risk intersection metrics

High-risk intersections can be categorised using two types of risk metrics as defined below:

- **Collective risk** also known as crash density is measured as the number of fatal and serious crashes per intersection in a crash period.
- **Personal risk** or crash rate is measured in terms of the number of F&S crashes per 100 million vehicles using an intersection.

Crashes used in the assessment of the above risk metrics are confined to those crashes occurring within 50m of an intersection (refer to section 1-6 for definition). However, if it can be demonstrated that a F&S crash occurred more than 50m from an intersection and was associated with the intersection, eg a rear-end collision involving queuing back from signals, then that F&S crash may be included in the risk assessment. Any such crashes can only be used for actual F&S crashes analysis (refer to section 4.2.1).

4.2.1 Collective risk

Of the two types of risk metrics, collective risk is the easiest to quantify. Two methods have been developed for defining collective risk at intersections.

The simplest definition of collective risk is to consider the history of F&S crashes that have occurred at an intersection in a period of time – normally five or 10 years. The number of F&S crashes at intersections can be extracted from the NZTA's crash analysis system (CAS). This definition is referred to as F&S crashes.

The second definition involves the estimation of the number of F&S crashes based on all injury crashes that have occurred at an intersection. It takes into account the effect of the crash movement type, intersection form and control, and collision speed on crash severity outcomes. The process involves the multiplication of injury crash movement types at an intersection by the F&S crashes/all injury crashes proportions provided in the tables in Appendix 3 corresponding to the intersection form and speed environment of the intersection being analysed. This definition is referred to as Estimated F&S crashes.

The second definition acknowledges that actual F&S crash data alone may not be a good indicator of the underlying F&S crash risk at many intersections.

1. **Reported F&S crashes:** These are intersections with a high observed number of F&S crashes.

   The criteria are set fairly high because due to the biases discussed above, it is necessary to minimise the risk of falsely identifying sites that are not high-risk. To be confident that an intersection is high-risk, there needs to be three or more serious and/or fatal crashes in five years (or five or more serious and fatal crashes in 10 years).

2. **Estimated F&S crashes:** These are intersections with a high estimated number of F&S crashes.

   The collective risk levels for Estimated F&S crashes are displayed in Table 4.1.

Table 4-1: Criteria for identifying intersection collective risk

Collective risk level	Estimated F&S crashes (5 years) from injury crashes
High	> 1.6
Medium high	1.2–1.6
Medium	0.85–1.2
Low medium	0.5–0.85
Low	< 0.5

An example of how the Estimated F&S crashes are derived from all injury crashes is provided in Appendix 3.

4.2.2 Personal risk

Because it is essential to have sufficient numbers of crashes to establish an appropriate safety countermeasure, the reported and estimated personal crash risk metrics should only be used for intersections that have four or more recorded injury crashes in the past five years. Sites with three or fewer injury crashes in the past five years should be excluded from assessment unless at least two of the injury crashes are F&S crashes.

Crash prediction models are more appropriate for assessing personal risk where there are low crash numbers. A typical application might be setting up programme of improvements on a network of rural crossroads.

The average annual daily traffic (AADT) volume data is required for all legs of an intersection in order for the personal risk to be quantified. Where AADT volume data is unavailable from a traffic count database then it can be estimated from other sources such as transportation models, from SCATS (for traffic signals) from RAMM data, or CAS. In all situations the accuracy of the data must be considered, before utilising it.

The AADT volume data needs to be known for each leg of an intersection so the ‘product of flow’ can be calculated. The product of flow is a method used to standardise the number of potential vehicle conflicts that could occur at an intersection.

The product of flow formula is $(\text{Qmajor} \times \text{Qminor})^{0.4}$ where:

Qmajor = the highest two-way link volume (AADT) for crossroads and the primary road volume for T-intersections.

Qminor = the lowest of the daily two–way link volumes (AADT) for crossroads and the side road flow for T-intersections..

The product of flow formula also applies to roundabouts even though the crash prediction models for roundabouts are calculated per approach and do not use Qmajor and Qminor terms (refer Appendix 4).

The personal risk calculation makes use of the reported, estimated or predicted F&S crash information calculated for the collective risk metric. The personal risk calculation formula is:

$$\textbf{Personal risk} = \frac{\textbf{The greater of: reported F\&S crashes / 2 or estimated or predicted F\&S crashes} \times 10^{8}}{\textbf{Product of flow } (\text{Qmajor} \times \text{Qminor})^{0.4} \times \textbf{5 years} \times \textbf{365 days}}$$

The personal risk levels for intersections are displayed in table 4.2.

Table 4-2: Criteria for identifying intersection personal risk

Personal risk level	Risk metrics
High	> 130
Medium high	100–130
Medium	70–100
Low medium	40–70
Low	< 40

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4.2.3 High-risk definitions

At present there are currently two definitions of a high-risk intersection, as follows:

- an intersection where the number of reported F&S crashes (collective risk) or the reported number of F&S crashes relative to the volume of traffic passing through an intersection (personal risk) is classified as high or medium–high compared with other intersections (section 4.2.1 and figures 4-1 and 4-2) and / or
- an intersection where the number of estimated F&S crashes (collective risk) or the number of estimated F&S crashes relative to the volume of traffic passing through an intersection (personal risk) is classified as high or medium–high compared with other intersections (section 4.2.2 and figures 4-1 and 4-2).

The above two definitions are more reactive than proactive in nature, especially where reported F&S crash numbers are used. The need to move away from a reactive to proactive approach to road safety is well established in the industry.

For rural roads, the KiwiRAP star rating system (for state highways) and RISA (for local authority roads) have been developed as a predictive measure of personal safety along a length of road based on the physical and operational characteristics of the road. Intersection crash prediction models would allow us to more proactively deal with risk factors that are likely to lead to future crashes without waiting for them to happen but there is not currently a full database of intersection features to permit this to happen. However there is nothing to stop an RCA from collecting data for a subset of intersections likely to have high personal risk, such as rural crossroads in their area, and using crash prediction models to assess crash risk.

To allow full proactive analysis of the whole network using crash prediction models in the future it is desirable that RCAs start collecting information on the features at each intersection. It is likely that NZTA will produce guidance on the data needs so a proactive list of potentially at risk intersections can be developed.

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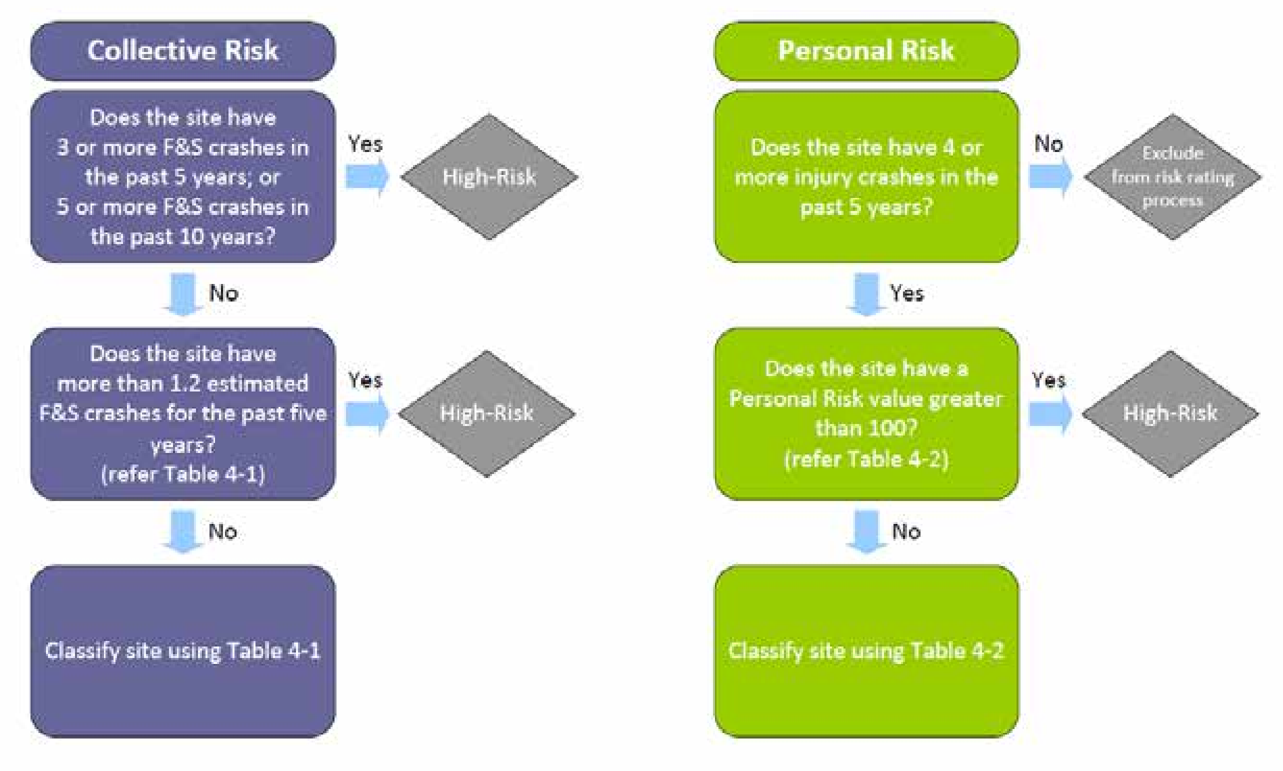
4.2.4 Risk rating assignment process summary

A summary of the risk rating assignment process for collective and personal risk is shown in figure 4-1.

Figure 4-1: Process for assigning risk ratings to intersections



4.3 Prioritising high-risk intersections for investigation

4.3.1 Purpose

The primary way of prioritising intersections for investigation is based on the collective and personal risks. However there is a secondary method that is appropriate for identifying those intersections that have a poor safety performance when compared to intersections of the same type. Their reported crash history is compared to the performance predicted from crash prediction models. Those that have a worse than expected crash history are likely to have unsafe features, such as a poor layout, poor visibility or an inappropriate signal phasing regime, and are most likely to have effective countermeasures that can be applied without changing the intersection type.

The purpose of this section is to provide road controlling authorities with a method for prioritising these intersections for investigation within a limited funding base. The method acknowledges that some road controlling authorities will not have sufficient funding to investigate high-risk intersections and introduce road safety countermeasures in the three-year funding cycle in which the high-risk intersections are identified. The method provides a sound basis for prioritising intersections with the same risk classifications for investigation and ensures that those sites which are likely to achieve the most benefit in terms of crash reduction are investigated first.

The technique used to refine the priority of intersections for investigation is known as level of safety service (LoSS).

4.3.2 Level of safety service (LoSS) method

This method can only be used for sites that have enough reported crashes to permit a reasonable estimate of personal risk - see the minimum reported crash requirements in section 4.2.2.

It is important to note that LoSS analysis is only applicable at intersections where enhancements or modifications are proposed to the existing intersection form. This prioritisation technique does not apply at sites where a change to the intersection form or other Safe System transformational change is being considered. For instance a roundabout that is performing poorly when compared to other roundabouts may still be much safer than a priority controlled crossroad, and a form change from a priority crossroad to a roundabout may still be appropriate even though an intersection's LoSS is typical for its type. .

This method compares the number of observed injury crashes at an intersection against the number of predicted crashes derived from the general flow only crash prediction models. The general flow only crash prediction models from the NZTA *Economic evaluation manual* (EEM) are reproduced in Appendix 4 of this guide. Conveniently, LoSS calculations do not require any additional information from that used to calculate personal risk levels.

The LoSS method takes into account the speed environment, intersection form and amount of traffic travelling through an intersection. Intersections which have the greatest differential between actual crash performance and predicted crash performance from the crash prediction models can be used to indicate the likely potential for crash reduction at sites where the crash history exceeds the modelled crash prediction.

The injury crash performance of an intersection has been separated into five LoSS bands to help prioritise intersections for treatment where that have the same collective and/or personal risk levels. The LoSS bands are shown in table 4.3.

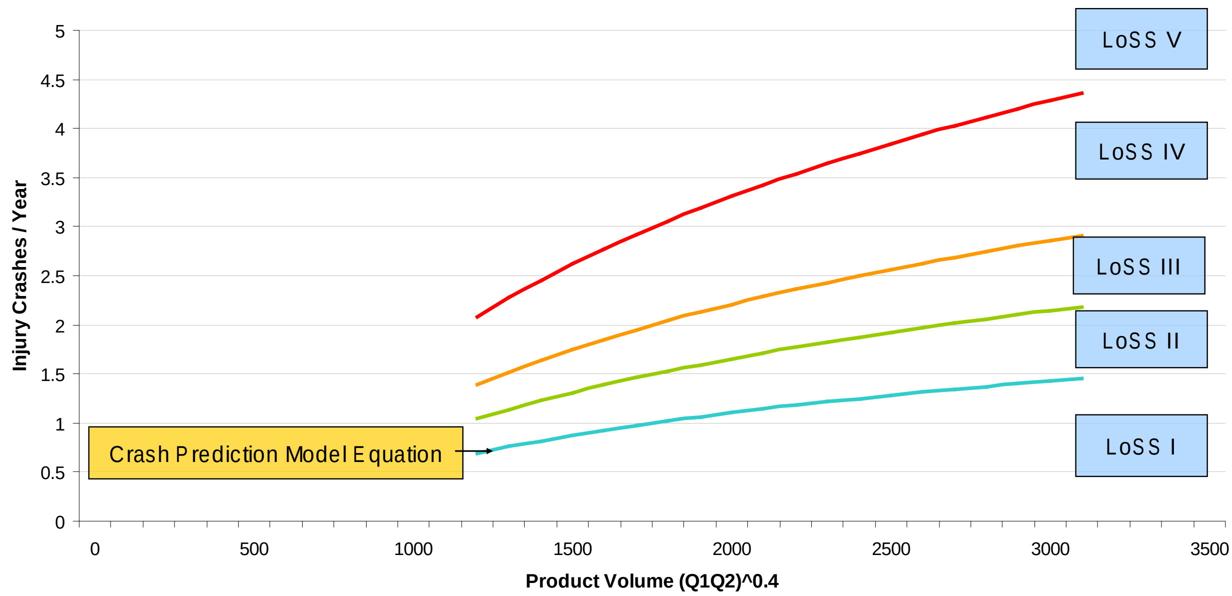
Table 4-3: Level of safety service bands

Level of safety service	Definition
LoSS V	The number of observed injury crashes divided by the predicted number of injury crashes is greater than 3.0.
LoSS IV	The number of observed injury crashes divided by the predicted number of injury crashes is greater than 2.0 and less than or equal to 3.0.
LoSS III	The number of observed injury crashes divided by the predicted number of injury crashes is greater than 1.5 and less than or equal to 2.0.
LoSS II	The number of observed injury crashes divided by the predicted number of injury crashes is greater than 1.0 and less than or equal to 1.5.
LoSS I	The number of observed injury crashes divided by the predicted number of injury crashes is less than or equal to 1.0.

Intersections classified as LoSS I have a safety performance that is better than other intersections of that type, in the same speed environment and with similar traffic flows. By comparison, intersections classified as LoSS V have a very poor safety performance when compared to the performance expected from similar intersections.

The LoSS charts showing the predicted safety performance for a range of traffic flows for each intersection form and speed environment combination are provided in Appendix 5. An example of the shape of these charts is shown in figure 4-2.

Figure 4-2: LoSS bands for urban signalised crossroad intersections



It should be noted that many intersections are likely to fall outside of one of more of the criteria for using the crash prediction models provided in the EEM, e.g. traffic volumes are outside of the permitted ranges, traffic volumes on opposite legs are significantly different, one or more of the approaches is one-way, or other feature of the physical layout. For these intersections, we recommend using the crash prediction model that best matches the physical and operational characteristics so all intersections can be prioritised using this methodology. However, the outputs of any intersection that falls outside of the criteria should be treated with caution.

The use of LoSS charts, which are based on all injury crashes, should be used in combination with figures shown in section 6.5.2, which incorporate known severity relationships for different intersection form and speed environment combinations and are useful in estimating the effects of changing the form of intersection on F&S crashes.

4.3.3 Risk rating

In order to prioritise works at high-risk sites, and ultimately to indicate the degree and type of countermeasure that is appropriate, we need to consider collective and personal risk as well as the LoSS together. The relative risk associated with each of the risk metrics provides a useful guide for road controlling authorities to prioritise road safety countermeasures.

Intersections that are high-risk in terms of collective and personal risk have the greatest potential for reducing F&S crashes and personal risk. Intersections that are high risk for either collective or personal risk have potential for reductions in actual F&S crashes and improvements in personal risk respectively. The manner in which intersections with different risk rating combinations are most appropriately treated is described in section 4.5.

Intersections that are assessed to be high-risk in terms of both collective and personal risk should be prioritised for investigation ahead of intersections that are assessed as being high-risk in terms of collective or personal risk alone. The LoSS ratings should be used as a means of refining the order in which intersections that have the same risk ratings in terms of collective and personal risk are prioritised.

It must be acknowledged that safety countermeasures for intersections assessed as high-risk in terms of collective and personal risk will generally be more costly than intersections assessed as high-risk in terms of collective risk and are likely to be considerably more costly than intersections assessed as high-risk in terms of personal risk. This needs to be taken into account when prioritising a package of safety improvement works.

4.4 Identifying high-risk intersections in a road network

Unlike for rural state highways where the KiwiRAP star rating system is available for rating roads there is currently no system for rating the majority of intersections. However, the KiwiRAP star rating system does provide some metrics and methods that are valid to intersection assessment around crash risk maps (refer to the *High-risk rural roads guide* for more detail on the KiwiRAP star rating system).

4.4.1 Crash risk maps

To be consistent with KiwiRAP the development of crash risk maps showing the historic safety performance in terms of both collective and personal risk for intersections is desirable. Maps could show the actual or estimated F&S crash histories for each intersection.

Crash risk maps can be a particularly useful tool to identify routes or clusters of intersections that have a higher crash risk. Mapping is expected to be especially useful in large urban networks. Investigation of these sites collectively can be beneficial both economically and in providing consistent treatments along corridors or in areas that have common crash themes and can be dealt with on a mass action basis.

(a) Collective and personal crash risk maps

The crash risk maps for collective and personal risk should be developed for all intersections. Aside from crash data, CAS is a useful repository for information on traffic flows, speed limits and the form of intersection (where crashes have occurred). Other information sources will need to be referenced to obtain complete and accurate data for analysing an entire road network area. This may include obtaining information from sources such as but not limited to: RAMM, traffic count databases, transport models and capital works programmes (to identify intersections that have undergone transformational change within the past five to 10 years).

This process will require all intersections to be classified as urban (all approaches 70km/h or under) or rural (two or more approaches 80km/h or above), by intersection form (crossroads or T-intersection) and by form of control (signalised, roundabout, priority or uncontrolled). In the absence of upgrade information, the intersection form and control at the time of the most recent crashes is used in the development of the risk maps. Where upgrade information is available intersections that have been upgraded will need to be identified on the maps. A five year historical crash period will typically be used.

As already specified, the KiwiRAP star rating system is not currently available for urban intersections, due to the lack of data on intersection layout and operation. As with the personal crash risk maps it is expected that when star ratings are applied that they will focus on certain parts of the road network, at least to start with. This will be an area for future development and is likely to be included in future versions of this manual. It is recommended that councils start collecting information on their intersections that will allow star ratings to be developed in the future.

To assist local authorities, the NZTA will publish a list of intersections that have high collective risk on an annual basis. Local authorities will still be required to determine the personal risk for each intersection in their network as this assessment requires knowledge of traffic volumes, which in many instances will be held locally.

(b) Level of safety service maps

In addition to the personal and collective risk maps further mapping can be carried out detailing deficient intersections in terms of LoSS. Using the LoSS method described in section 4.3.1, each intersection in a network can be classed as low risk through to high-risk (LoSS I to LoSS V). Using colour coding and a GIS system, it is possible to show those intersections that perform well (low risk) and poorly (high risk) across a network based on the intersection form, speed environment and number of vehicles travelling through the intersection.

The method allows different types of intersections, in different speed environments and with different traffic flows to be compared directly. Those sites that are classed as high-risk have a high potential for crash reduction from safety countermeasures.

An example of a LoSS map in an urban area is shown in ffigure 4-3.

Figure 4-3: Example of a LoSS map for an urban area

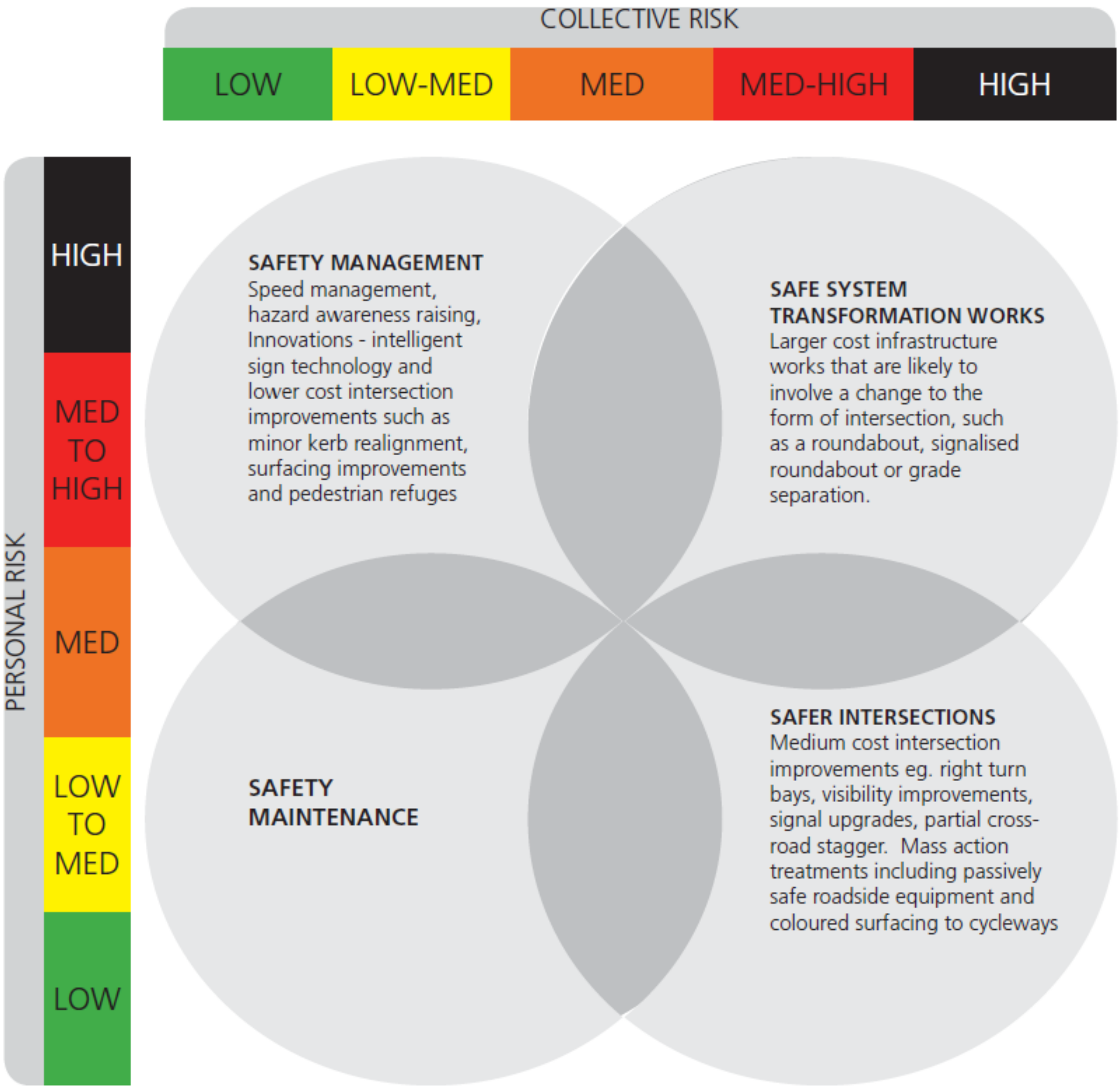
4.5 Treatment of high-risk intersections

This section provides guidance on how to use the above risk metrics to determine an appropriate treatment strategy together with some examples of the process.

4.5.1 Process

Using the processes described in sections 4.2, 4.3 and 4.4, we have now determined the level of risk for each intersection. Using the calculated risk levels collective and personal risk, we can now use the 'treatment philosophy strategy' (ffigure 4-4) for guidance on the appropriate treatment type for each intersection.

Figure 4-4: Intersection treatment philosophy



4.5.2 Safety improvement strategy

Figure 4-4 provides a schematic of the general treatment philosophy strategy that has been developed to guide the selection and implementation of various improvement measures based on the various metrics that define the risk of a particular intersection under consideration. These are:

- Reported, estimated or predicted F&S crash risk, known as collective risk, shown on the top horizontal x-axis, and
- Reported, estimated or predicted F&S crashes relative to the volume of traffic passing through an intersection, known as personal risk, shown on the left-hand vertical y-axis.

In the upper right corner of figure 4-47, are those intersections with both high collective and personal risk. Intersections in this quadrant have considerable scope to reduce personal risk and have sufficient F&S crash reduction benefits to justify larger infrastructure improvements. In many cases this may involve a transformational change to the form of the intersection.

At the other extreme, in the lower left quadrant, both the collective and personal crash risk is low. There is in effect no identifiable safety problem.

The lower right quadrant comprises intersections with higher collective risk but lower personal risk. These intersections tend to have high traffic flows on all legs of the intersection, which results in a high 'product of flow' calculation. In these situations, significant benefits are only likely to be achievable with the introduction of Safe System intersection features, such as removing conflicting movements (for all road users), removing roadside hazards, introducing severe speed management measures to reduce collision forces and mass action treatments. As these intersections have a low personal risk there are probably insufficient crash benefits to justify a complete transformation of the intersection. Many of these intersections are likely to have already been the focus of crash reduction studies.

The upper left quadrant is characterised by high personal risk and low collective risk. These intersections tend to have lower traffic volumes on one or more of the legs of the intersection, which results in a low pproduct of flow calculation. At these intersections, the potential crash reduction benefits in terms of absolute F&S crashes are limited, but low-cost safer intersection improvements are likely to be effective at reducing the potential for future F&S crashes. Therefore strategies focused around minor improvements to address deficiencies at the intersection, such as visibility, signage, markings and surface issues are likely to be the most appropriate types of treatment. Attention should also be paid to speed management through the intersection, recognising that appropriate speeds will reduce both the likelihood and severity of crash outcomes.

It should be noted that those sites which fall outside of transformational works, whether they are high personal or collective risk may benefit from a combination of safer intersections or safety management. However it is likely that most high collective risk sites will have usually had safer intersection form improvements.

In most jurisdictions a combination of transformational improvement at the high personal and collective risk sites, lower-cost treatments at high personal risk sites and mass-action application of new safety measures at collective risk sites will be necessary. A balanced strategy that looks to maximise the safety return in each jurisdiction in terms of the number of F&S crashes saved in 10 years per $100m invested is required. It is expected that most jurisdictions will have some projects in each of the three categories.

1 What type of safety problem do we have?

Figure 4-4 provides guidance on the nature of type of improvement strategy that is likely to be most appropriate for an intersection. It does not necessarily identify the specific measures that may be most appropriate for a particular intersection. The first step in such an investigation is to determine what type of safety problem we have, whether the current crash patterns have thematic commonality, causal commonality or other common themes, such as crashes occurring in wet conditions.

Guidance for understanding the safety issues is given in section 5. Further analysis and treatments of high-risk intersections can also be found in the *New Zealand guide to the treatment of crash locations.*

2 Interim safety treatments

It is recognised that where Safe System transformation works are identified as the most appropriate treatment strategy it is likely to involve a long-term period of incubation and implementation given the higher cost of infrastructure-type treatments. Therefore consideration should be given to providing interim safety treatments where they could still be cost effective, i.e. the treatment should not create difficulty or increase costs significantly when programming for larger infrastructure works in the future.

4.6 Risk profile assessment and treatment strategy example

This section provides a demonstration of how the risk profile and treatment strategy of an intersection is assessed using the technique described earlier in this section.

4.6.1 High collective and high personal risk intersection, Central Waikato SH1/5

1. Description

This intersection of State Highway 1 (SH1) and State Highway 5 (SH5) is located just south of the small rural township of Tirau in the Central Waikato. It is situated in a rolling 100km/h rural environment and is commonly used by tourists. The ‘through’ route is SH1 which negotiates a tight bend and is the main north/south route for the north island. SH5 joins SH1 at approximately the apex of the bend, as shown in figure 4-5.

Figure 4-5: Imagery of the SH1/SH5 intersection

Aerial view of intersection

Looking south towards the intersection on SH1

Looking north towards the intersection on SH1

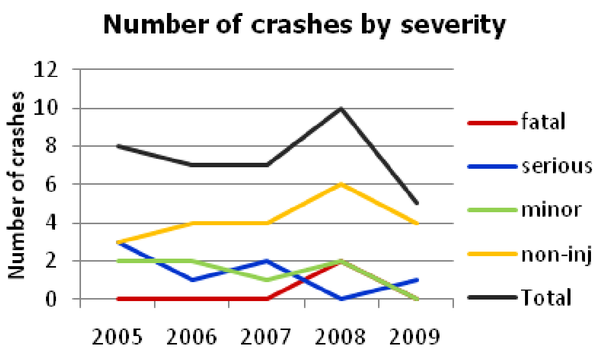
Looking west towards the intersection on SH5

2. High-risk metrics assessment

Crash data

- CAS crash history for past five years.
- 16 injury crashes.
- 9 F&S crashes.

As the intersection has had three or more F&S crashes in the past five years that means it is a high-risk intersection in terms of collective risk.



Collective risk = HIGH

Traffic volume data

- SH1 (north of intersection) 11,577 vehicles per day (vpd).
- SH1 (south of intersection) 8,325 vpd.
- SH5 (east of intersection) 3,461 vpd.

$$\text{Personal risk} = \frac{9 \text{ F\&S crashes} \times 10^{8}}{(11{,}577 \times 3{,}461)^{0.4} \times 5 \text{ years} \times 365 \text{ days}}$$

Personal risk = 449

As the personal risk value is greater than 100 the intersection is also classified as a high-risk intersection in terms of personal risk.

Personal risk = HIGH

Crash prediction model

- A = b0 x Qmajor^b1 x Qminor^b2.
- A = 0.000432 x 11,577^0.39 x 3,461^0.50.
- A = 0.26 injury crashes / 5 years.

$$\text{LoSS} = \frac{16 \text{ injury crashes}}{0.26 \text{ injury crashes} \times 5 \text{ years}}$$

LoSS = 12.3

As the number of reported injury crashes is more than three times that expected for an intersection of this type in this speed environment with these traffic flows then the intersection is classified as LoSS V.

LoSS = V

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3. Previous improvements

A number of safety improvements to this intersection have been made in recent years. In 2009, the following were carried out:

- 'Stop ahead high crash rate' signs installed.
- Vehicle activated 'Stop ahead' flashing warning sign installed on the right-hand side of the approach SH5 approach.
- Transverse bars painted on the road surface to provide drivers with additional visual cues of the approaching intersection and to encourage them to reduce speed.
- White backing boards added to the stop signs.
- Sight fence installed on the left-hand side of the SH5 approach to reduce visibility to the south.

4. Treatment approach

The high-risk metrics assessment shows that the intersection is high-risk in terms of both collective and personal risk. This indicates that a Safe System transformation approach, such as intersection transformation to a roundabout or grade-separation is likely to be appropriate.

There is some preliminary evidence that the safer intersection, safety maintenance and safety management treatments to date may have reduced crashes at this intersection; however another two to three years of crash data is required to determine whether this has occurred or if the recent reduction in crashes is a temporary response to the previous improvements.

The Safe System approach suggests that even with improvements over recent years, the crash history of the intersection should warrant transformational works to create an inherently safe intersection.

Although the intersection treatment philosophy (figure 4-7) indicates that there is potential for Safe System transformation works, this does not necessarily rule out safer intersection or safety management improvements as potential countermeasures. Section 5 gives further guidance on evaluation of appropriate countermeasures.

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5 Understanding the issues

As discussed in section 4 of this guide, we have determined where our high-risk intersections are likely to be through a set of processes. These will use reported F&S crashes, or estimates of F&S crash risk based on the all-injury crash record to determine our highest-risk sites.

Although using F&S crash risk (whether it be reported, estimated or predicted) is the underlying factor in determining most sites, it is important to provide further analysis on all crash data and to visit the site in order to confirm there are specific site deficiencies which are likely to contribute to the DSi safety problem. Following this the most appropriate countermeasures for our treatment strategy can be identified.

5.1 Analysing the data

Crash analysis is an essential first step before visiting a site and eventually, choosing countermeasures. Using all the crash data rather than just the high-severity crashes provides a larger sample size to enable us to identify the risk issues and make more informed decisions on what type of countermeasures may be appropriate for any given intersection. Certain crash movement types as identified in section 3 of this guide, are more likely to result in F&S crashes. These crash movement types should be given specific consideration and countermeasures identified that reduce the likelihood and / or severity of these high severity crash movement types.

In these investigations the road safety practitioner should look to understand:

- crash patterns for both:
  - F&S crashes, i.e. those resulting in death or serious injury, as they may differ from lower-severity crashes
  - all crashes (the inclusion of minor and non-injury crashes will better highlight crash movement commonalities or factor patterns)
- in the case of pedestrian and cycle crashes the spatial location of crashes – whether they are clustered or distributed between intersections along a route
- consistency of expectation and provision of intersection and roadside infrastructure.

In addition to this section it is recommended that the NZTA's *New Zealand guide to the treatment of crash locations* and *Austroads: Part 8 Treatment of crash locations* are referenced for additional details on diagnosing crash problems.

Other data that could help develop treatments would include changes to development / residential / commercial growth in the area, traffic volumes, and key stakeholder and community concerns.

5.2 Detailed crash analysis

To help understand the safety problems, a detailed analysis of the crash history is required. Although the CAS plain English and coded reports will assist, the original traffic crash reports should be analysed and reviewed, as these provide information not available in the summary reports.

Generally the most recent five-year period is considered, however, there can be value in reviewing the previous five-year period as this may confirm patterns and trends identified. Although caution should be given to drawing conclusions solely from the older data as site conditions may have changed, i.e. control and layout, surfacing, signage and road markings.

The crash movement types need to be considered with all other factors such as direction of travel, day of week, time of day, month of year, day or night, wet or dark, objects struck, vehicle type, driver age and any trends in these. All of the contributory factors identified in the CAS report also need to be considered alongside these crash movement types such as; inattention, misjudged speed, distance size or position of, alcohol and drugs, too fast for the conditions.

Consideration also needs to be given to the traffic volumes and composition and an assessment given as to whether the appropriate intersection form and control is provided.

When thorough analysis of the crash record has been undertaken, a site investigation is necessary to identify potential site specific issues that may be a factor contributing to these crashes. Specific common intersection issues often include deficient; sight distance, alignment, signage and delineation, poor signal visibility as well as consistency and readability of the intersection.

It is important to understand the issues as the treatment may live in more than one part of the Safe System. For instance, road user factors such as inattention and fatigue can be addressed through road interventions such as rumble strips and electronic warning signs.

Pedestrian and cyclist issues

It is recognised that the severity of crashes increases within higher speed environments. However, in the case of lower speed or urban environments there are higher numbers of vulnerable users which are susceptible to serious injury at much lower speeds.

It is common for pedestrian and cycle crashes to go unreported, particularly for less severe crashes. This makes it more difficult to identify whether pedestrian and cyclist issues are present at high-risk sites. The estimation of F&S crash risk based on all injury crashes takes account of the higher severity of pedestrian crashes.

At present a similar method has not been available for cyclists, as crashes involving cyclists do not have a separate movement code associated with them. It is intended that during the consultation period that a method of predicting cyclist F&S crashes will be developed and included in the procedures.

Dealing proactively with walking and cycling risk is more difficult than for other road users as crash prediction models are not so well developed and exposure data (pedestrian and cyclist volumes) are rarely collected. So proactive methods require local knowledge of where cycling and walking activity is focused and to look for features that are known to be less safe for pedestrian and cyclists.

Section 6.4.4 discusses approaches to treating high-risk intersections where vulnerable road users are represented in the crash statistics or where there is a high level of use of the intersection by pedestrians or cyclists.

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6 Safer intersection countermeasures

6.1 Introduction

A key component of the Safe System approach is safe roads and roadsides. As noted earlier, a large percentage of crashes on road networks occur at intersections, especially in urban environments. Therefore the installation of appropriate types of intersections and the application of best practice in intersection design has the potential to make a significant contribution to crash and injury reduction on road networks.

Our understanding of what constitutes a Safe System compliant intersection is still evolving and trials of innovative treatments are occurring overseas. Roundabouts are potentially one of the more Safe System compliant intersection forms as they largely manage conflict speeds within Safe System limits with the exception of vulnerable road users, particularly cyclists. Signalised roundabouts are another Safe System intersection form. Monash University Accident Research Centre (MUARC) is looking to trial a signalised 'hamburger' intersection.

Other Safe System intersections are those that physically manage speed through elevated platforms and other speed management devices. Until we learn more about and trial new layouts we are reliant on many of our traditional countermeasures that have proven to reduce the likelihood of crashes, and to a lesser extent the severity of crashes, from many years of experience. In the meantime, practitioners must consider the extent the which traditional countermeasures are likely to support a Safe System compliant intersection prior to introducing such a treatment.

This countermeasures section concentrates mainly on traditional engineering measures which are specifically targeted towards reducing fatal and serious crashes. These measures may also be of benefit for minor or non-injury crashes but do not form the main focus of this guide and so should not be interpreted as an exhaustive list of the various possible intersection improvements.

Safer intersection improvements vary between low cost minor works through to high cost transformational works. Traditionally, due to cost and timescales a stepped approach in the treatment of casualty sites is usually adopted. This comprises the installation of low cost works followed by a period of monitoring to gauge effectiveness before considering higher cost measures. In some cases, the treatments can be of limited benefit which can result in further casualty occurrence in the interim period. Therefore it is important to recognise the level of a particular countermeasure's effectiveness and consider whether this is likely to achieve the aims of a Safe System.

This guide aims to provide information on the most effective measures to reduce casualties and severity by particular intersection form and control within the overarching philosophy of a Safe System.

6.2 Network evaluation

When a high-risk intersection is identified the safety issues at the site need to be investigated and appropriate countermeasures considered. However, it is important to also consider the overall strategic factors around this such as:

- identifying where the intersection fits within the local and national route hierarchy
- considering if the intersection form and control is appropriate to the hierarchy and traffic volumes
- consider whether the importance and function of the intersection is intuitive to users and whether it is consistent with others of similar strategic role
- identifying whether this is the most appropriate access point, there may be a more suitable alternative which could be promoted
- the impact of future planning designations on traffic patterns and volumes

- identifying if the intersection crosses or forms part of a strategic route for key users groups.

Factors such as these will ultimately be beneficial in achieving the most appropriate countermeasures and contribute to a consistent approach being adopted throughout the network.

6.3 Wider network treatments

6.3.1 Mass action treatments

Crash risk mapping may highlight a number of high-risk intersections on a route or within an area which may benefit from mass action treatments. These are likely to be more minor works which treat a shared or common crash movement type within an area. With these treatments it may be beneficial to treat sites which do not feature as a high-risk site but share the same deficient characteristics. A key element of limiting driver error is making the road environment more intuitive and consistency of approach is important factor in achieving this. However, with the Safe System approach it must be recognised that drivers will still make errors and hence we must attempt to reduce the severity of outcomes.

There are many types of lower cost measures that are appropriate for this treatment, examples include; installation of frangible posts, signal head upgrades, extended or expanded cycle lanes and delineation improvements.

6.3.2 Network-wide treatments

There may be some high-risk intersections which have been subject of previous improvement works which continue to remain unresolved. These sites may have limited scope for further improvement within the confines of the intersection, particularly in urban areas where there is adjacent development and complicated land use. In these cases the surrounding network may need to be considered as part of the treatment works giving consideration to the wider network crash record.

Examples where a network wide treatment may be appropriate is where; turning movements are reduced or banned which will result in an increase in movements at other intersections in the network or; when the use of an intersection attracts more traffic due to improvements such as a right turn facility and traffic patterns could change to through less suitable intersections. In either case an assessment will need to be considered as to the adequacy of the other intersections and improvements to these may be necessary.

6.4 Countermeasure evaluation

6.4.1 Engineering countermeasures

Prior to the recommendation of countermeasures the key deficiencies relevant to the crash history, site evaluation and network should be identified. Appropriate countermeasures should then be considered based on these factors and their likely assessed effectiveness. The guidance for this process is contained in the Land Transport NZ document *A New Zealand guide to the treatment of crash locations* (2004). In order to identify the most effective and well targeted countermeasures, it is essential to review the police TCR reports contained in CAS.

Careful consideration needs to be given to some types of countermeasure and their suitability for the environment. Standard intersection layouts contained in design guidance may not always be appropriate. An example is the provision of right turn bays on right hand curves – these can exacerbate the severity of the curve for right turning traffic, effectively reducing the lead-in taper length. In some instances this can result in vehicles losing control. In this case, the installation of the right turn bay may necessitate the curve radius being eased and/or the taper length being increased.

6.4.2 Speed management

Speed or inappropriate speed for the environment and road use are a significant factor in F&S crashes. Based on the survivability speed curves, we know that managing side impact speeds to below 50km/h, impacts with fixed objects, such as poles, to below 40km/h and impacts with vulnerable road users to below 30km/h significantly reduces the likelihood of death and serious injury.

Aside from carrying out transformational works, a key factor in achieving a Safe System is speed management. This is particularly important when considering finite improvement budgets. This can comprise a range of measures including speed limits, enhanced warning signage and road markings as well as psychological measures.

Appropriate speed management related countermeasures for intersections include the use of red light cameras for speed enforcement at urban intersections and active warning signs at rural intersections. Designing self-explaining roads have proven to be effective overseas and in New Zealand for both urban and rural roads, including at intersections.

The default speed limit on New Zealand open/rural roads is 100km/h and it is generally applied to all rural roads with only limited exceptions at the present time. A more suitable speed limit for these roads might in future be one that more closely matches the design speed and the present safety features. The NZTA recognises that there is some merit in applying a safer operating speed limit or speed zones[2] for roads on which the standard rural speed limit is inappropriate. This also applies to intersections.

A common technique employed in crash reduction is that of secondary management, which in the example above may take the form of raising driver awareness on main road approaches and reducing through speeds. This has proven to be an effective method and could take the form of:

- enhanced or enlarged signage
- enhanced line marking
- electronic warning signs.

An issue with this type of approach is that it is reliant on a reaction from a driver removed from the problem. Also road users can become habituated to signing over time reducing the overall benefit in the long term. Care should also be given to 'over-signing' a high-risk location as this may result in nearby intersections becoming relatively less visible.

In the case of electronic warning signs, intelligent options have been developed which are both, more prescriptive so that a driver is more aware of the type of risk and can engage on a number of chosen risk variables such as approach speed, weather and presence of a vehicle on the side road, thus reducing trigger frequency and as a result driver complacency of the sign.

A range of psychological measures have been trialled and adopted both in New Zealand and in other countries which can alter driver behaviour without actually being physically invasive. It is well documented that features such as speed limit gateways, visual narrowing, changes in road markings, rumble strips and changes in road surface can raise awareness as well as reduce speeds. These areas will be expanded further in the following countermeasures section.

6.4.3 Intersection visibility

In the case of an intersection which is high-risk and site investigation has identified poor visibility from the side road as the issue, there are a number of potential measures that can be employed which will provide some improvement. These could include, increasing visibility, reducing visibility (in the case of excessive visibility being a contributing

[2] A speed zone takes into account the alignment of a route or section of road and in particular the 85th percentile operating speed of vehicles. This is in contrast to the historical (and still the current (2010)) method of setting speed limits, which is based primarily on the amount of frontage development.

factor to crash occurrence and severity), balancing the visibility on all approaches to an intersection, considering an alternative intersection form, providing more prominent signs on the main road approaches to raise awareness, or managing speeds such that the risk of fatal or serious injury is less likely.

When we need to consider the possibility of improving the visibility, we also need to assess the likelihood of other underlying issues such as traffic composition. It may be that the proportion of side road to main road traffic is such that there are already operational issues at peak times. In this case the obvious countermeasure of improving the visibility will only partially treat the problem. In the absence of funding for a transformational countermeasure it may be that the visibility be improved alongside mitigating the risk by effectively managing through speeds.

6.4.4 Vulnerable road users

Where the crash analysis indicates that pedestrians, cyclists or motorcyclists are represented in the crash history of an intersection then considering appropriate facilities for these types of road users is important when developing any countermeasure strategy. This will require not only an understanding of the nature of crashes that have occurred, but also information to understand the level of use, the age and abilities associated with pedestrians, cyclists and motorcyclists crossing and travelling through intersections.

In most urban cases and to a lesser extent rural cases, specific provision for vulnerable users will need to be considered. The development of countermeasures for main motor vehicle crash movement types will need to consider their needs. For instance, if a signalised intersection has an issue with right turn against crashes, the solution maybe to have an exclusive right turn phase. This may have an adverse effect on cycle times which may result in excessive delays to pedestrians waiting to cross. With this in mind signal timings may need to be optimised so that pedestrians are not frustrated at the delay and cross against a red signal. [26]

Where pedestrians and cyclists are present, the NZTA's draft non-motorised user review procedures should be consulted to assist in defining the issues

6.4.5 Road user responsibilities

While the Safe System approach moves away from driver blame and recognises that crashes are the result of driver error, it does not remove road user responsibility. Road users must be compliant with the rules, alert and understand the risks of their behaviours and act accordingly.

It is important to recognise that road user responsibility will often be involved, and while Safe System solutions aim to be more forgiving of human errors, reducing the likelihood of those errors is part of the Safe System approach. So while the main focus at intersections may be on engineering improvements, consideration should be given to engaging with the at risk groups. This may lead to better behaviour by users – and may also lead to solutions that better meet their needs.

For instance, if an intersection is located near a school and safety of children crossing the intersection is being compromised by parental parking and manoeuvres, then it will be important to work with community so that improvements and behavioural issues are dealt with in tandem. The parents will better understand how their behaviour is compromising the safety of their children and the school authorities and designers may understand that parents are tempted to behave inappropriately by inadequate parking provision.

Road safety messages highlighting high crash sites and high crash routes are useful to highlight identified issues to drivers. However, where there is an engineering solution these methods should be employed only as an interim and/or supporting measure.

Speed cameras and red light cameras may be considered where there is an on-going F&S crash record. However, the emphasis should be first put on removing or mitigating the reason for the crash record. For example; where there is a red light running issue it would first be prudent to consider issues such as improving visibility of signals or providing speed discrimination equipment (in higher speed environments) or; where there is an issue with excess speed, look at methods to manage the speed environment such as gateway features, enhanced signage and raised platforms.

6.5 Transformational works

Transformational works generally require a large financial investment. Before such a commitment is made it is important that there is a high degree of certainty that there is a long term problem at an intersection. In addition to the detailed study of the most recent five-year crash record, unless there has been significant change to the site, the five or 10-years prior to this should be reviewed to confirm there is a longstanding problem.

A key starting point in the evaluation of a high-risk intersection should be to assess the suitability of the intersection form and control relative to the environment, traffic flows, flow composition and Safe System outcomes. There are a number of reasons why the intersection form may not be suitable for its current or future use. These include evolving road network usage as a result of development, changing travel patterns and natural increases in traffic flow. Also changes in speed limits and travel modes such as increased walking and cycling can render a previously serviceable intersection unsuitable without significant change. As a result of research and experience, design standards and good practice can change over time. Many intersections still take the form that they were designed to 20 or 30 years previously, many more have never had any formal design, having merely evolved from historic tracks from horse and cart days when operating speeds were only a little faster than walking pace.

6.5.1 Safe System compliance of transformational works

It should be noted that that there are some intersection layouts that remain in the design guidance but are not considered good practice and are only to be used in exceptional circumstances, some layouts are not Safe System compliant. Specific layouts that should be avoided if possible as they have been proven to have particular safety issues are crossroads with high speed traffic signals and priority 'seagull' layouts.

High speed signals are inherently problematic due to the difficulty making a decision to stop and the high severity outcomes that result when a collision occurs. This is not a particular issue where drivers are either in the vicinity of; or at an approach distance well in excess of the stopping sight distance when green changes to yellow, however when they are in the area between termed the 'dilemma' zone it becomes difficult to accurately judge distances and progress over time.

Seagull layouts in theory should improve safety as they provide a degree of separation between through and turning traffic and they enable vehicles turning right from the side road to wait mid-way. However, in practice these layouts often result in an elevated crash record. This is due to; the layout which dictates a large intersection area making it difficult to observe all traffic when turning out of the side road; driver confusion as to its use and; higher through speeds which make it difficult to judge gaps in traffic. Research conducted on a number of studies worldwide indicates mean increases in injury crashes of 16% for full channelisation of T-intersections. [2]

The potential crash reduction benefit of a transformational change can be assessed by using the accident prediction models contained in Appendix A6 of the NZ Transport Agency *Economic evaluation manual* (EEM). An example of this is detailed below.

(a) Assessment of potential safety benefit of transformational change from a rural crossroads to a roundabout

A rural crossroads with 14 injury crashes of which there are five F&S crashes in a five-year period has been rated as having a high collective and personal risk. A further nine injury crashes of which five are F&S crashes are also identified in the five-year period prior to this, these all form a similar crash pattern and confirm a long term problem at the site. The crash prediction formula in the EEM shows an expected crash rate of 4.7 injury crashes in five years. A level of safety service analysis shows that this site is classified as LoSS V, so the crash history is much higher than expected for an intersection of this type and traffic volume.

Previous minor improvement works to rectify unequal visibility from the eastern leg have been unsuccessful in reducing crashes at the site. Following further site investigation and study of the CAS records, the ongoing crash record appears to be due to the combination of the complexity of the crossroads and associated conflicting turning movements and exacerbated by high major road approach speeds. This intersection is defined as both a high collective and high personal F&S crash site. It is therefore considered that transformational works are appropriate. Reference to figure 6-5 below indicates that the most appropriate intersection form is a roundabout. A factor in effective roundabout operation, particularly for smaller or single lane circulatory types approaching capacity is a suitable balance in traffic flows, without which, significant delays may be experienced on one leg that could result in other crash movement types such as rear-end into unexpected queuing traffic. Notwithstanding, a roundabout would still manage speeds and reduce the risk of a F&S crash from occurring.

The main road AADT flows are 11,500 vpd and 9,000 vpd north and south of the intersection and the side roads are 5,500 vpd and 3,500 vpd on the eastern and western legs respectively (see figure 6-1). In order to calculate the typical (all injury) crash rate for a rural roundabout, the crashes for each approach can be calculated by the following formula:

$$A_T = b_0 \times Qapproach^{b1}$$

Where:
Qapproach = the two-way link volume (AADT) on the approach being examined.
Values for b_0 and b_1 are provided in table 6.1 below.

Table 6-1: Extract from EEM table A6.9 (a)

	b_0	b_1
Roundabout	1.50×10^{-3}	0.53

Figure 6-1: Site traffic flow data

The typical (all injury) annual crash rate is therefore determined by the sum of that calculated for each leg as follows:

A_T (Approach 1- 11500AADT) = $1.50 \times 10^{-3} \times 11500^{0.53}$ = 0.21

A_T (Approach 1- 8300AADT) = $1.50 \times 10^{-3} \times 9000^{0.53}$ = 0.19

A_T (Approach 1- 5500AADT) = $1.50 \times 10^{-3} \times 5500^{0.53}$ = 0.14

A_T (Approach 1- 3500AADT) = $1.50 \times 10^{-3} \times 3500^{0.53}$ = 0.11

Total A_T = 0.65 or 3.25 injury crashes in 5 years.

In order to compare the existing F&S crash occurrence at the crossroads with the likely number of F&S crashes for a roundabout, the expected ratio of F&S crashes to all injury crashes (severity ratio) needs to be applied and multiplied by the five-year period. See Appendix 2 for the severity ratio tables for each intersection form, control and speed environment. The anticipated comparable F&S crash number can be calculated by the following formula:

KSi_T = total A_T x (total average severity ratio).

KSi_T = 0.65 x 0.15 (for rural roundabouts) = 0.1 F&S crashes per year or 0.5 F&S crashes in five years.

For comparison and assessment of the likely safety benefit the results can be tabulated as shown in table 6-2.

Table 6-2: Crash reduction comparison table

	All injury crashes	F&S crashes	Severity index (SI)
Existing crossroads (5-year period)	14	5	0.36
Proposed roundabout (5-year period)	3.25	0.5	0.15
Expected crash reduction	10.75	4.5	

The potential benefits of a transformational change can be clearly seen in terms of overall crash reduction and more importantly the numbers of F&S crashes. In this case there is a high anticipated reduction in F&S crashes so sufficient cost benefit is likely. To confirm this, a benefit/cost ratio (BCR) should be calculated whereby the project can be ranked accordingly. Further information on this is contained within the EEM.

It is likely that there will be a time lapse to construction, in this case measures to manage speed such as electronic warning signs, rumble strips or transverse markings should be considered as an interim measure. The countermeasures section of this guide gives more detail on appropriate speed management methods.

6.5.2 Selection of intersection form and control

Graphs showing the relationship between the product of the minor and major road flow $(Q_1 \times Q_2)^{0.4}$ and the expected number of F&S crashes for a five-year period are provided below in figure 6-2 and 6-3. These graphs can be used as a guide to the most suitable safe intersection layout for urban speed environments. The graphs were developed using the data for the crash prediction models for all injury crashes and the severity index factors contained in Appendix 3 were applied to determine the likely F&S crash numbers. Similar graphs for rural speed environments will be developed during the consultation phase.

It should be noted that these categories are broadly defined and there is likely to be some overlap in suitability dependant on specific site attributes.

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Figure 6-2: Flow range and crash relationship for various methods of control at urban crossroad intersections

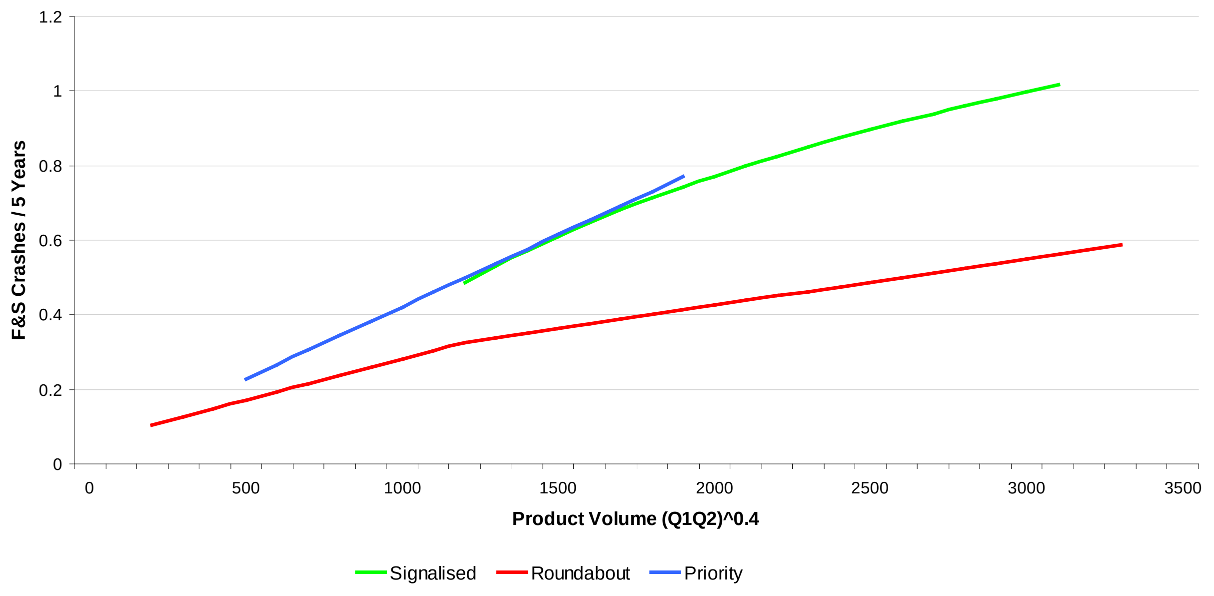

Figure 6-2 shows that the expected number of F&S crashes at urban crossroad intersections is almost identical for priority and traffic signal controls where these flow ranges overlap. Not unsurprisingly, the expected number of F&S crashes for roundabout controlled crossroads is notably lower than the other two forms of control. The difference becomes more pronounced as the product of flow increases.

Figure 6-3: Flow range and crash relationship for various methods of control at urban T-intersections

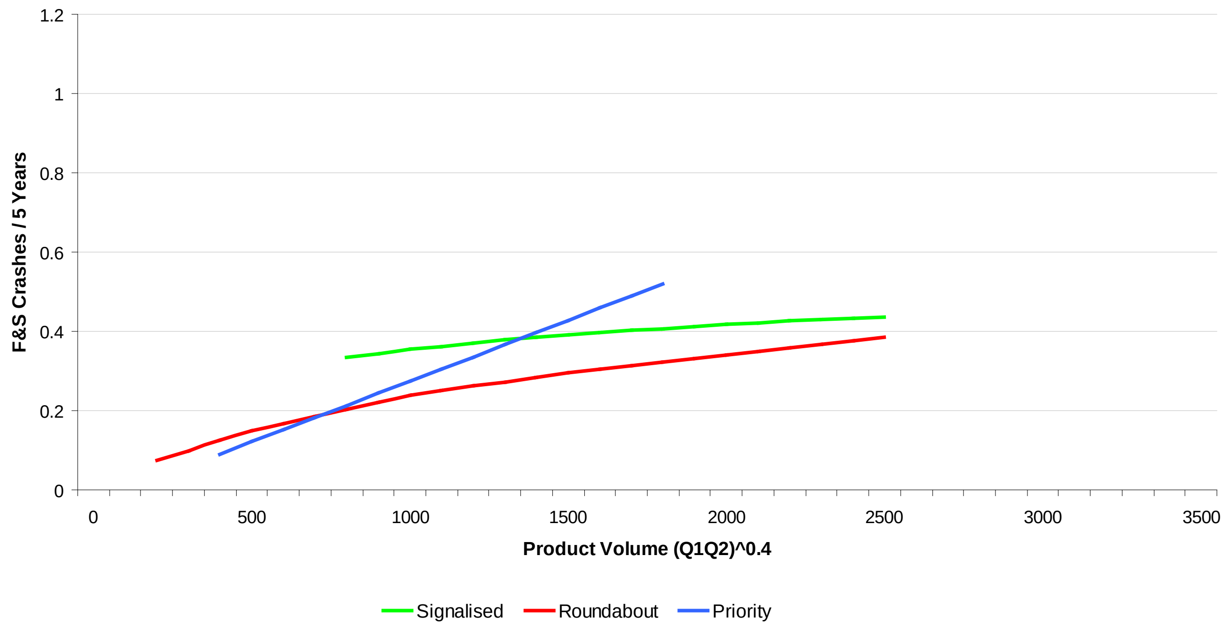

Figure 6-3 shows that the expected number of F&S crashes at urban T-intersections is similar for all control types.

6.5.3 Common intersection issues resulting in F&S crash movement types

In addition to transformational works and safety maintenance works (i.e. surfacing, drainage, signage and road marking cleaning and renewal), the F&S crash movement types can respond well to safety management and safer intersection modifications.

The following table 6.3 provides a guide to some of the common issues that may contribute to the key F&S crash movement types identified in section 3. The corresponding likely safety management and safer intersection countermeasures are referenced, the details of which are contained in the countermeasures section in Appendix 5.

Table 6-3: Countermeasures reference table by crash movement type

Intersection form	Potential site issues	Countermeasure reference
Urban uncontrolled	**Vehicle lost control (CA/CB/CC/DA/DB/DC)**	
	- Poor skid resistance	S3
	- Lack of advance visibility of intersection	S5, IS13
	- Poor turning guidance, no minor road channelisation, lack of road markings	IS1
	- Excessive approach speed on major/minor road	S1, S4, S5
	- Poor drainage	
	- Unyielding road side hazards, e.g. poles	C1
	Pedestrian (all pedestrian movements)	
	- Lack of crossing facilities, dropped kerb, tactile paving, refuge	IS4
	- Poor inter-visibility at crossing points. Obstructed by fence lines, street furniture/signs	
	- Excessive crossing width	
	- Large entry radii allowing higher entry speeds	
Urban T/Y give way controlled	**Vehicle lost control (CA/CB/CC/DA/DB/DC)**	
	- Poor skid resistance	S3
	- Lack of advance visibility of intersection	S5, IS3
	- Poor turning guidance, no minor road channelisation, lack of road markings	IS1
	- Excessive approach speed on major or minor road - Poor drainage	S1, S4, S5
	- Unyielding road side hazards, e.g. poles	C1
	Crossing (HA/JA/JC)	
	- Poor visibility from/to intersection. Obscured by fence line, street furniture, other traffic where two entry lanes (left & right) provided.	IS3
	- Poor turning guidance, no minor road channelisation, lack of road markings	IS1
	- Excessive approach speed on major or minor road	S1, S4, S5, E1
	Right turn against (LA/LB)	

Intersection form	Potential site issues	Countermeasure reference
	- Poor visibility of opposing traffic	IS1, IS2
	- Poor turning guidance, no minor road channelisation, lack of road markings	IS1
	- Excessive approach speed	S1, S4, S5, E1
	- Difficulty in achieving gaps to turn leading to risk taking or acceptance of smaller gaps	IS3
	- Unexpected delay entering the side road caused by activity in immediate vicinity of intersection from accesses, driveways, parking or bus stops	
Urban crossroads	**Crossing (HA/JA/JC)**	
	- Poor visibility from/to intersection. Obscured by fence line, street furniture, other traffic particularly where two entry lanes (left & right) provided.	IS3
	- Opposing side road arm gives impression of a straight through road particularly where fence lines or buildings restrict advance visibility of intersection.	IS1
	- Poor turning guidance, no minor road channelisation, lack of road markings	IS1
	- Excessive approach speed on major or minor road	S1, S4, S5, E1
Urban signals	**Crossing (HA/JA/JC)**	
	- Poor or obscured signal head location	IS8
	- Restricted inter-visibility from side road to main road traffic	IS3
	- Short cycles times leading to frustration, short inter-green times and excessive approach speed all leading to red light running	IS6, E1
	Right turn against (LA/LB)	
	- Poor or obscured signal head location	IS8
	- Filtered Turn with no separate right turn phase resulting in conflict	IS7
	- Restricted or obscured forward visibility due to street furniture, signs, trees	IS3
	- Opposing or left offset right turn bays resulting in turning vehicles restricting visibility of through traffic	IS9
	- Excessive opposing through approach speed or differential through speeds where multiple opposing through lanes	IS6, IS7, IS9, E1
	- Short cycles times leading to frustration, short inter-green times and excessive approach speed all leading to red light running	IS7
	- Where separate right turning phase is provided alongside filtering phasing may not be optimal	IS7
Urban roundabouts	**Vehicle lost control (CA/CB/CC/DA/DB/DC)**	
	- Excessive visibility on roundabout approach leading to early decision making and higher entry speeds	IS13
	- Poor entry deflection leading to higher entry speeds, particularly when exit radius is tighter	IS12
	- Poor advance signing and poor delineation /lighting of approaches/ circulatory	IS14
	- Poor skid resistance on approach and/or circulatory	S3
	- Adverse camber or abrupt camber changes - Poor drainage	IS17
	- Unyielding road side hazards, e.g. poles	C1

Intersection form	Potential site issues	Countermeasure reference
	Crossing (HA/JA/JC)	
	- Poor visibility around circulatory and to other arms often restricted by signage or planting	IS13
	- Imbalance in visibility to right at entry leading to differential entry speeds	IS13
	- Poor skid resistance on approach	S3
	Cyclist (All cycle movement types)	
	- Differential speeds with motor vehicle traffic on larger roundabouts, particular issues when cyclist are passing exits	IS16
	- Lack of continuous cycle routes through roundabouts – often stopping short on intersection	
	- Inadequate lane widths on approach to and through roundabout- particular issue where high truck usage	
Rural uncontrolled	**Vehicle lost control (CA/CB/CC/DA/DB/DC)**	
	- Poor skid resistance	S3
	- Lack of advance visibility of intersection	S1, S5, IS3, IS5
	- Poor turning guidance, no minor road channelisation, lack of road markings	IS1
	- Excessive approach speed	S1, S2, S4, S5
	- Poor skid resistance	S3
	- Imbalance in left and right visibility along major road – leading to driver concentrating on restricted direction, often resulting in collision from other direction	IS3
	- Lack of advance visibility of intersection	S1, S5, IS3
	- Poor drainage	
	- Unyielding road side hazards, e.g. poles	C1
Rural T/Y intersection	**Vehicle lost control (CA/CB/CC/DA/DB/DC)**	
	- Poor skid resistance	S3
	- Lack of advance notice of intersection – poor forward visibility and advance signing	IS3, S5
	- Poor turning guidance, no minor road channelisation, lack of road markings	IS1
	- Excessive approach speed on minor or major approaches	S1, S2, S4, S5
	- Poor drainage	
	Crossing (HA/JA/JC)	
	- Poor visibility from/to intersection. Obscured by fence line, street furniture, other traffic where two entry lanes (left & right) provided.	IS3
	- Poor turning guidance, no minor road channelisation, lack of road markings	IS1
	- Excessive approach speed on major or minor road	S1, S2, S4, S5, E1
	- Imbalance in left and right visibility along major road – leading to driver concentrating on restricted direction, often resulting in collision from other direction	IS3

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Intersection form	Potential site issues	Countermeasure reference
Rural crossroads	**Crossing (HA/JA/JC)**	
	- Poor visibility from intersection along major road, often results in re-start crashes	IS3
	- Poor visibility of the intersection on the minor road arms giving impression of a straight through road. Usually no central splitter island present and or/poor advance signing. Continuation of telegraph or power poles through intersection can reinforce this false impression.	S1, S5, IS1
	- Imbalance in left and right visibility along major road – leading to driver concentrating on restricted direction, often resulting in collision from other direction	IS3
	- Poor visibility of intersection due to alignment	S1, S5
	- Excessive approach speed on major or minor road	S1, S2, S3, S4, S5, E1
Rural signals	**Vehicle lost control (CA/CB/CC/DA/DB/DC)**	
	- Poor or obscured signal head location	IS8
	- Poor visibility of intersection due to alignment	S2, S5, IS3
	- Restricted inter-visibility from side road to main road traffic	IS3
	- Excessive approach speed to be able to stop for signals when in dilemma zone	IS6
	- Associated street furniture can represent a collision risk - Poor skid resistance - Poor drainage	C1
	Right turn against (LA/LB)	
	- Poor or obscured signal head location	IS8
	- No separate right turn phase	IS7
	- Restricted or obscured forward visibility due to alignment, street furniture, signs, trees	IS3
	- Opposing or left offset right turn bays resulting in turning vehicles restricting visibility of through traffic	IS9
	- Excessive opposing through approach speed or differential through speeds where multiple opposing through lanes	S1, S2, S3, E1
Rural roundabout	**Vehicle lost control (CA/CB/CC/DA/DB/DC)**	
	- Excessive visibility on roundabout approach leading to early decision making and higher entry speeds	IS13
	- Poor entry deflection leading to higher entry speeds, particularly when exit radius is tighter	IS13
	- Poor advance signing and poor delineation /lighting of approaches/ circulatory	S4, IS14
	- Poor skid resistance on approach and/or circulatory	S3
	- Poor drainage	
	- Unforgiving roadside on exits	C1

7 Implementation, monitoring and evaluation

7.1 Introduction

This section covers the implementation, monitoring and evaluation of countermeasures at high-risk intersections with the emphasis on reducing fatal and serious injury crashes. These process areas are significant for both the individual crash site and the assessment of the effectiveness of counter measures for future use elsewhere. Once sites have been identified a suitable programme of implementation and a system to monitor the effectiveness of the countermeasures is necessary.

In this section we look at issues associated with developing programmes for treating high-risk intersections, and then monitoring the effectiveness of those programmes to:

1. identify the benefits or rather the effectiveness of the various treatments
2. identify the most effective packages of treatments
3. assess the levels of funding that may be required to achieve various levels of crash reduction
4. prove that funding has been spent wisely.

Figure 7-1 is a modified version of the safety management triangle. The foundation of this triangle is the identification and analysis of crash issues, which would include the means of identifying high-risk intersections.

Figure 7-1: Modified safety management triangle

1) Primary outcome

2) Secondary outcome

3) Intermediate outcomes

4) Programs of treatment for
- speed
- consistency

5) Identification of high-risk intersections

Having identified our sites/routes and clarified our safety concerns, this guide discusses some possible treatments or strategies to improve the safety of our high-risk intersections, with particular emphasis on the primary outcome of reducing fatal and serious injury.

Further information on implementation, monitoring and evaluation is contained in Land Transport NZ *A New Zealand guide to the treatment of crash locations* and Austroads *Guide to traffic engineering practice part 4: Treatment of crash locations.*

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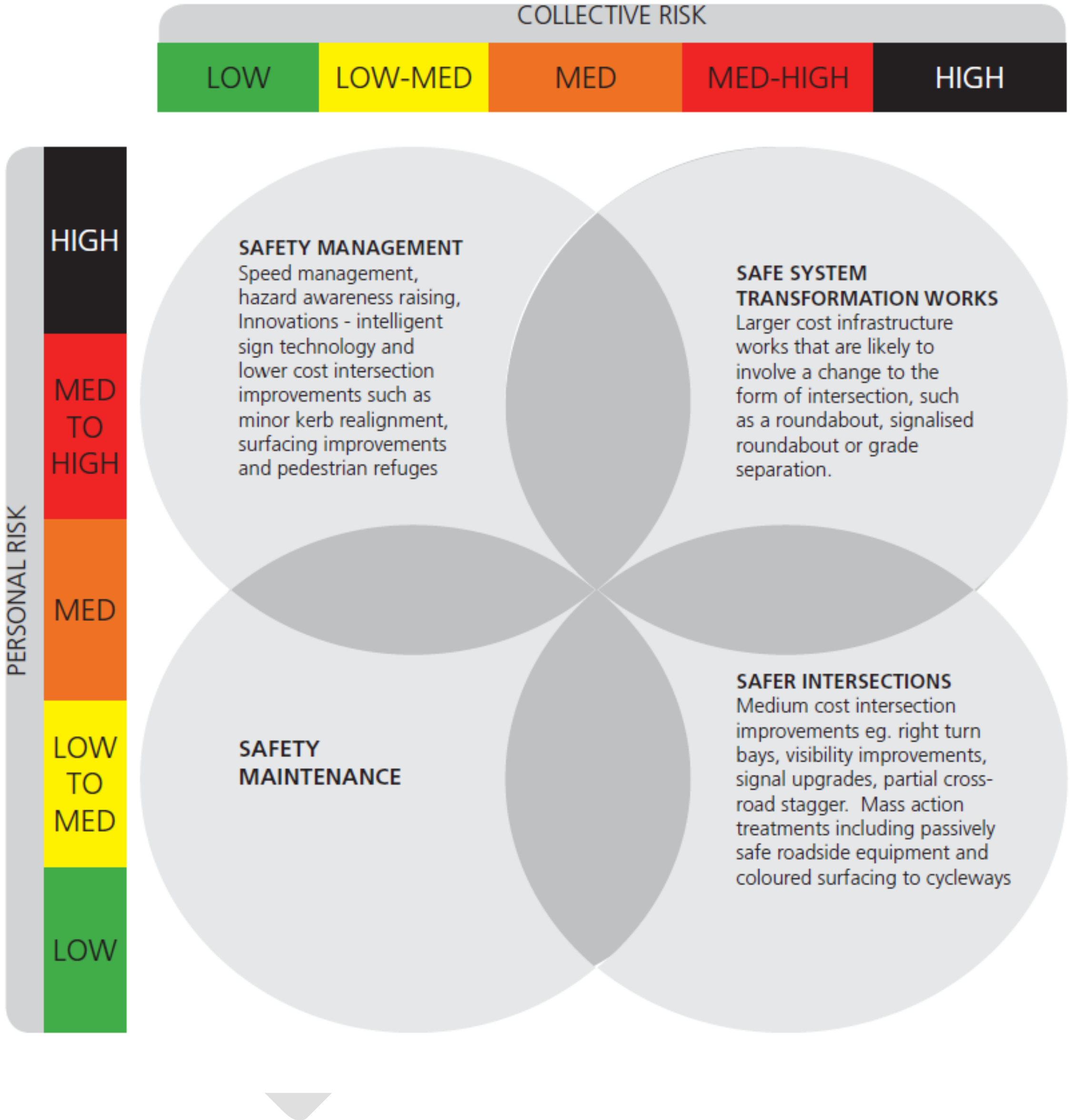
7.2 Programme development

While the focus of the HRIG is on high-risk intersections, (those typically located in the upper and right sides of figure 7-2) it is important to remember low-cost safety management treatments still apply to the bottom left quadrant.

Figure 7-2: Safety improvement strategies



Many intersections will not feature in the upper and right side portions of figure 7-2, but that does not preclude a programme of ongoing safety improvements at these locations, just that these improvements should be proportional to the problem. Having identified an intersection with potential safety improvement benefit, the crashes must be investigated to identify the crash and risk issues that must be addressed. Risk issues are road safety deficiency issues which are not supported by a crash history – in essence a predicted crash risk rather than a crash history. In these investigations the road safety practitioner should look to understand:

- crash patterns for both:
  - F&S crashes
  - all injury crashes (the inclusion of minor injury crashes will better highlight crash movement or factor patterns)

- consistency of intersection provision along a route or area.

With any treatments consideration needs to be given to the benefits of one against another to determine cost effectiveness. Countermeasures can be applied to either single intersections and on an area-wide or mass action basis. Mass action treatments are generally less well targeted than site specific crash issues and are generally likely to be lower cost measures such as signage and road markings.

7.3 Implementation

7.3.1 Lead-in time

Even with a high ranking project, it is unlikely that it will be implemented in the financial year current to the study. Often due to issues such as funding availability and timelines for consultation, it can be years before a scheme is progressed to design stage. In this case it is good practice for the safety engineer to revisit the crash record prior to the preliminary design stage to ensure the crash pattern has not changed.

Consideration should also be given to other aspects such as new or future development and local road network improvements that may have occurred in the interim. These will need to be explored to ensure that the measures remain appropriate and are likely to achieve the desired results. In the case that significant design changes are required, the BCR may need to be recalculated.

7.3.2 Interim improvements

Identified transformational improvements or mass action will have to compete for funding against other projects and when approved will generally be subject of long lead-in times before the project is delivered. Doing nothing until the project eventuates continues to place road users at an increased risk of fatal or serious injury.

As responsible road safety practitioners and network managers, we need to consider this risk. Interim improvements are viable if they return an economic road safety benefit in the period before the realistic delivery of the transformational works.

7.3.3 Continual involvement

While the crash investigation and recommendation process is often seen as a separate work package to the design and implementation process, it is important that the safety engineer is involved throughout this process to avoid watering down of the original objectives. Details can easily be lost in translation or misinterpreted, and minor or subtle changes to the countermeasures (on which safety schemes often rely), can be severely detrimental to safety projects. Public consultation can also result in changes being made which can result in fundamental changes to a project which could alter scheme effectiveness.

Ideally improvement works will be to optimum design standards. However, safety engineering work is frequently a case of mitigating risk. The ideal or model standards cannot always be applied and compromises are sometimes necessary. It is necessary that any departures from standard are effectively communicated to the design team so that the desirable outcome is achieved. Maintaining a dialogue with the designer and construction teams throughout the project will maximise the likelihood of an effective scheme.

7.3.4 Consistency / self-explaining intersections

It is important that a consistent approach to intersection layout and warning is taken along a route or within a network so that the intersection is intuitive or self-explaining to users. The layout of the intersection and associated facilities provided should reflect the environment, it uses and its role within the roading hierarchy. Pedestrian and cycle facilities such as crossing phases, dropped crossings, pedestrian islands and advance cycle boxes should be provided so that satisfactory levels of service at intersections along routes and within networks can be maintained.

7.3.5 Communication and consultation

It is vital to engage with key stakeholders (community, affected and interested parties) when developing projects in order to create a common sense of purpose, draw on and learn from other's perspectives, make better decisions, align mutual interests, identify and mitigate risks, and find shared solutions to challenges.

Relationship building, the basis for effective engagement, takes time. Many of the hallmarks of good relationships – trust, mutual respect and understanding – are intangibles that develop and evolve over time. Early engagement provides a valuable opportunity to set a positive tone with stakeholders from the outset of a project. The absence of established relationships and communication channels can put our project at an immediate disadvantage.

Establishing and maintaining good relationships requires a long-term view. Organisations that take this approach see the value of consistently following through on their commitments to stakeholders. They take grievances seriously and deal with them in a reliable and timely manner. They continually invest in communicating about their work in a way that makes sense to their stakeholders. Effective engagement and communication will ultimately ensure the project's success. [24]

As stated in the Austroads research report *Community consultation process and methods for quantifying community expectations on the levels of service for road networks* AP-R290-06 [25]:

- An ideal consultation with road users and other stakeholders is one that:
  - consists of a number of clearly defined stages, each with their own specific objectives
  - includes both external stages (i.e. those that include road users and stakeholders) and internal stages (i.e. those that include employees of the road agency only)
  - is iterative in nature (i.e. part of an ongoing and iterative cycle of learning, refinement and improvement embedded within the development process rather than an 'isolated event' that takes place externally to it).
- The development of levels of service and intervention criteria for maintenance and improvement activities through community consultation is complex and requires careful planning. The process consists of several iterative stages: listen, communicate, reflect and plan, implement, monitor and measure. The process alternates stages that involve the community with stages that require bi-internal agency assessment and evaluation. Each stage is conducted in a structured manner and requires specific techniques and specialised skills.
- The process begins with a two-way communication (listen and communicate) between the road agency and the community with the purpose of gaining a common understanding of community concerns, priorities, current road classification system and levels of service as well as agency issues, priorities and budget limitations. This part of the process also helps develop a common language and identify the most effective channels for further communication of road maintenance issues. The two-way communication establishes the foundation for a transparent and strong relationship between the road agency and the community.

7.3.6 Safety audit

As with any roading project it is important that high-risk intersection safety schemes are subject of an independent road safety audit at benchmark stages of the design and construction. Safety audits are generally carried at four stages:

- Stage 1 feasibility / concept stage.
- Stage 2 scheme / preliminary design stage.
- Stage 3 detailed design stage.
- Stage 4 post-construction stage.

While the completion of all these stages may only be appropriate for larger scale projects, it is essential that stages 2, 3 and 4 are carried out on all high-risk projects no matter how minor.

A safety audit should not be considered an alternative to the investigating safety engineer's involvement in the design and construction process. The role of safety audit is solely to identify and assess the potential safety issues that may arise from the improvement work. The NZTA (Transfund) *Road safety audit procedures for projects* 1994 provides further guidance. However, in addition to this, the safety audit should take into account the principles of a Safe System.

In order to maintain a focus on vulnerable users it is advisable to carry out separate non-motorised user (NMU) audits in urban environments or locations where there are likely to be significant numbers of pedestrians and cyclists.

7.4 Monitoring and evaluation

Monitoring and evaluation is important in gauging the effectiveness of different safety treatments. This is also important when developing types of countermeasures for specific issues and implementation procedures for future programmes. Specifically:

- Monitoring involves an assessment of progress and collecting information through the course of a project, can be before, during and after to gather results for which to do an evaluation (section 7.3.1).
- An evaluation analyses the results of monitoring and determines the results and effectiveness of the types of treatments used (section 7.3.2).

7.4.1 Monitoring

Following scheme implementation it is necessary to adopt a system of regular monitoring of the site to ensure that the improvement is having the desired effect and more importantly not having an adverse impact.

It is useful for the safety engineer to visit the site soon after construction to assess whether the project has been constructed as anticipated and that it is likely to achieve its aims. A stage 4 safety audit should not be considered as an alternative to this.

In the absence of any crash data there are various methods that can be adopted to analyse the projects at an early stage these include; conflict studies, which is essentially an observation of traffic behaviour and feedback from the local Police, transport operators and members of the public.

Often when there is a significant change in road layout, driver behaviour will evolve over the initial weeks as they learn the new system. Mitigation of these temporary risks can usually be achieved by additional short time warning signage to alert drivers to the change in environment. However, there may be issues that require permanent adaptation of the scheme.

A review of the crash data at high-risk sites should be undertaken on a regular basis following the immediate monitoring. As there may be a delay of a few months before crash data is available to CAS. It is suggested that the first crash review be carried out at the earliest opportunity or six months, followed by reviews at 12, 24 and 36 months.

7.4.2 Monitoring of crash data and treatment effectiveness (CAS)

The key to effective evaluation of specific works is to ensure the data required for evaluation of individual projects, treatments or initiatives is collected over the course of the programme and staff are not faced with the arduous task of trawling back through project files to identify when and which works have been completed.

The best way of addressing this issue is to ensure the project monitoring is stepped up at the start of a project and, as discussed above, the entering of monitoring data forms part of the contract, in-house service agreement or task plan for the works. This is best done using the crash analysis system (CAS). CAS is able to record three types of sites:

- **Sites of interest** (figure 7-3) – these are simply locations that users can identify spatially and for which crash data can be recalled. Once recalled the user can then analyse the effects of a programme of works. Recording works as sites of interest relies on recording key data about the works undertaken elsewhere, so sites of interest may be useful when monitoring areas to determine on-going trends, whether these are related to improvement programmes or not.
- **Safety improvement projects or crash reduction monitoring sites** (figures 7-4 and 7-5) – these two types of site are essentially the same in terms of the inputs required. The first data entry screen (figure 7-3) allows the user to input site description data (the sites are spatially defined later in the process). The second screen is used to identify the crash issues at the site and explicitly links the proposed solutions to the problems and the expected crash savings. While entering projects as safety improvement projects or monitoring sites involves a larger amount of more detailed data, monitoring site performance data automatically adjusts for potential regression to the mean impacts.

It is, however, important to recognise that, under the Safe System approach, we are looking toward more proactive treatment, rather than waiting for crash histories to develop, and implementing synergetic corridor treatments to increase consistency. It is therefore quite likely that in some situations works will be undertaken with a view to decreasing risks rather than to treat a documented crash history. In such situations crash performance monitoring may well be invalid because of a lack of a 'before' crash risk. In these situations we need to monitor and evaluate our programme as a whole, or develop some other key performance measures.

Figure 7-3: CAS sites of interest

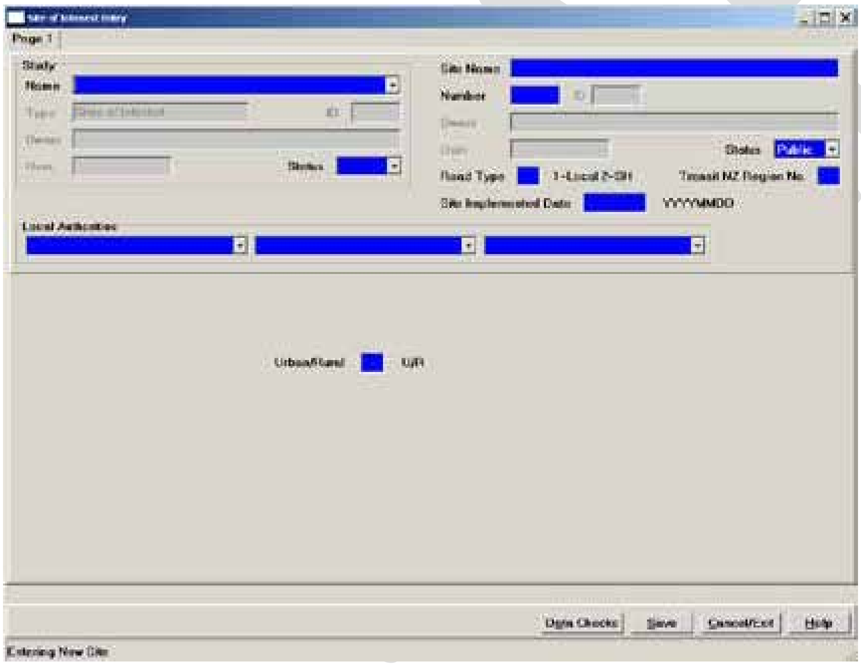


Figure 7-4: Monitoring site data entry screen 2

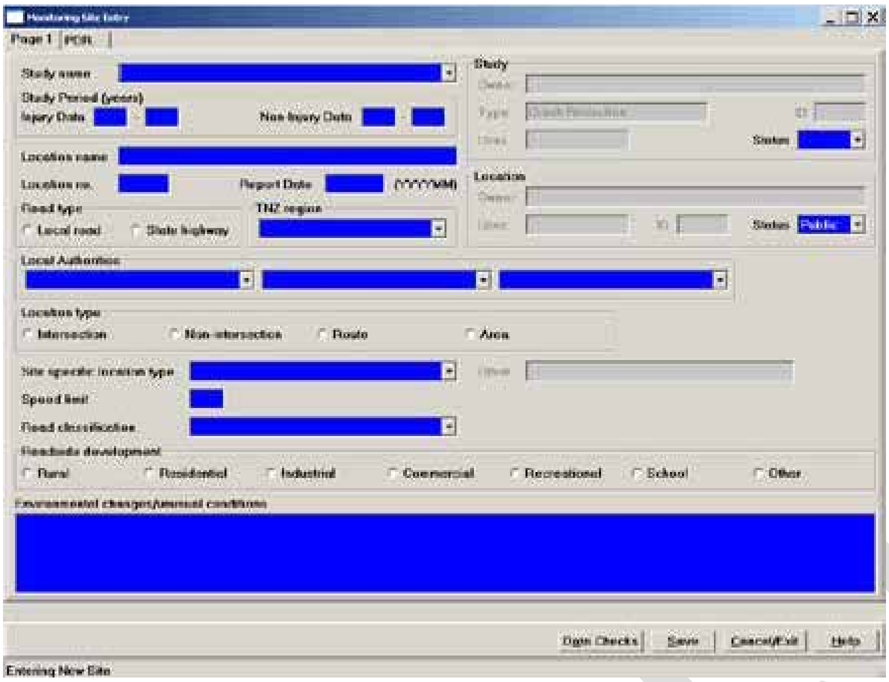


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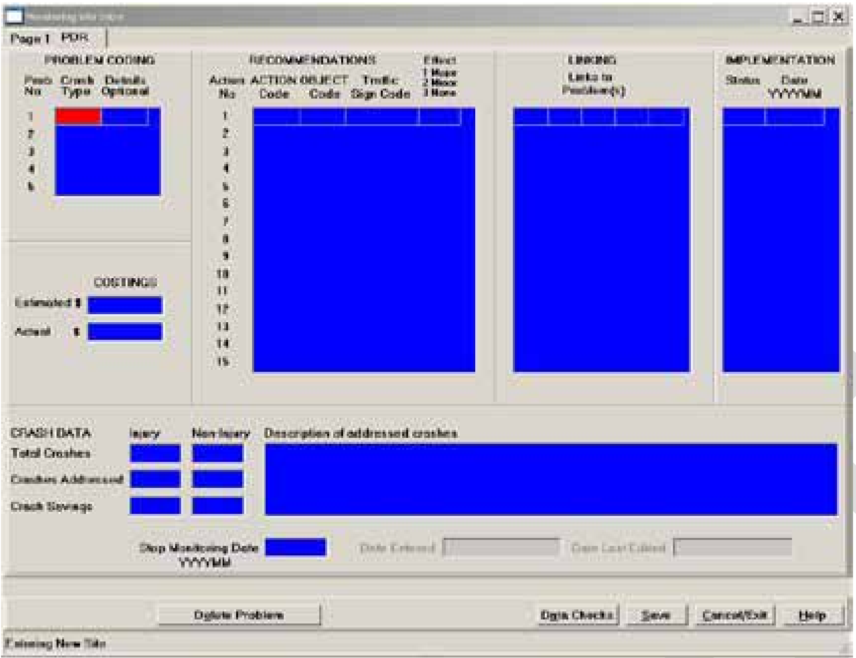
Figure 7-5: Monitoring site data entry screen 1



7.4.3 Evaluation

Post scheme evaluation can be used to determine the overall effectiveness in terms of crash reduction as well as to identify any areas of the countermeasures that could be improved upon and any lessons learnt during the design and implementation stages.

The most common way of evaluating scheme effectiveness is by comparison of before and after fatal and serious crash data. It is generally considered that a minimum reliable 'after' study period is 36 months. In the case of high-risk sites the overall numbers of fatal and serious crashes are likely to be lower than traditional blackspot sites which are selected on the basis of all injury crashes. In order to achieve a meaningful result that has a high level of confidence attached, this method may require many years of 'after' data. Austroads details basic categories of evaluation of traffic studies:

- Observational cross-section studies (OCS)
  - which compares performance of similar sites over a given time period.
- Observational before and after studies (OBAS)
  - comparison of before and after measures implemented (most commonly used).
- experimental before and after studies (EBAS)
  - similar to above but designed to control confounding factors across treatment and control sites.

Consideration to the effect on the minor injury record can also be an indicator, although is less reliable in high speed environments due to the higher impact forces involved. A range of statistical tests can be performed to indicate whether changes seen are likely to be reliable or are as a result of natural regression to mean. This can involve the use of control sites with similar layout, traffic composition and crash record. Austroads *Guide to road safety: Part 8: Treatment of crash locations* gives further details on this and include:

- chi-squared test of crash frequencies
- comparisons of crash rates using the paired t-test
- comparisons of proportions using z-test.

Crash movement types should also be evaluated to determine whether the countermeasures have been an effective treatment for the intended crash movement types. Countermeasures can have unexpected side effects which result in other crash movement types increasing

When using all injury crashes as an indicator, care should be taken that the results are not misleading. Roundabouts are a particular example where the severity is generally reduced but there can be an increase in more minor or non-injury crashes. Similarly mitigation measures such as passively safe or frangible roadside equipment can reduce severity but not reduce crashes overall. A key indicator in the effectiveness of high-risk sites should be the measure of changes in the severity index (SI) which is the number of fatal and serious crashes as a proportion of overall injury crashes.

Area wide impacts on the crash record due to the project such as crash migration should also be considered. This can be a particular issue in the case of banned turns and other measures that may impact on traffic patterns. Conversely changes at other locations in the vicinity may result in changes at the crash site.

The evaluation should also take into account actual scheme costs as a measure of the accuracy of estimates and most importantly to give a reliable BCR. Often these benefits can be less than expected and this information should be fed back into a knowledge bank in order that future scheme rankings are most effective.

Evaluation of the site should also be measured against the overall network programme objectives of a Safe System, ultimately this necessitates sites to fall out of the high-risk category. Therefore determination on whether the project has resulted in sufficient casualty reduction for the site to fall from the high or medium-high-risk categories to medium or low rankings should be made.

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References

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[2] Elvik and Vaa *Handbook of road safety measures.*

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[5]PIARC *Catalogue of design safety problems and potential countermeasures*

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[10] Austroads *Guide to traffic engineering practice, Part 6: Roundabouts.*

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[16] Monash University *Findings on the effectiveness of intersection treatment included in the Victorian state wide accident blackspot program*.

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[28] Auckland Red Light Camera Project.

[29] NZ. Ministry of Transport *Safer Journeys: New Zealand's road safety strategy 2010–2020*.

Appendix 1: CAS Crash movement codes

	TYPE	A	B	C	D	E	F	G	O
A	OVERTAKING AND LANE CHANGE	PULLING OUT OR CHANGING LANE TO RIGHT	HEAD ON	CUTTING IN OR CHANGING LANE TO LEFT	LOST CONTROL (OVERTAKING VEHICLE)	SIDE ROAD	LOST CONTROL (OVERTAKEN VEHICLE)	WEAVING IN HEAVY TRAFFIC	OTHER
B	HEAD ON	ON STRAIGHT	CUTTING CORNER	SWINGING WIDE	BOTH OR UNKNOWN	LOST CONTROL ON STRAIGHT	LOST CONTROL ON CURVE		OTHER
C	LOST CONTROL OR OFF ROAD (STRAIGHT ROADS)	OUT OF CONTROL ON ROADWAY	OFF ROADWAY TO LEFT	OFF ROADWAY TO RIGHT					OTHER
D	CORNERING	LOST CONTROL TURNING RIGHT	LOST CONTROL TURNING LEFT	MISSED INTERSECTION OR END OF ROAD					OTHER
E	COLLISION WITH OBSTRUCTION	PARKED VEHICLE	ACCIDENT OR BROKEN DOWN	NON VEHICULAR OBSTRUCTIONS (INCLUDING ANIMALS)	WORKMANS VEHICLE	OPENING DOOR			OTHER
F	REAR END	SLOW VEHICLE	CROSS TRAFFIC	PEDESTRIAN	QUEUE	SIGNALS	OTHER		OTHER
G	TURNING VERSUS SAME DIRECTION	REAR OF LEFT TURNING VEHICLE	LEFT SIDE SIDE SWIPE	STOPPED OR TURNING FROM LEFT SIDE	NEAR CENTRE LINE	OVERTAKING VEHICLE	TWO TURNING		OTHER
H	CROSSING (NO TURNS)	RIGHT ANGLE (70° TO 110°)							OTHER
J	CROSSING (VEHICLE TURNING)	RIGHT TURN RIGHT SIDE		TWO TURNING					OTHER
K	MERGING	LEFT TURN IN	RIGHT TURN IN	TWO TURNING					OTHER
L	RIGHT TURN AGAINST	STOPPED WAITING TO TURN	MAKING TURN						OTHER
M	MANOEUVRING	PARKING OR LEAVING	'U' TURN	'U' TURN	DRIVEWAY MANOEUVRE	PARKING OPPOSITE	ANGLE PARKING	REVERSING ALONG ROAD	OTHER
N	PEDESTRIANS CROSSING ROAD	LEFT SIDE	RIGHT SIDE	LEFT TURN LEFT SIDE	RIGHT TURN RIGHT SIDE	LEFT TURN RIGHT SIDE	RIGHT TURN LEFT SIDE	MANOEUVRING VEHICLE	OTHER
P	PEDESTRIANS OTHER	WALKING WITH TRAFFIC	WALKING FACING TRAFFIC	WALKING ON FOOTPATH	CHILD PLAYING (TRICYCLE)	ATTENDING TO VEHICLE	ENTERING OR LEAVING VEHICLE		OTHER
Q	MISCELLANEOUS	FELL WHILE BOARDING OR ALIGHTING	FELL FROM MOVING VEHICLE	TRAIN	PARKED VEHICLE RAN AWAY	EQUESTRIAN	FELL INSIDE VEHICLE	TRAILER OR LOAD	OTHER

Appendix 2: Crash analysis

F&S crash and DSi casualty analysis by speed environment and intersection form

This analysis provides a summary of the most common F&S crash and DSi casualty crash movement types for a range of speed environments and intersection forms. The analysis is based on data from CAS for the five-year period 2006–2010. The analysis should not be considered as an exhaustive list of all potential F&S crash movement types.

The figures on the following pages show the composition of crash movement types for F&S crashes and DSi casualties separately. The analysis also includes a ratio of DSi casualties to F&S crashes for each intersection form. The ratio for specific crash movement types can be calculated from the data presented enabling those crash movement types have historically resulted in more than one death or serious casualty in a crash to be identified.

The figures on the following pages use the 'key' shown below.

Type B - Head on	Type C - Loss of control or off road	Type D - Cornering
Type G - Turning versus same direction	Type H - Crossing (no turning)	Type J - Crossing (turning)
Type L - Right turn against	Type N - Pedestrian crossing road	Other

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Signalised intersections

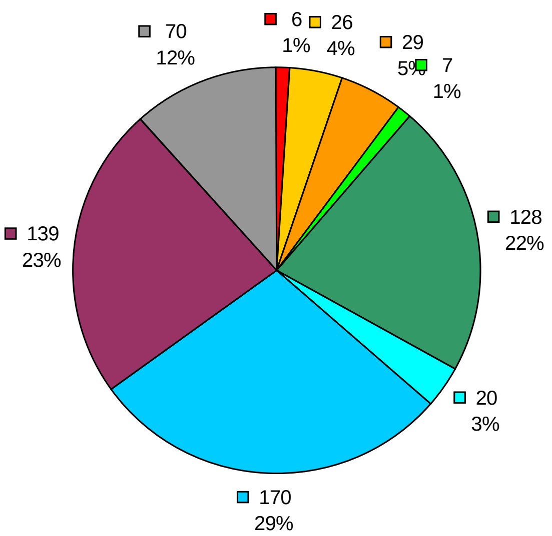
Urban

The main F&S crash and casualty crash movement types at urban signalised intersections are right turn against, pedestrian and crossing (no turning).

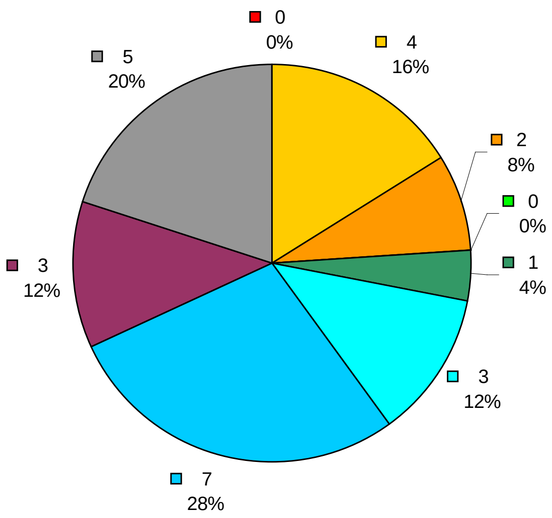
Rural

The main F&S crash and casualty crash movement types at rural signalised intersections are right turn against, loss of control (straight road). Any conclusions drawn from the rural data should be treated with caution because of the small sample size of F&S crashes.

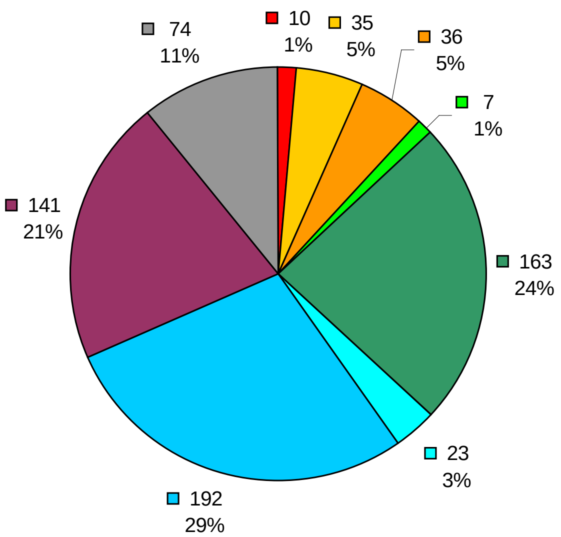
Urban F&S crashes



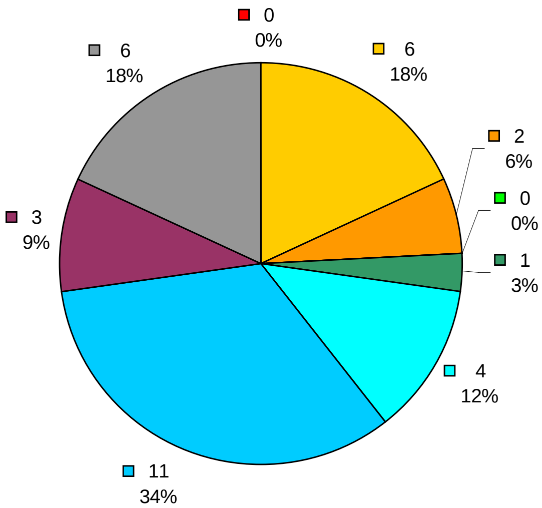
Rural F&S crashes



Urban DSi casualties



Rural DSi casualties



F&S Crashes = 595
DSi Casualties = 681
DSi Casualties / F&S Crashes = 1.14

F&S Crashes = 25
DSi Casualties = 33
DSi Casualties / F&S Crashes = 1.32

Roundabouts

Urban

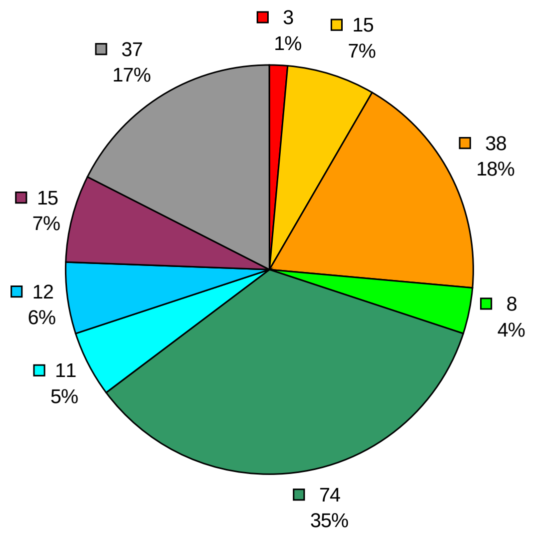
The main F&S crash and casualty crash movement types at urban roundabouts are entering vs circulating loss of control cornering.

Rural

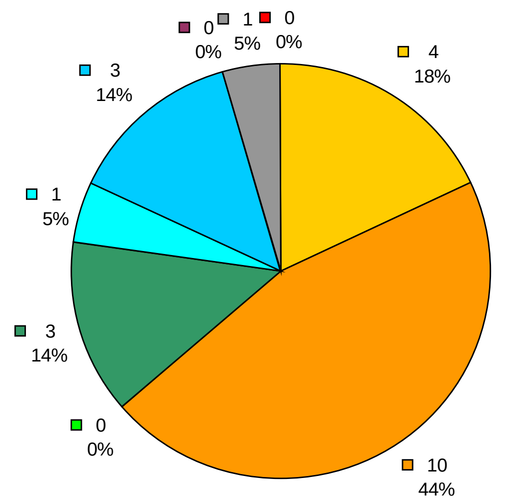
The main F&S crash and casualty crash movement types at rural roundabouts are loss of control cornering, loss of control (straight road) and entering vs circulating Any conclusions drawn from the rural data should be treated with caution because of the small sample size of F&S crashes.

The mix of F&S crash and casualty crash movement types is quite dissimilar between urban and rural environments. Not unsurprisingly, single vehicle loss of control type crashes comprise more than 60% of all F&S crashes at rural roundabouts, whereas multiple vehicle crashes form the majority of F&S crashes in the urban environment.

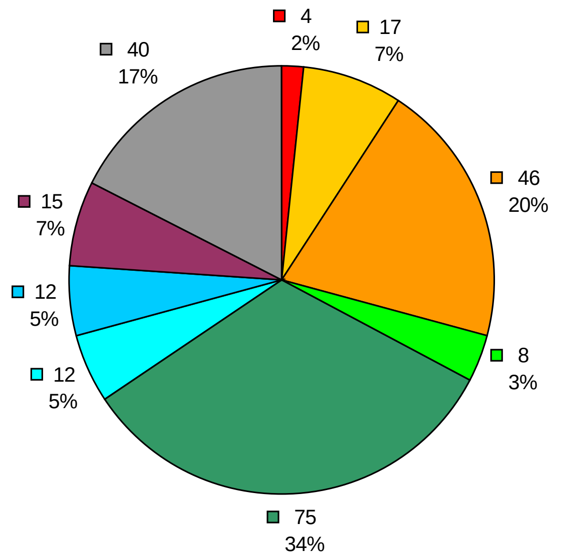
Urban F&S crashes



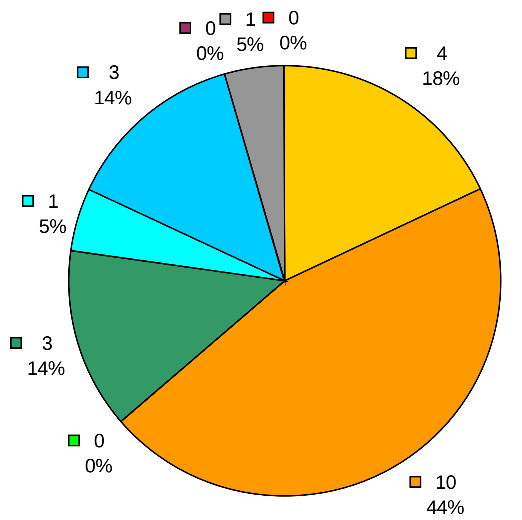
Rural F&S crashes



Urban DSi casualties



Rural DSi casualties



F&S Crashes = 213
\# DSi Casualties = 229
DSi Casualties / F&S Crashes = 1.08

\# F&S Crashes = 22
\# DSi Casualties = 22
DSi Casualties / F&S Crashes = 1.00

Give way/stop (priority) controlled crossroads

Urban

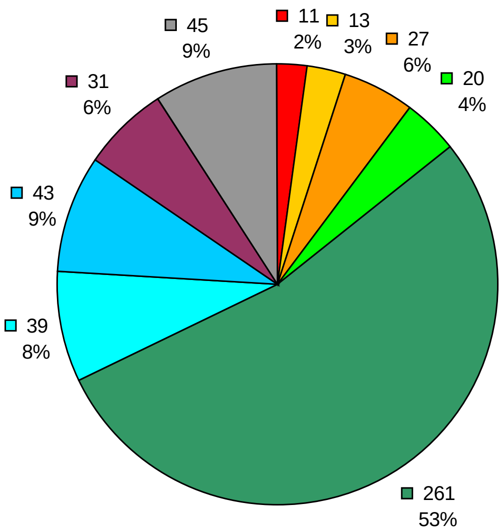
The main F&S crash and casualty crash movement type at urban priority controlled crossroads is overwhelmingly crossing (no turning).

Rural

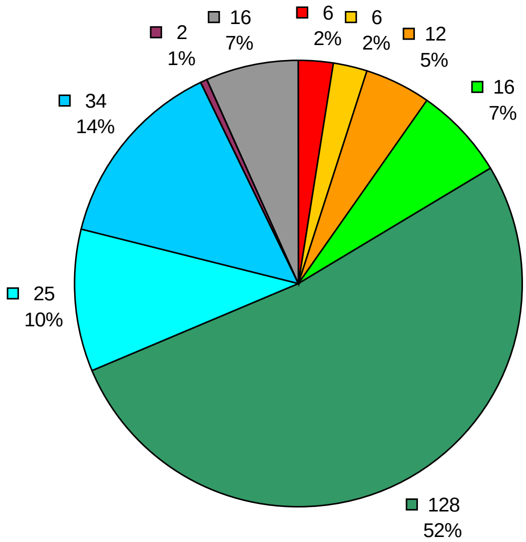
As with urban crashes, the main F&S crash and casualty crash movement type at rural priority controlled crossroads is overwhelmingly crossing (no turning).

The mix of F&S crash and casualty crash movement types is very similar between urban and rural environments.

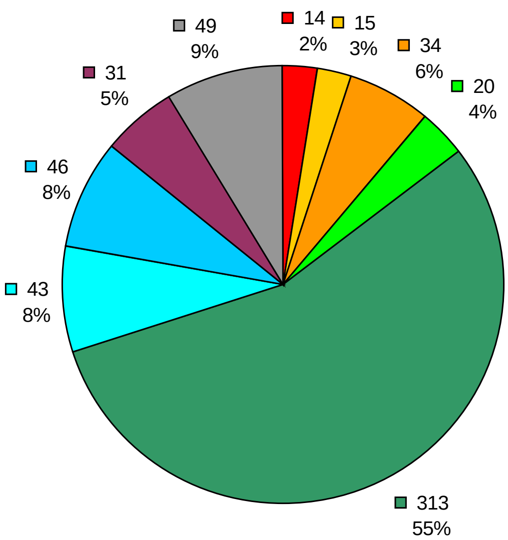
Urban F&S crashes



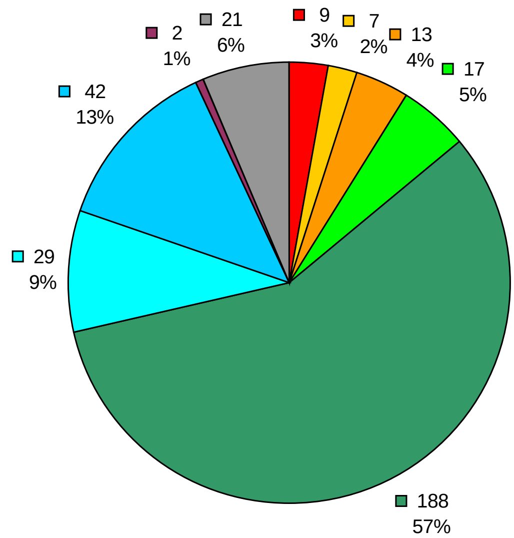
Rural F&S crashes



Urban DSi casualties



Rural DSi casualties



F&S Crashes = 490
DSi Casualties = 565
DSi Casualties / F&S Crashes = 1.15

F&S Crashes = 245
DSi Casualties = 328
DSi Casualties / F&S Crashes = 1.34

Give way/stop (priority) controlled T and Y intersections

Urban

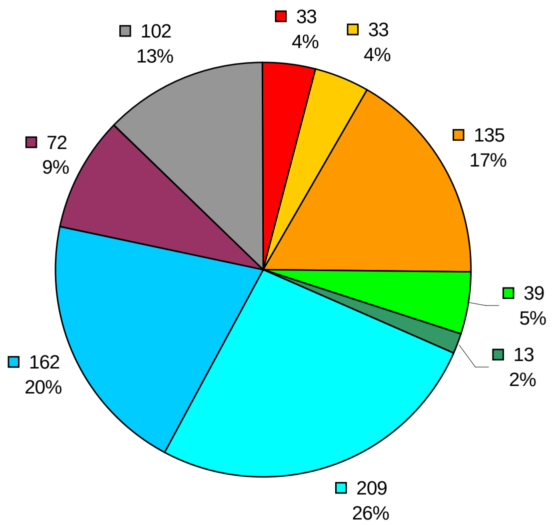
The main F&S crash and casualty crash movement types at urban priority controlled T and Y intersections are crossing (turning), right turn against and loss of control cornering.

Rural

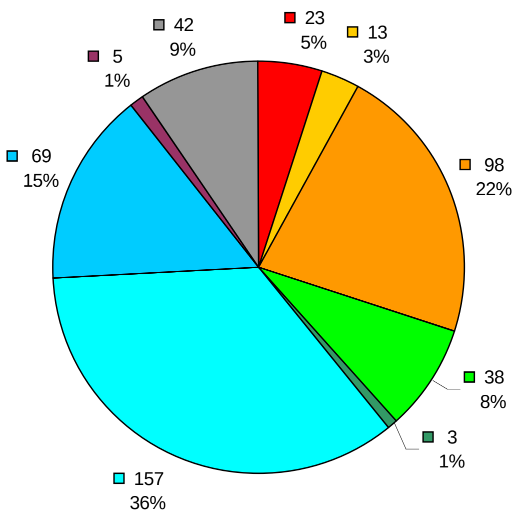
As with urban crashes, the main F&S crash and casualty crash movement types at rural priority controlled T and Y intersections crossroads are also crossing (turning), right turn against and loss of control cornering.

The mix of F&S crash and casualty crash movement types is similar between urban and rural environments – the main difference being fewer pedestrian F&S crashes in rural environments and more crossing (turning) F&S crashes. The crossing (turning) crash movement type involves a vehicle turning right from a side road being struck by a vehicle on the main road from the right. In high speed environments this commonly results in a F&S crash due to the impact being in the driver's side door.

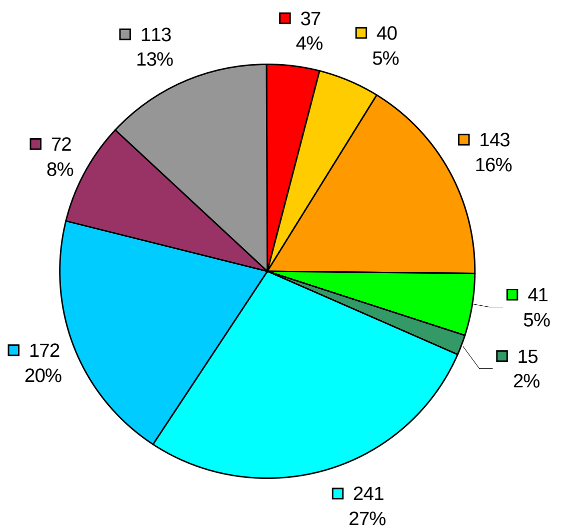
Urban F&S crashes



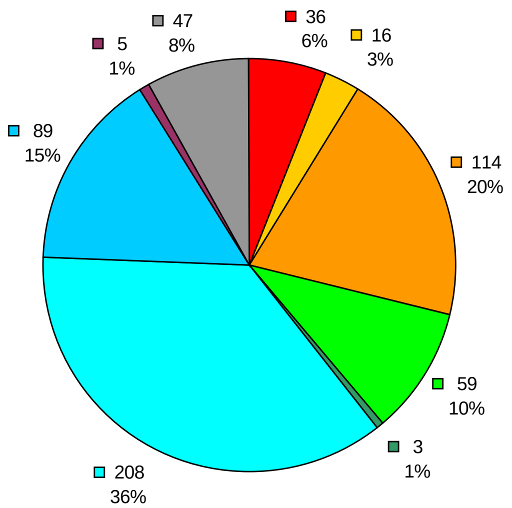
Rural F&S crashes



Urban DSi casualties



Rural DSi casualties



F&S Crashes = 798
DSi Casualties = 874
DSi Casualties / F&S Crashes = 1.10

F&S Crashes = 448
DSi Casualties = 657
DSi Casualties / F&S Crashes = 1.29

Uncontrolled intersections

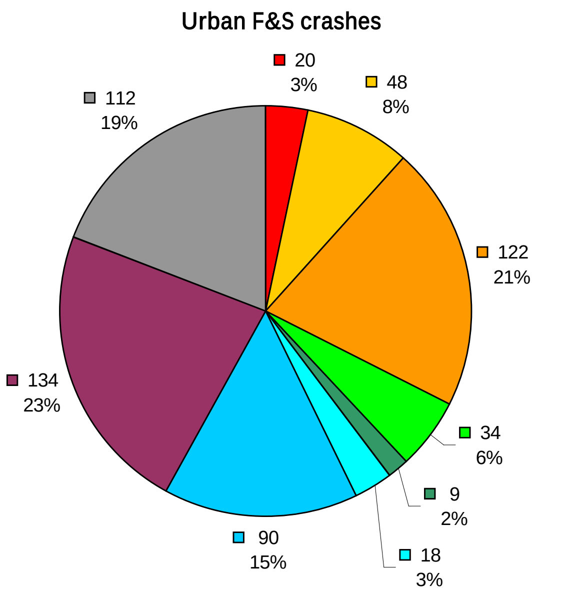
Urban

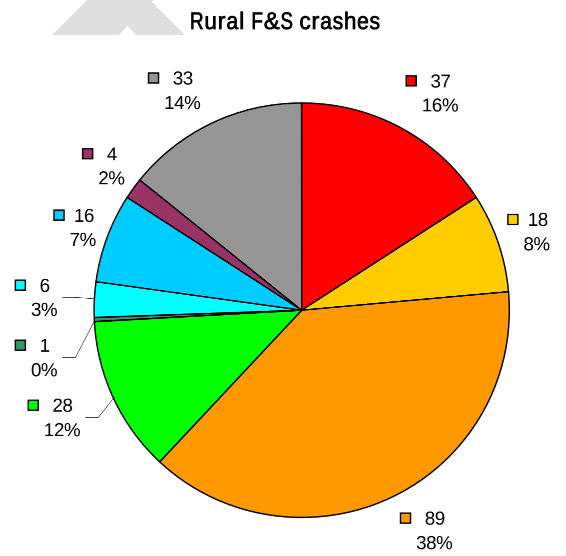
The main F&S crash and casualty crash movement types at urban uncontrolled intersections involve pedestrians, loss of control cornering and right turn against.

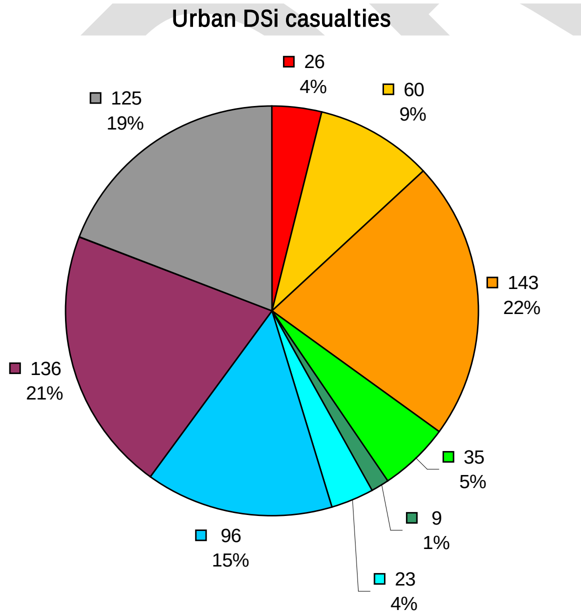
Rural

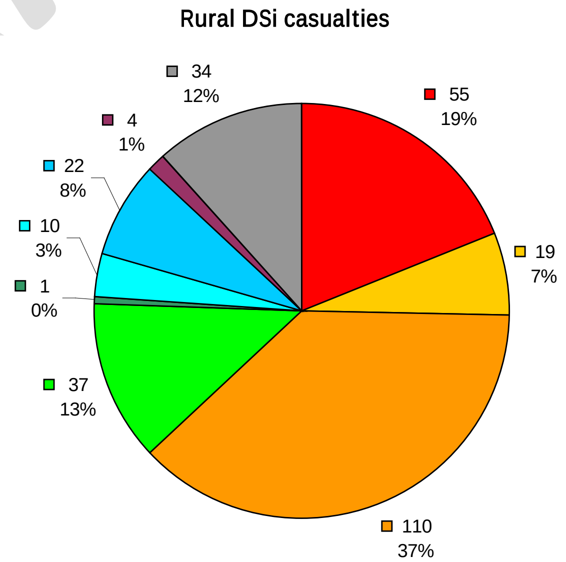
The main F&S crash and casualty crash movement types at rural uncontrolled intersections are loss of control cornering, head-on and turning versus same direction.

The mix of F&S crash and casualty crash movement types at uncontrolled intersections is noticeably dissimilar to other types of intersections.









F&S Crashes = 587
DSi Casualties = 653
DSi Casualties / F&S Crashes = 1.11

F&S Crashes = 232
DSi Casualties = 292
DSi Casualties / F&S Crashes = 1.26

Appendix 3: Severity ratio tables

Development of severity index tables

The main use of these tables is for estimating the expected number of F&S crashes based on all injury crashes at a site. This is the method used to define a high-risk injury crash site and corresponding high-risk injury crash rate in section 4.1.2 and 4.1.3.

Under current rules, high-risk intersections identified using the severity ratio method described below can only achieve medium strategic fit.

The severity outcome of any crash is known to vary substantially depending on the type of conflict, type of intersection and collision speed. The police record all of these aspects for each crash they attend. This information is then entered into CAS.

This information has been used to determine the severity index (SI) of each crash movement type for a number of intersection forms and controls in urban and rural speed environments. The SI is the number of F&S crashes divided by all injury crashes for each primary crash movement type for each intersection form and speed environment combination. These are shown in the tables that follow.

When determining the estimated F&S crashes at the site as detailed in section 4, the SI should be based on the *adjusted F&S crashes column. This is adjusted where the sample size for that movement type was too small to give a reliable estimate of the SI. Adjusted F&S have been estimated based on the movements at similar intersection forms and control types. This method allows us to estimate the underlying F&S crash risk based on the movement codes from the crash history.

This method automatically accounts for the higher severity of pedestrian crashes as they have their own movement category. It is intended that during the consultation period, a method of accounting for the severity of cyclist F&S crashes will be developed and included in the procedures.

Use of SI tables

Consider a signalised crossroad intersection in an urban environment (refer table 8-1). The site has eight reported injury crashes in the past five years. The movement types comprise of 3 x Type F, 2 x Type H and 3 x Type N injury crashes. We can use this individual crash movement type information to determine the F&S crash risk.

The following table illustrates how this overall adjusted risk rating can be calculated for this site.

Crash movement type	Number of recorded injury crashes	Adjusted SI (from SI table for urban priority T)	Estimated number of F&S crashes (injury crashes x SI)
F	3	0.05	0.15
H	2	0.15	0.30
N	3	0.21	0.63
			Total = 1.08

Table 4-1 indicates this site would have a medium collective risk based on estimated F&S crash risk.

Urban severity index tables

Table 8.1 Urban Signalised Crossroads: Death and Serious Casualty Analysis

Primary Crash Type	Number of Injury Crashes	Number of F&S Crashes	Number of DSi Casualties	DSi Casualties / All Injury Crashes	F&S crashes / All Injury crashes	Adjusted F&S crashes / All Injury crashes
Type A	56	6	6	0.11	0.11	0.11
Type B	31	4	6	0.19	0.13	0.13
Type C	87	14	17	0.2	0.16	0.16
Type D	109	16	20	0.18	0.15	0.15
Type E	21	3	3	0.14	0.14	0.15
Type F	385	21	24	0.06	0.05	0.05
Type G	74	6	6	0.08	0.08	0.08
Type H	765	118	156	0.2	0.15	0.15
Type J	96	8	10	0.1	0.08	0.08
Type K	48	10	10	0.21	0.21	0.21
Type L	871	116	128	0.15	0.13	0.13
Type M	29	6	6	0.21	0.21	0.21
Type N	452	93	94	0.21	0.21	0.21
Type P	4	1	1	0.25	0.25	0.31
Type Q	5	2	2	0.4	0.40	0.25

Table 8.2 Urban Signalised T- Intersections: Death and Serious Casualty Analysis

Primary Crash Type	Number of Injury Crashes	Number of F&S Crashes	Number of DSi Casualties	DSi Casualties / All Injury Crashes	F&S crashes / All Injury crashes	Adjusted F&S crashes / All Injury crashes
Type A	30	4	4	0.13	0.13	0.13
Type B	30	2	4	0.13	0.07	0.07
Type C	36	10	16	0.44	0.28	0.28
Type D	88	12	15	0.17	0.14	0.14
Type E	10	0	0			0.15
Type F	210	6	7	0.03	0.03	0.03
Type G	33	1	1	0.03	0.03	0.03
Type H	21	1	1	0.05	0.05	0.05
Type J	158	11	12	0.08	0.07	0.07
Type K	33	3	3	0.09	0.09	0.09
Type L	284	48	57	0.20	0.17	0.17
Type M	12	2	2	0.17	0.17	0.17
Type N	140	36	37	0.26	0.26	0.26
Type P	6	2	2	0.33	0.33	0.31
Type Q	2	0	0			0.25

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Table 8.3 Urban Roundabouts: Death and Serious Casualty Analysis

Primary Crash Type	Number of Injury Crashes	Number of F&S Crashes	Number of DSi Casualties	DSi Casualties / All Injury Crashes	F&S crashes / All Injury crashes	Adjusted F&S crashes / All Injury crashes
Type A	40	4	5	0.13	0.10	0.10
Type B	18	3	4	0.22	0.17	0.17
Type C	55	15	17	0.31	0.27	0.27
Type D	224	38	46	0.21	0.17	0.17
Type E	10	1	1	0.10	0.10	0.14
Type F	172	8	8	0.05	0.05	0.05
Type G	73	8	8	0.11	0.11	0.11
Type H	518	73	74	0.14	0.14	0.14
Type J	73	11	12	0.16	0.15	0.15
Type K	165	18	20	0.12	0.11	0.11
Type L	101	12	12	0.12	0.12	0.12
Type M	14	2	2	0.14	0.14	0.14
Type N	76	14	14	0.18	0.18	0.26
Type P	119	37	37	0.31	0.31	0.26
Type Q	6	3	3	0.50	0.50	0.25

Table 8.4 Urban Priority Controlled Crossroads: Death and Serious Casualty Analysis

Primary Crash Type	Number of Injury Crashes	Number of F&S Crashes	Number of DSi Casualties	DSi Casualties / All Injury Crashes	F&S crashes / All Injury crashes	Adjusted F&S crashes / All Injury crashes
Type A	17	3	4	0.24	0.18	0.18
Type B	45	11	14	0.31	0.24	0.24
Type C	75	13	15	0.20	0.17	0.17
Type D	142	27	34	0.24	0.19	0.19
Type E	12	3	3	0.25	0.25	0.15
Type F	94	8	9	0.10	0.09	0.09
Type G	105	20	20	0.19	0.19	0.19
Type H	1821	261	313	0.17	0.14	0.14
Type J	239	39	43	0.18	0.16	0.16
Type K	139	18	19	0.14	0.13	0.13
Type L	277	43	46	0.17	0.16	0.16
Type M	36	7	8	0.22	0.19	0.19
Type N	146	31	31	0.21	0.21	0.21
Type P	12	5	5	0.42	0.42	0.31
Type Q	2	1	1	0.50	0.50	0.25

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Table 8.5 Urban Priority Controlled T- Intersections: Death and Serious Casualty Analysis

Primary Crash Type	Number of Injury Crashes	Number of F&S Crashes	Number of DSi Casualties	DSi Casualties / All Injury Crashes	F&S crashes / All Injury crashes	Adjusted F&S crashes / All Injury crashes
Type A	56	12	16	0.29	0.21	0.21
Type B	179	33	37	0.21	0.18	0.18
Type C	160	33	40	0.25	0.21	0.21
Type D	679	134	142	0.21	0.20	0.20
Type E	44	7	7	0.16	0.16	0.15
Type F	373	22	26	0.07	0.06	0.06
Type G	354	39	41	0.12	0.11	0.11
Type H	77	13	15	0.19	0.17	0.17
Type J	1527	209	241	0.16	0.14	0.14
Type K	356	40	42	0.12	0.11	0.11
Type L	932	161	171	0.18	0.17	0.17
Type M	106	14	15	0.14	0.13	0.13
Type N	321	72	72	0.22	0.22	0.22
Type P	20	5	5	0.25	0.25	0.31
Type Q	12	2	2	0.17	0.17	0.25

Rural severity index tables

Table 8.6 Rural Signalised Crossroads: Death and Serious Casualty Analysis

Primary Crash Type	Number of Injury Crashes	Number of F&S Crashes	Number of DSi Casualties	DSi Casualties / All Injury Crashes	F&S crashes / All Injury crashes	Adjusted F&S crashes / All Injury crashes
Type A	2	1	1	0.50	0.50	0.32
Type B	1	0	0			0.35
Type C	7	4	6	0.86	0.57	0.25
Type D	6	1	1	0.17	0.17	0.26
Type E	0	0	0			0.31
Type F	20	1	1	0.05	0.05	0.08
Type G	1	0	0			0.23
Type H	13	1	1	0.08	0.08	0.10
Type J	6	1	2	0.33	0.17	0.21
Type K	3	1	2	0.67	0.33	0.17
Type L	32	7	11	0.34	0.22	0.22
Type M	1	0	0	0.00	0.00	0.15
Type N	1	1	1	1.00	1.00	0.73
Type P	0	0	0			0.73
Type Q	0	0	0			0.50

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Table 8.7 Rural Signalised T- Intersections: Death and Serious Casualty Analysis

Primary Crash Type	Number of Injury Crashes	Number of F&S Crashes	Number of DSi Casualties	DSi Casualties / All Injury Crashes	F&S crashes / All Injury crashes	Adjusted F&S crashes / All Injury crashes
Type A	2	0	0			0.32
Type B	1	0	0			0.35
Type C	4	0	0			0.25
Type D	8	1	1	0.13	0.13	0.26
Type E	0	0	0			0.31
Type F	24	1	1	0.04	0.04	0.08
Type G	3	0	0			0.23
Type H	0	0	0			0.10
Type J	8	2	2	0.25	0.25	0.21
Type K	3	0	0			0.17
Type L	22	0	0			0.08
Type M	0	0	0			0.28
Type N	2	2	2	1.00	1.00	0.73
Type P	0	0	0			0.73
Type Q	0	0	0			0.50

Table 8.8 Rural Roundabouts: Death and Serious Casualty Analysis

Primary Crash Type	Number of Injury Crashes	Number of F&S Crashes	Number of DSi Casualties	DSi Casualties / All Injury Crashes	F&S crashes / All Injury crashes	Adjusted F&S crashes / All Injury crashes
Type A	4	0	0			0.10
Type B	0	0	0			0.17
Type C	12	4	4	0.33	0.33	0.33
Type D	46	10	10	0.22	0.22	0.22
Type E	2	0	0			0.22
Type F	28	1	1	0.04	0.04	0.05
Type G	8	0	0			0.11
Type H	25	3	3	0.12	0.12	0.14
Type J	5	1	1	0.20	0.20	0.15
Type K	9	0	0			0.11
Type L	8	3	3	0.38	0.38	0.15
Type M	0	0	0			0.14
Type N	0	0	0			0.30
Type P	1	0	0			0.30
Type Q	2	0	0			0.25

Table 8.9 Rural Priority Controlled Crossroads: Death and Serious Casualty Analysis

Primary Crash Type	Number of Injury Crashes	Number of F&S Crashes	Number of DSi Casualties	DSi Casualties / All Injury Crashes	F&S crashes / All Injury crashes	Adjusted F&S crashes / All Injury crashes
Type A	8	3	4	0.50	0.38	0.32
Type B	19	6	9	0.47	0.32	0.35
Type C	24	6	7	0.29	0.25	0.25
Type D	51	12	13	0.25	0.24	0.24
Type E	4	1	1	0.25	0.25	0.31
Type F	17	3	3	0.18	0.18	0.08
Type G	74	16	17	0.23	0.22	0.22
Type H	373	128	188	0.50	0.34	0.34
Type J	76	25	29	0.38	0.33	0.33
Type K	26	6	9	0.35	0.23	0.23
Type L	115	34	42	0.37	0.30	0.30
Type M	9	3	4	0.44	0.33	0.28
Type N	2	2	2	1.00	1.00	0.73
Type P	2	0	0			0.73
Type Q	1	0	0			0.50

Table 8.10 Rural Priority Controlled T- Intersections: Death and Serious Casualty Analysis

Primary Crash Type	Number of Injury Crashes	Number of F&S Crashes	Number of DSi Casualties	DSi Casualties / All Injury Crashes	F&S crashes / All Injury crashes	Adjusted F&S crashes / All Injury crashes
Type A	19	6	6	0.32	0.32	0.32
Type B	63	23	23	0.37	0.37	0.35
Type C	57	13	16	0.28	0.23	0.25
Type D	361	98	114	0.32	0.27	0.27
Type E	7	3	6	0.86	0.43	0.31
Type F	66	5	5	0.08	0.08	0.08
Type G	159	38	59	0.37	0.24	0.24
Type H	16	3	3	0.19	0.19	0.19
Type J	552	156	207	0.38	0.28	0.28
Type K	77	20	22	0.29	0.26	0.26
Type L	238	69	89	0.37	0.29	0.29
Type M	18	5	5	0.28	0.28	0.28
Type N	6	5	5	0.83	0.83	0.73
Type P	2	1	1	0.50	0.50	0.73
Type Q	3	2	2	0.67	0.67	0.50

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Appendix 4: EEM crash prediction models

Crash models (urban ≤ 70km/h)

A = b0 X Qmajor^b1 X Qminor^b2

Intersection form		b0	b1	b2	
Uncontrolled	(T)	0.00253	0.36	0.19	
Priority	(Cross)	0.00125	0.21	0.51	
Priority	(T)	5.65E-05	0.76	0.2	
Traffic signals	(Cross)	0.00325	0.46	0.14	
Traffic signals	(T)	0.152	0.04	0.12	
Roundabout		0.000919	0.58		per approach

Crash models (high-speed ≥ 80km/h)

A = b0 X Qmajor^b1 X Qminor^b2

Intersection form		b0	b1
Priority	(Cross)	0.000432	0.39
Priority	(T)	0.000407	0.18
Traffic signals	(Cross)	0.000364	0.52
Traffic signals	(T)	0.051	0.37

For details on how to apply these general flow only models, refer to part A6 of Volume 1 of the EEM. The EEM also contains more detailed conflict by conflict models which are superior where detailed turning volumes and other modelled features are known.

These models predict the number of injury crashes. To predict F&S crashes they need to be adjusted for severity using the appropriate severity index, in similar way to the method shown in Appendix 3.

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Appendix 5: Level of safety service figures by intersection form and speed environment

This appendix of the guide shows the level of safety service (LoSS) bands for all intersection form and speed environment combinations presented in Appendix 3 excluding roundabouts. The LoSS band definitions are presented in table 4-3.

Figure A5-1: LoSS bands for urban signalised crossroad intersections

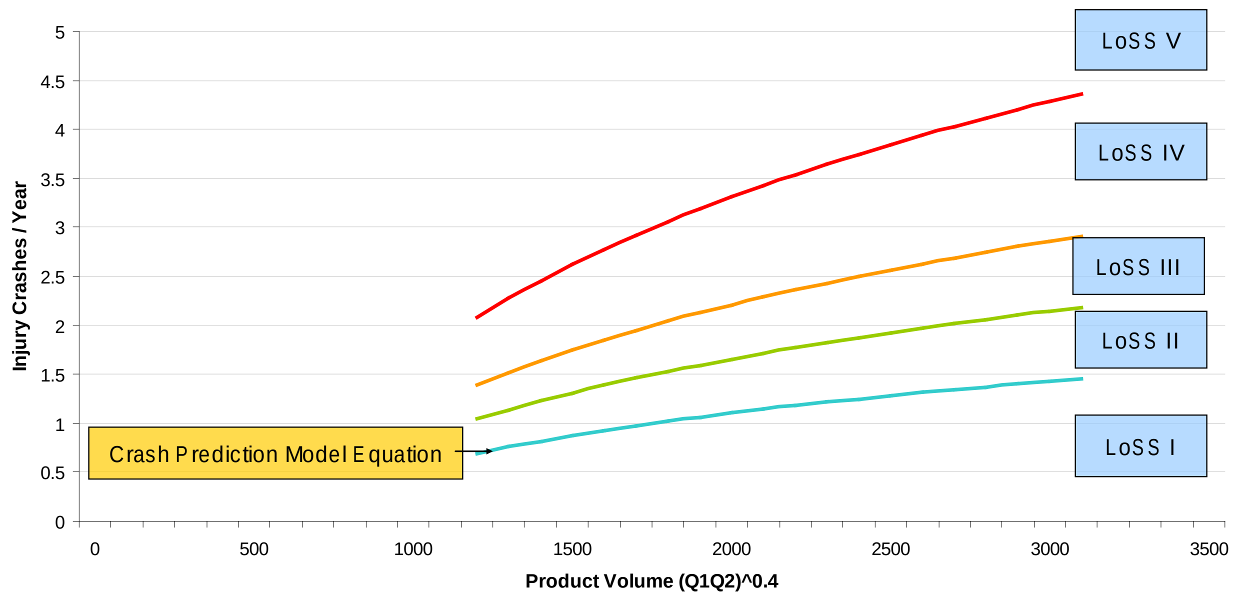


Figure A5-2: LoSS bands for urban signalised T-intersections

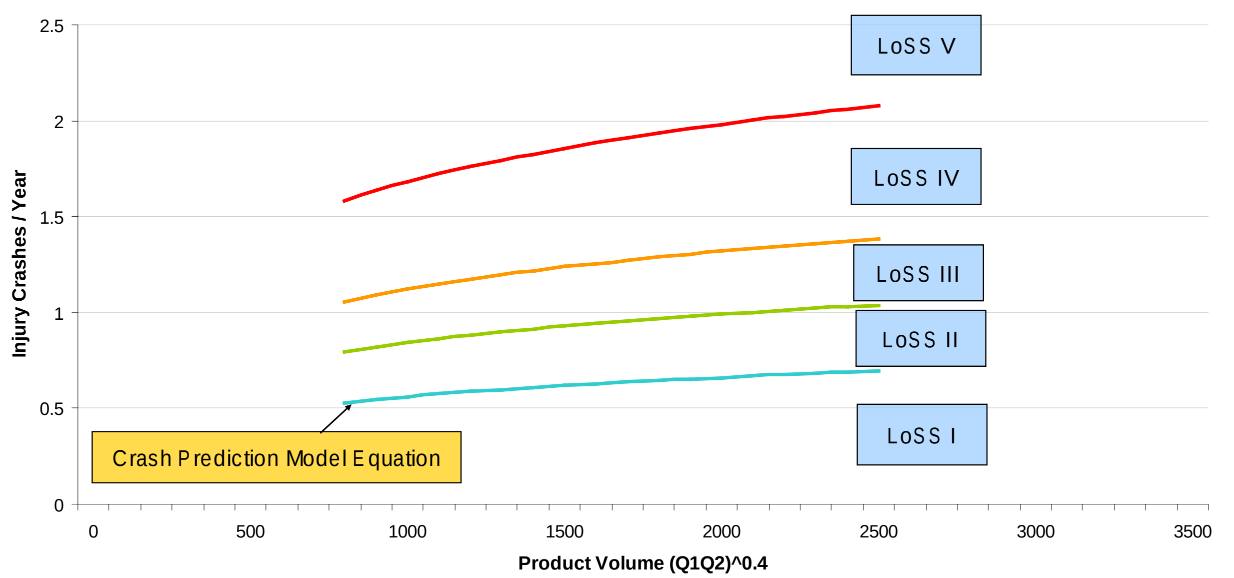


Figure A5-3: LoSS bands for urban priority controlled crossroad intersections

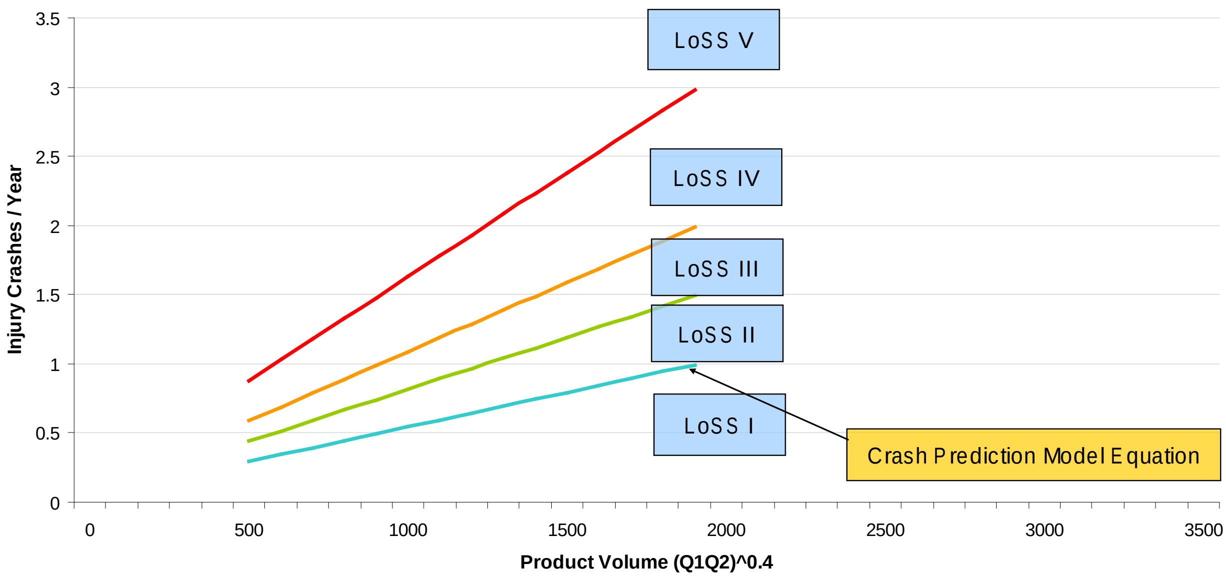


Figure A5-4: LoSS bands for urban priority controlled T-intersections

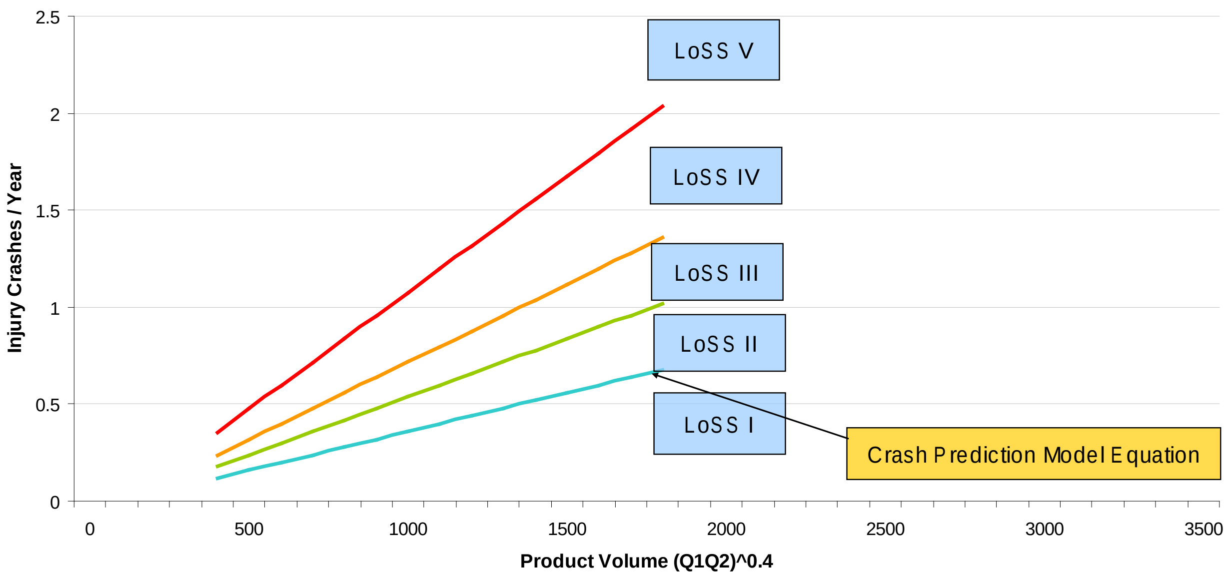


Figure A5-5: LoSS bands for rural signalised crossroad intersections

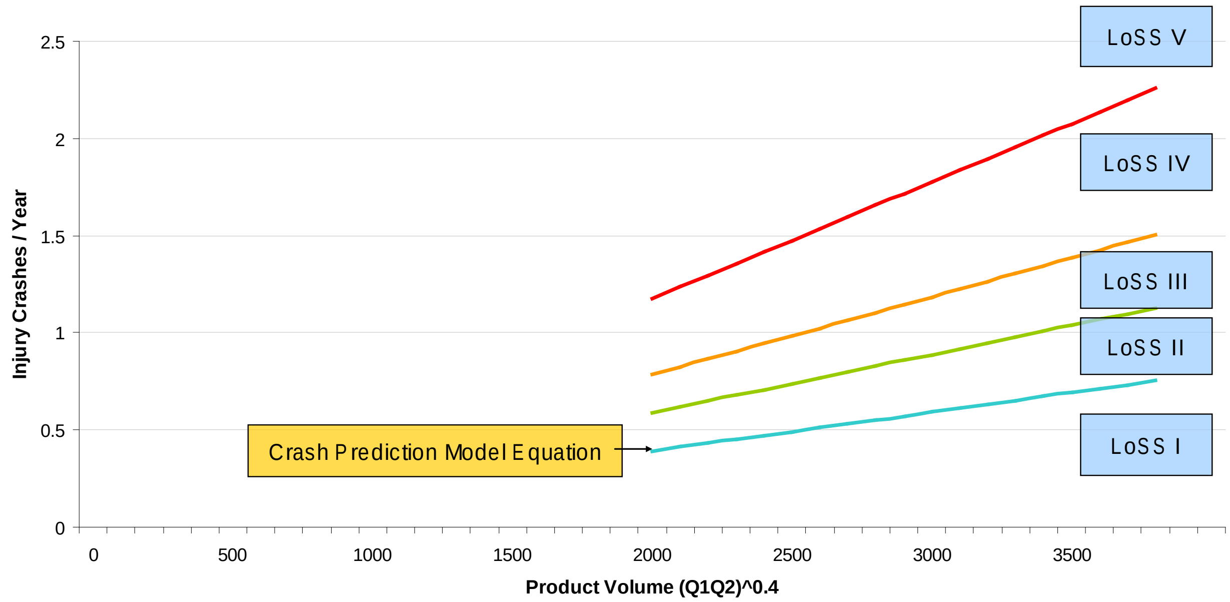


Figure A5-6: LoSS bands for rural signalised T-intersections

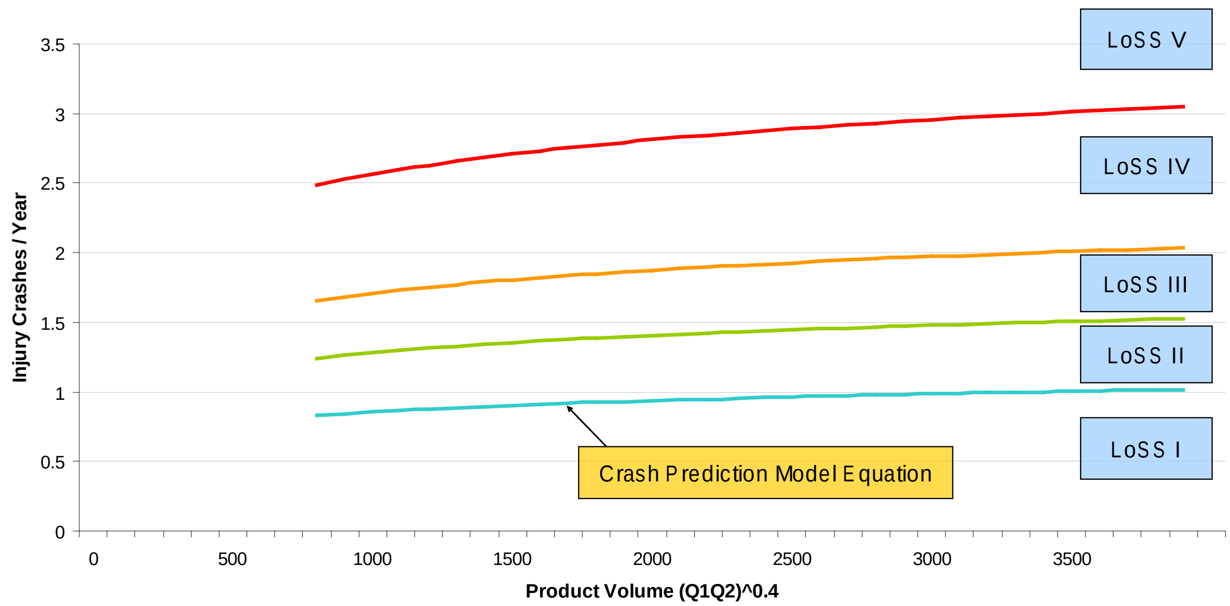


Figure A5-7: LoSS bands for rural priority controlled crossroad intersections

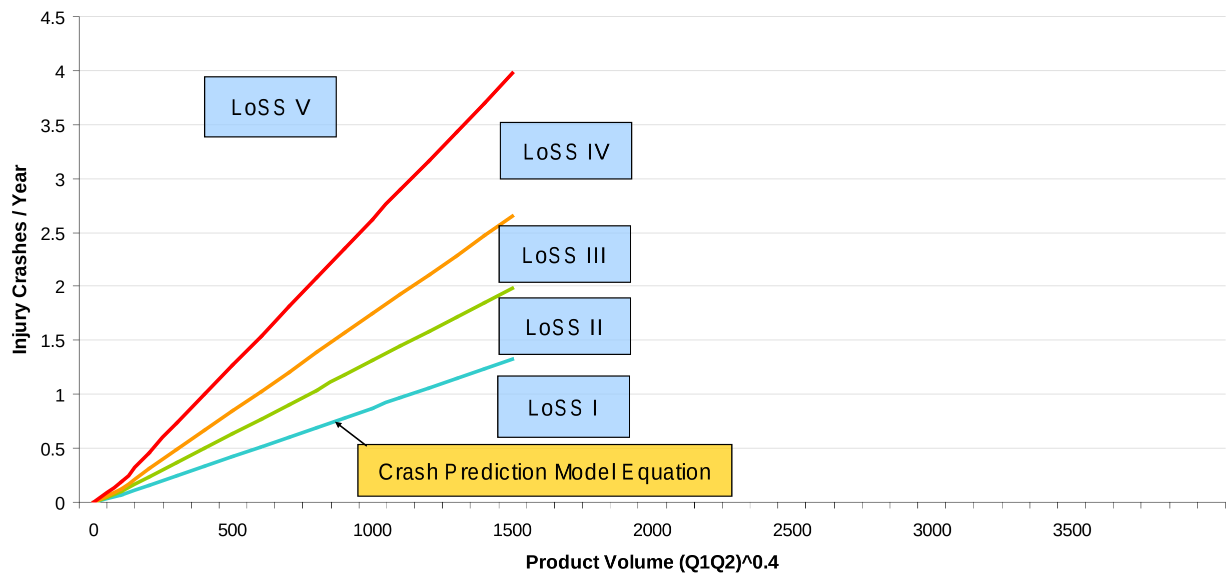
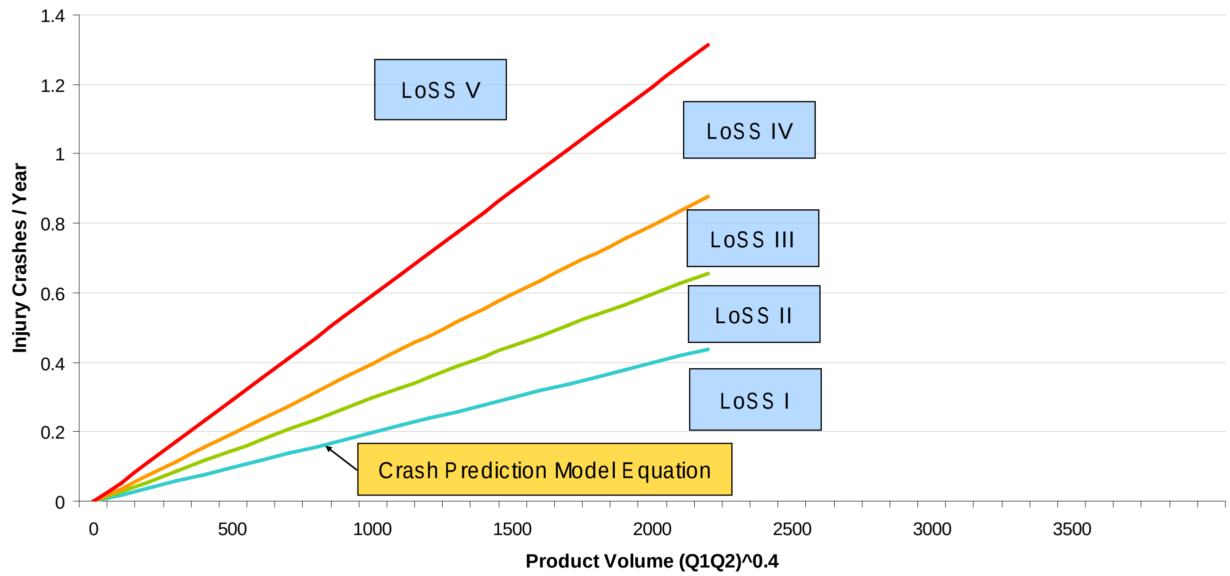


Figure A5-8: LoSS bands for rural priority controlled T-intersections



Appendix 6: Key high-risk countermeasures detail sheets

Countermeasures

References to specific countermeasures which relate to the key high-risk and vulnerable user crash movement types are provided in the table below. Further details are provided in the following countermeasures sheets. These sheets are by no means an exhaustive list of countermeasures but give guidance as to the most likely countermeasures.

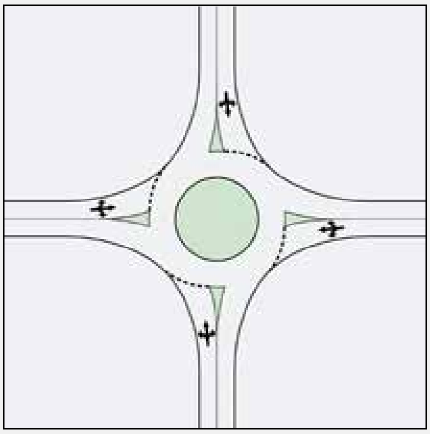
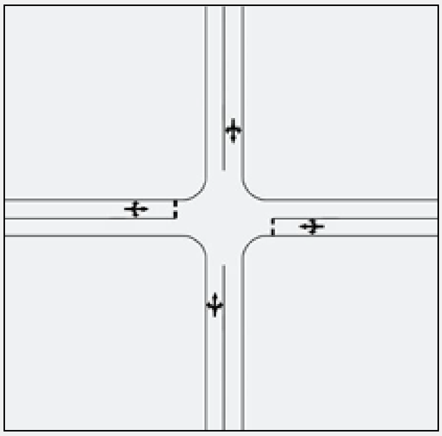
Countermeasure	Ref	**Rural / High Speed >= 80 km/h**	Signalised Intersection	Roundabout	Priority Crossroads	T Intersections	Staggered T	Y Intersections	**Urban <= 70 km/h**	Signalised Intersection	Roundabout	Priority Crossroads	T Intersections	Staggered T	Y Intersections
Transformational															
Roundabout	T1		X		X	X	X	X		X		X	X	X	X
Staggered T from X	T2				X										
T From Y	T3							X							
Signals From Uncontrolled / Give way	T4											X	X	X	X
Grade Separation	T5		X	X	X	X	X	X							
Speed Management & Intersection Awareness															
Intelligent Electronic Warning Signs	S1		X	X	X	X	X	X		X	X	X	X	X	X
Rumble Strips	S2		X	X	X	X	X	X							
High Friction Coloured Surfacing	S3		X	X	X	X	X	X		X	X	X	X	X	X
Transverse Markings	S4		X	X	X	X	X	X							
Enhanced Signing	S5		X	X	X	X	X	X		X					
Intersection Improvement															
Minor Road Channelisation	IS1				X	X	X	X		X		X	X	X	X
Turning Bays	IS2				X	X	X	X		X		X	X	X	X
Sight Distance Improvement	IS3				X	X	X	X		X		X	X	X	X
Pedestrian Facilities at uncontrolled/giveway	IS4				X	X	X	X				X	X	X	X
Cyclist Facilities at uncontrolled/giveway	IS5				X	X	X	X				X	X	X	X
Signals															
Speed Discrimination Equipment	IS6		X							X					
Provide Separate Right Turn Phase	IS7		X							X					
Improve Signal Conspicuity	IS8		X							X					
Align Opposing Right Turns	IS9		X							X					
Pedestrian Facilities at Signals	IS10		X							X					
Cycle Facilities at Signals	IS11		X												

Countermeasure	Ref	**Rural / High Speed >= 80 km/h**	Signalised Intersection	Roundabout	Priority Crossroads	T Intersections	Staggered T	Y Intersections	**Urban <= 70 km/h**	Signalised Intersection	Roundabout	Priority Crossroads	T Intersections	Staggered T	Y Intersections
Roundabouts															
Reverse Curves on approach to Roundabout	IS12			X											
Geometry Improvements to Roundabout	IS13			X							X				
Central Lighting of Roundabout	IS14			X							X				
Pedestrian Facilites at Roundabouts	IS15			X							X				
Cyclist Facilities at Roundabouts	IS16			X							X				
Adverse Camber Rectification Roundabouts	IS17			X							X				
Collision Severity Mitigation															
Clear or Safe Zones	C1		X	X	X	X	X	X		X	X	X	X	X	X
Enforcement															
Speed and Red Light Cameras	E1		X	X	X	X	X	X		X	X	X	X	X	X

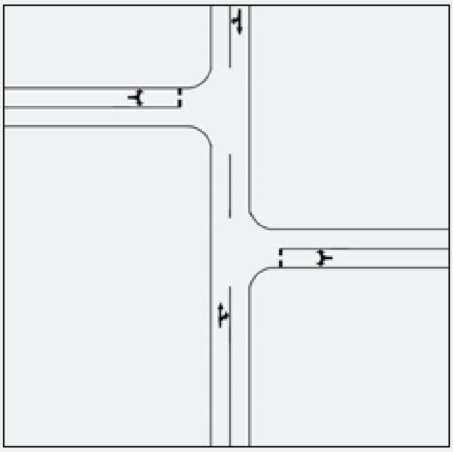
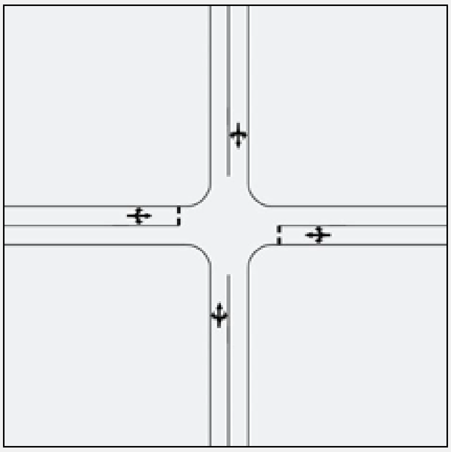
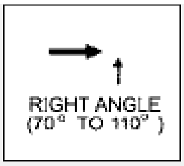
DRAFT

Transformational works

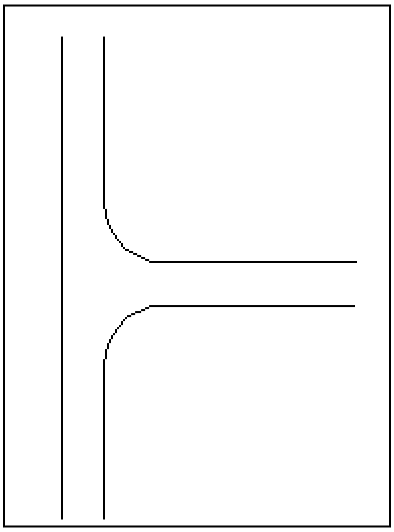
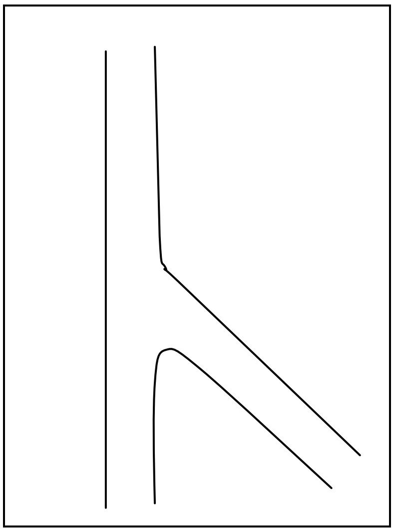
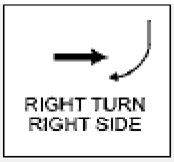
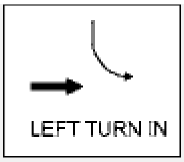
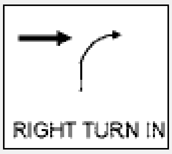
Roundabout from ‘T’ or crossroads intersection T1

Description	Roundabouts are an effective method of reducing both the number and severity of injury crashes. This is due to the number of conflict points and speeds being reduced when compared with other layouts. [10] **Roundabout**  **Crossroads** 
Application	At T junctions and crossroads.
Issues	Larger footprint than other simple junction forms. In 80km/h+ environments, speeds need to be managed down on approach so as not to result in unacceptably high entry speed onto the circulating carriageway. [10] The proportion of cycle crashes can increase when compared with other intersection forms, although single lane entry layouts are generally safer than multi-lane. [11]
Crash reduction	10-40% reduction in injury crashes. [2] 70-90% reduction in fatal and serious crashes. [7] 25-80% reduction in all crashes from uncontrolled intersection. [5] 25%-50% reduction in all crashes from traffic signals. [5]
Other benefits	Improved flow – with reduced delays for side road traffic.
Cost	High
Treatment life	25 years
Applicable key high-risk crash movement types	Most crash movement types with the exception of pedestrian and cyclist crashes.
References	[10] [11] [12] [14]

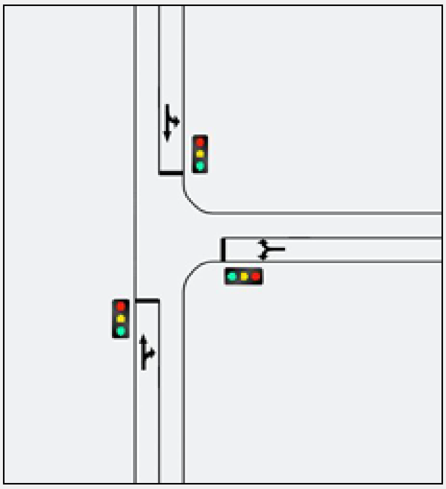
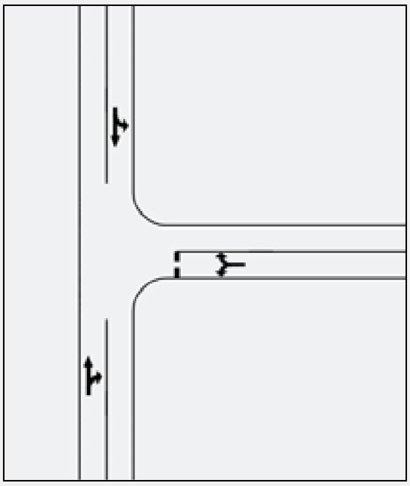
Staggered T-intersection from crossroads T2

Description	Providing offset between opposite side road legs to decrease conflict points. **Staggered T** **Crossroads**  
Application	Usually applied to rural crossroads where there is a history of overrun crashes where there is sufficient land available to accommodate.
Issues	Where minor road traffic is low, unlikely to have significant safety benefit. [2] Less effective with left / right stagger composition due to limited stacking length.
Crash reduction	25-33% In situations where there are high minor road flows. [2] 40-95% Reduction in injury crashes. [5]
Other benefits	
Cost	High
Treatment Life	25 years
Applicable key high-risk crash movement types	
References	[2] [5] [10]

T-intersections from Y-intersections T3

Description	T-intersections have the main advantage over Y-intersections of having a square side road approach which enables drivers to have equal ease of viewing along both directions of the major road. They are also more intuitive for turning traffic which can be a particular issue with Y-intersection layouts at night. **T intersection**  **Y intersection** 
Application	At unsignalised Y–intersections.
Issues	May not be appropriate where minor road flows are high. Likely to require additional land acquisition.
Crash reduction	15-50% reduction in all crashes. [5] 87% reduction in injury crashes. [16]
Other benefits	Improved flow – with reduced delays for side road traffic.
Cost	Medium/high
Treatment life	25 years
Applicable key high-risk crash movement types	  
References	[5] [16]

Signals from uncontrolled/give way T4

Description	Traffic signals are an effective method of managing conflicting traffic flows and user types in urban/peri-urban areas. **Signals** **T-intersection**  
Application	At T-intersections and crossroads in urban/peri-urban locations. Can be used to manage vehicular, pedestrian and cycle modes.
Issues	Not Safe System compliant for high speed roads. Requires careful consideration to layout and phasing including particular attention to opposing right turns, cycle and pedestrian facilities.
Crash reduction	15-30% reduction in all crashes from uncontrolled intersection. [5]
Other benefits	Improved flow – with reduced delays for side road traffic.
Cost	Medium/high
Treatment life	25 years
References	[5] [10]

Grade separation T5

Description	A grade separated interchange improves traffic operation and safety at a site by removing conflict between major traffic movements and controlling conflict associated with minor traffic movements. 
Application	Generally for high speed, high through flow motorway intersections although can be used in other lower speed environments.
Issues	Larger footprint than other simple junction forms. Off-ramps need careful geometric design to ensure alignment and visibility is adequate and of suitable length to ensure appropriate speed reduction before approach to road feature such as curvature or intersection. On-ramps need to be of sufficient length for vehicles to merge at main road speeds, where main road flows are at saturation ITS measures may be necessary to reduce conflict. Structures and ramps can be hazards can present collision risk if unprotected.
Crash reduction	50% reduction in injury crashes when replacing crossroads. [2]
Other benefits	Improved flow – with reduced delays for side road traffic.
Cost	High
Treatment life	25 years
References	[2] [10]

7.4.4 Speed management and intersection awareness

This section concentrates on speed management measures which can be utilised on approaches to various intersection forms to mitigate the risk of a fatal or serious crash occurring. It should be noted that legal or advisory speed limits may help reduce speeds but are likely to be most effective when coupled with changes in the road and roadside environment.

Intelligent electronic warning signs S1

Description	Electronic warning signs that are activated by approaching vehicles which can be based on a number of variables such as speed, surface condition and presence of other vehicles or user types. 
Application	To reduce speeds and raise awareness of an intersection with deficiencies or crash problems where transformational works are not appropriate or possible.
Issues	If overused can result in drivers becoming habituated to them. Sufficient permanent signing as a back up to sign failure may be necessary.
Crash reduction	35% reduction in injury crashes. [3]
Other benefits	
Cost	Low/medium
Treatment life	25 years
Applicable key high-risk crash movement types	All crash movement types.
References	[3] [13]

Rumble strips S2

Description	Changes in surface usually raised and constructed of coarse material which leads to vibration or noise within a vehicle. 
Application	To reduce speeds and raise awareness of an intersection with deficiencies or crash problems where transformational works are not appropriate or possible.
Issues	Not suitable near residential property due to noise. Subject to wear, requiring regular refurbishment.
Crash reduction	33% reduction in injury crashes. [3] 17-50% reduction in total crashes. [5]
Other benefits	
Cost	Low
Treatment life	1-3 years depending on traffic volumes.
Applicable key high-risk crash movement types	All crash movement types.
References	[5][20]

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High friction coloured surfacing S3

Description	Surface with a high skid resistance which can be combined with change in colour of surface to raise driver awareness.
Application	To reduce speeds and raise awareness. To reduce stopping distances on approaches to intersection.
Issues	Can lose effectiveness to colour fade. More expensive to maintain than standard surfacing.
Crash reduction	18-74% reduction in injury crashes due to improved skidding resistance. [5] Limited data on the effectiveness of colour alone as it is usually used in conjunction with other measures, although generally accepted by industry as an effective measure to raise awareness. 40% reduction in rear-end crashes. [14]
Other benefits	
Cost	Low
Treatment life	25 years
Applicable key high-risk crash movement types	All crash movement types.
References	[5] [14]

DRAFT

Transverse markings S4

Description	A series of transverse markings placed on approach to an intersection often at decreasing spacing to give the impression of increased speed. 
Application	To reduce speeds and raise awareness, particularly useful at locations where high speeds are possible for considerable distance and featureless environments where drivers can have an adjusted perception of speed.
Issues	Subject to wear, requiring regular refurbishment.
Crash reduction	24-54% reduction in crashes. [5]
Other benefits	
Cost	Low
Treatment life	25 years
Applicable key high-risk crash movement types	All crash movement types.
References	[6][20]

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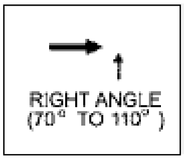
Enhanced signing S5

Description	Improvement to signing including; gating (doubling up), larger signs and providing coloured backing boards.  Example of a gateway entry feature. Source MOTSAM.
Application	To reduce speeds and raise awareness on both main and minor road approaches to intersections, most useful for high speed locations.
Issues	Less benefit in urban locations due to visually eventful environment.
Crash reduction	24-54% reduction in crashes. [5]
Other benefits	
Cost	Low
Treatment life	25 years
applicable key high-risk crash movement types	All crash movement types.
References	[5]

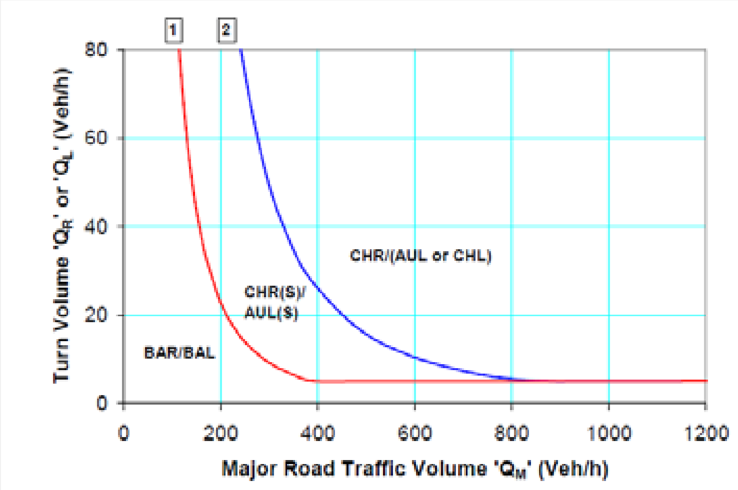
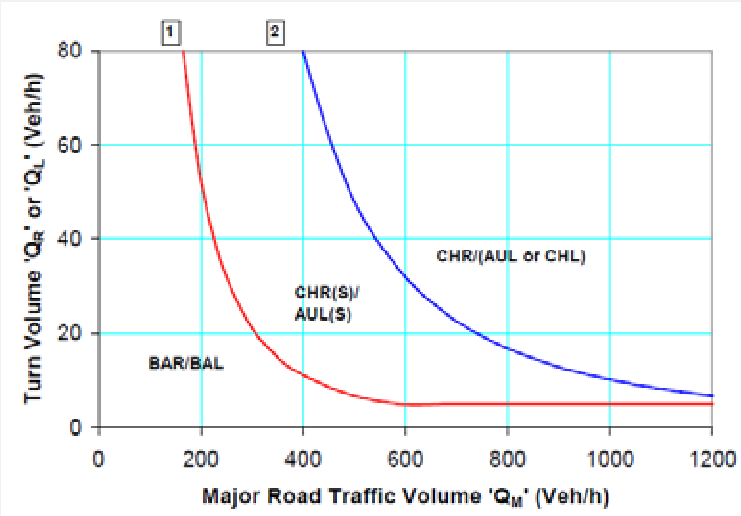
Intersection improvement

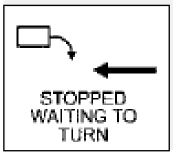
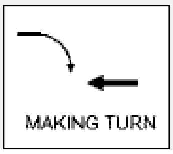
Minor road central islands IS1

Description	Central islands on the side road approaches. Can be combined with slight offset of minor intersection arms to break up through vision.
Application	Where there are issues with vehicles failing to stop or give way on the side road approach. As a method for separation of traffic turning. In urban situations to aid pedestrian crossing.
Issues	Consideration needs to be given to width to accommodate truck turning circles.
Crash reduction	17-35% reduction in injury crashes at crossroads. [2] 39% reduction in total crashes. [5]
Other benefits	
Cost	Low
Treatment life	10-15 years
Applicable key high-risk crash movement types	
References	[2][5]

Turning bays

IS2

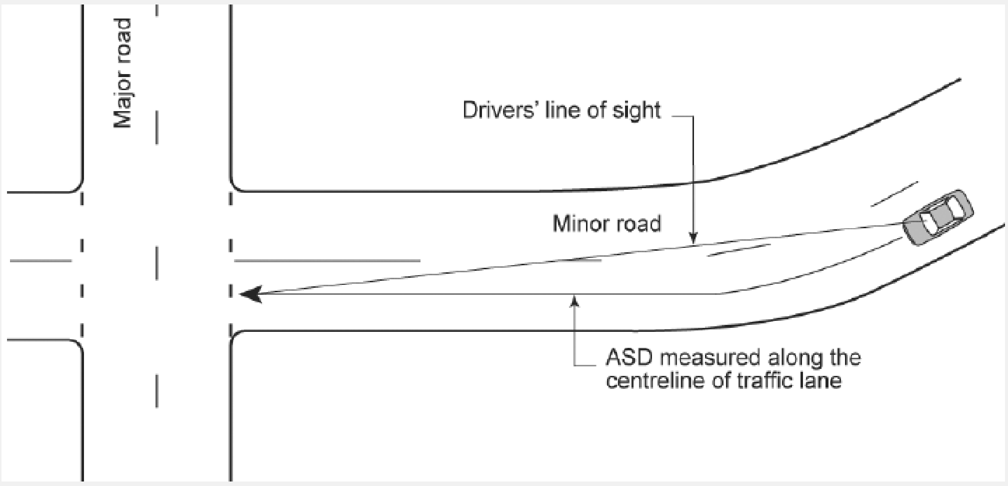
Description	Right turn and left turn (diverge) bays on the main road to remove turning traffic from conflict with through traffic.   Rural  Urban Indicative volumes for right turn bay treatments where CHR = channelised right turn on major road. Source: Austroads.
Application	At T, Y and crossroads intersections were there are high turning volumes leaving main road or difficulty turning due to high through traffic volume on major road.

Issues	Care is required as turn bays typically reduce rear-end crashes which are of low severity, but in many situations can increase crossing crashes which are most severe. Right turn bays: I. Can be an issue at staggered T-intersections with right / left configuration as limited stacking space. II. Can result in increased crossing crashes at crossroads, as it is more difficult to anticipate oncoming traffic due to the widened intersection. Left turn bays: I. Can restrict visibility for traffic turning out of side road (especially where side road on inside of curve). II. Turning traffic can mask faster moving through traffic. Both require larger footprint than other simple junction forms.
Crash reduction	33% reduction in injury crashes. [15] 35% reduction in injury crashes. [3]
Other benefits	Improved through flow.
Cost	Medium / high
Treatment life	25 years
Applicable key high-risk crash movement types	 
References	[3] [15] [23]

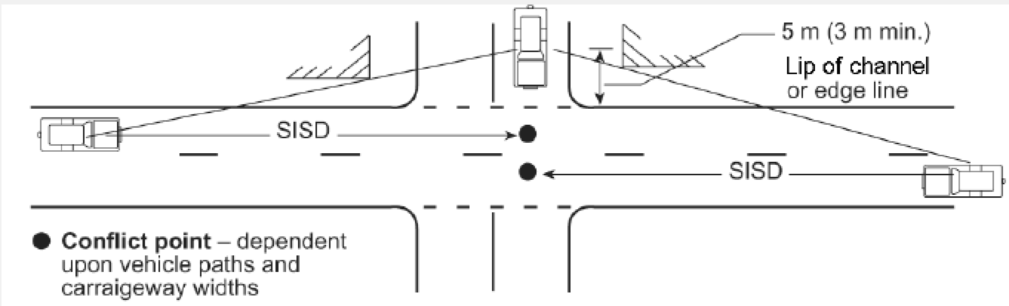
Sight distance improvements — IS3

Description

Sight distance improvements to either insufficient, excessive or unbalanced visibility from the side road. There are three key sight distances that need to be considered; the approach sight distance (ASD) on the minor road, the safe intersection site distance (SISD) measured along the major road from the side road and the set back distance from the edge line from which this should be achieved.



Approach sight distance. Source: Austroads.



Safe intersection sight distance. Source: Austroads.

Application

For intersections where side road sight distance is not consistent with design guidance and speed environment.

Issues

- Full visibility which is available too far back from the limit line can result in early decision making potentially resulting in conflict.
- Where full overall sight distance is achieved but is interrupted by features such as signage, vegetation or by an unusual road alignment, it can be counterproductive.
- Severe in-balance in sight distance left and right along the major road can result in drivers concentrating too much on one direction.

Crash reduction

30% reduction where sight distance is improved. [3]

Other benefits

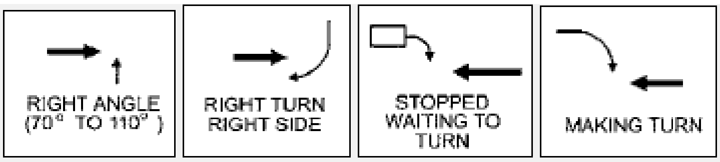
Cost

Low to moderate

Treatment life

1-25 years (vegetation maintenance required annually).

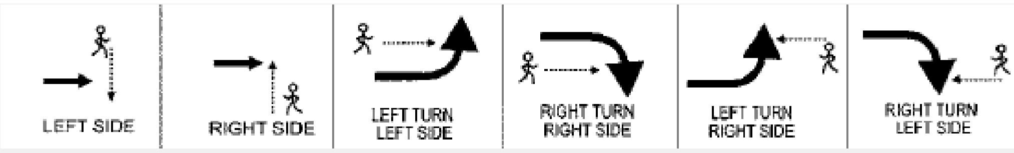
applicable key high-risk crash movement types



References

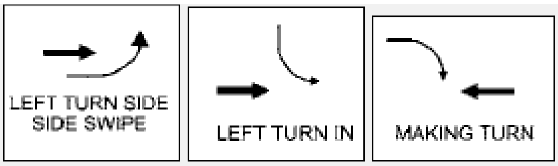
[3]

Pedestrian facilities — Uncontrolled / give way IS4

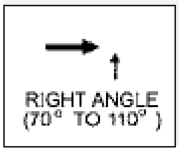
Description	There are a number of measures that can improve safety for pedestrians including: · pedestrian refuges to side roads and on the adjacent major road (ideally to the right of side road to avoid pedestrians being obscured by right turning (in) vehicles) · dropped kerbs with associated tactile paving · tightening junction radius to slow turning traffic and improve inter-visibility from / to crossing point (urban environment only) · removal of signs and street furniture that could mask a pedestrian (particularly small children) · exclusive crossing phases at signals and shorter cycle times to reduce likelihood of pedestrians crossing against a red signal.  Raised pedestrian platform at free left turn
Application	For all intersections where there is significant pedestrian movement or difficulty crossing due to traffic speed or volume.
Issues	
Crash reduction	
Other benefits	
Cost	Low / medium
Treatment Life	5-25 years
Applicable key high-risk crash movement types	
References	[21] [22]

Cyclist facilities

Uncontrolled/give way IS5

Description	There are a number of measures that can improve safety for cyclists including: · coloured surfacing to cycleway through intersection · tightening junction radius to slow turning traffic.  Coloured surfacing to cycleway through intersection
Application	To raise driver awareness of cyclists at intersections and reduce likelihood of cycle/vehicle conflict.
Issues	Surface life reduced due to concentrated turning movements at intersection.
Crash reduction	
Other benefits	
Cost	Low/medium
Treatment life	5-25 years
Applicable key high-risk crash movement types	
References	

Speed discrimination equipment — Traffic signals IS6

Description	Induction loops fitted in advance of high speed signals (80km/h<) which will increase the all red time when a vehicle is detected within the ‘dilemma’ zone at speeds were a vehicle is unlikely to be able to stop.
Application	Recommended for all high speed signals.
Issues	May not be compatible with all signal controller types.
Crash reduction	
Other benefits	
Cost	Medium
Treatment life	10-15 years
Applicable key high-risk crash movement types	
References	[17]

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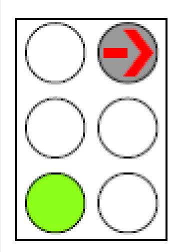
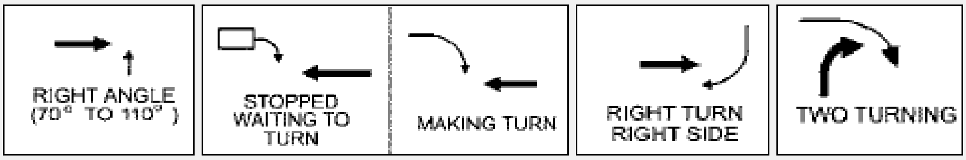
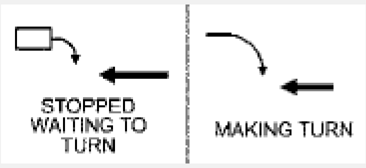
Provide separate right turn phase — Traffic signals IS7

Description	A separate turn phase to isolate conflicting traffic flows. 
Application	Where opposing right turning traffic restrict visibility and on multi-through lane intersections where gaps are difficult to judge.
Issues	Will increase signal cycle times.
Crash reduction	35% reduction in injury crashes. [3] 27% reduction in injury crashes. [16]
Other benefits	
Cost	Medium
Treatment life	10-15 years
Applicable key high-risk crash movement types	
References	[3] [16]

Improve signal conspicuity — Traffic signals IS8

Description	Improving signal conspicuity by measures including: secondary signals, overhead signals or high level signals and sight boards. Provision of shields to prevent opposing or adjacent signals being visible. 
Application	Where there is difficulty seeing signals due to other street furniture, high truck volumes (which can block signals), multiple lanes and where crash history of vehicles failing to stop / overshooting.
Issues	Additional equipment can provide additional collision hazard risk which will need to be protected or passively safe (particularly in higher speed locations).
Crash reduction	
Other benefits	
Cost	Medium
Treatment life	10-15 years
Applicable key high-risk crash movement types	
References	[18]

Align opposing right turns — Traffic signals IS9

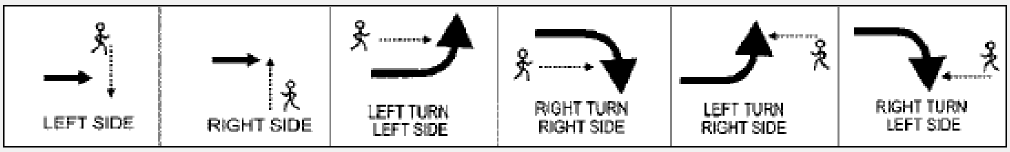
Description	Ensuring opposing right turns are either opposite or offset to the right to allow visibility of oncoming through traffic.  Right turn lanes offset to the left. Note opposing right turning vehicles will restrict visibility of oncoming through traffic.
Application	All traffic signals with opposing right turns, particularly where there are multiple opposing through lanes.
Issues	May require additional road width. Alternatively right turn phase may be more appropriate see IS7.
Crash reduction	
Other benefits	
Cost	Medium
Treatment life	25 years
Applicable key high-risk crash movement types	
References	[18]

Pedestrian facilities

Traffic signals IS10

<table>
<tr><td>Description</td><td>Typical measures:

Provision of separate crossing phase without conflict with traffic. Can be pedestrian or shared use cycle crossing.
Provision of early start for pedestrians so they are visible to turning traffic. This is especially important where heavy vehicles turn.
Pedestrian refuge islands where large crossing distances or multiple lanes to cross (with signal call up buttons).
Reducing pedestrian crossing against a red light by minimising pedestrian delay.
Provision of tactile paving to highlight crossing point for blind and partially sighted users.
Ensuring good sight lines by relocating or removing obstacles.
Provision of intersection on raised table as traffic calming or raised table at free left turns – free left turns are more of a perceived risk which could result in less safe crossing elsewhere.


Tactile paving as signalised crossing</td></tr>
<tr><td>Application</td><td>Where high urban pedestrian demand or where pedestrians are likely to cross high flow or speed signals (all environments).</td></tr>
<tr><td>Issues</td><td>Extended phase times necessary where children and elderly likely resulting in increased traffic delay.</td></tr>
<tr><td>Crash reduction</td><td>30% reduction in crashes. [4]</td></tr>
<tr><td>Other benefits</td><td></td></tr>
<tr><td>Cost</td><td>Low/medium</td></tr>
<tr><td>Treatment life</td><td>25 years</td></tr>
<tr><td>Applicable key high-risk crash movement types</td><td>
</td></tr>
<tr><td>References</td><td>[18]</td></tr>
</table>

Cycle facilities

Traffic signals IS11

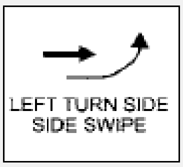
<table>
<tr><td>Description</td><td>
Typical measures:

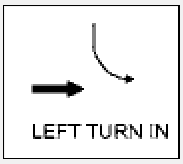
Hook turns for right turning cyclists particularly on multi-lane approaches.
Shared use cycle crossing – can be combined with hook turns.
Ensure refuge islands are of sufficient width for cyclists.
Advance cycle stop lines ideally with cycle lanes on approach (centrally located where a dedicated left turn lane to avoid cyclist/left turn conflict).
Coloured surfacing to highlight cycle facility.
Ensuring good sight lines by relocating or removing obstacles.
Provision of intersection on raised table as traffic calming or raised table at free left turns – free left turns are more of a perceived risk which could result in less safe crossing elsewhere.

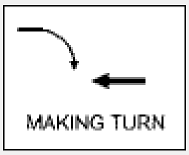
Other measures for consideration:

Blindspot mirrors fixed to street furniture for left turning trucks at intersections.

Advance cycle stop line with approach lane and coloured surfacing. Note centrally located to remove conflict with left turning vehicles.
</td></tr>
<tr><td>Application</td><td>Predominantly in urban/peri-urban areas or for crossing of high speed or high flow roads.</td></tr>
<tr><td>Issues</td><td>Facilities often require additional road space.

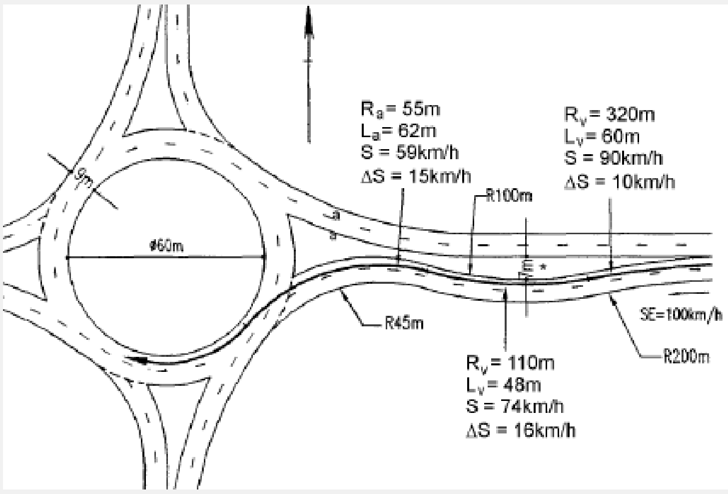
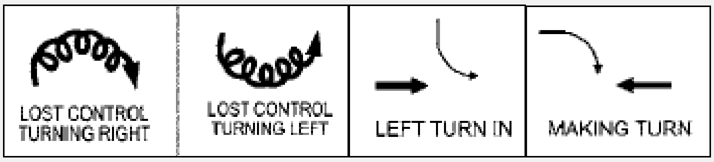
Inadequate formal provision such as narrow cycleways and disjointed routes/failure to consider cycleway routes as a whole can be counterproductive for safety.</td></tr>
<tr><td>Crash reduction</td><td>10-15% reduction in crashes for marked crossing at signals. [5]
35% reduction in crashes for advanced cycle stop box. [5]</td></tr>
<tr><td>Other benefits</td><td></td></tr>
<tr><td>Cost</td><td>Low/medium</td></tr>
<tr><td>Treatment Life</td><td>25 years</td></tr>
<tr><td>Applicable key high-risk crash movement types</td><td>




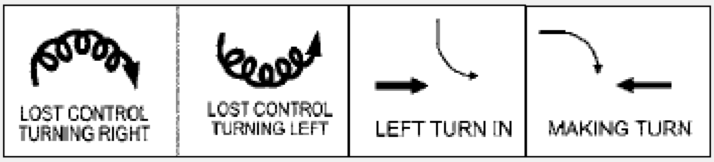


</td></tr>
<tr><td>References</td><td>[5] [11]</td></tr>
</table>

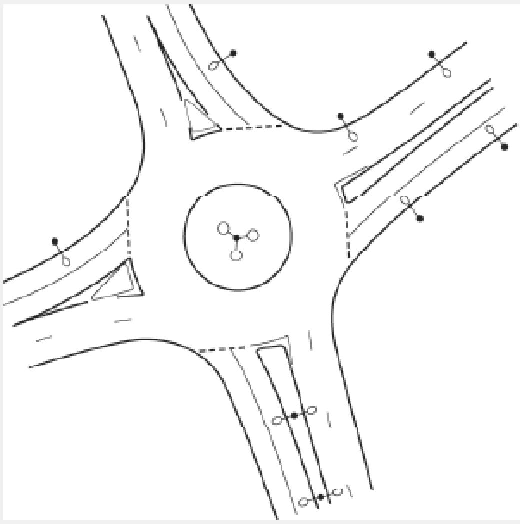
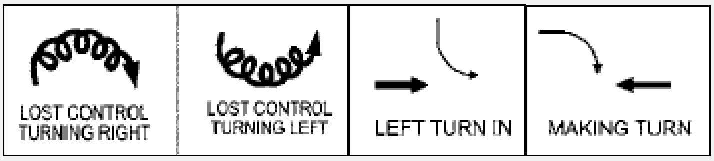
Reverse curves to reduce speeds — Roundabout IS12

Description	Typically a pair of curves on approach to a roundabout designed to reduce approach speeds. 
Application	Roundabouts with high speed approaches.
Issues	Additional road space required. Curves can result in trucks overrunning cycling space resulting in conflict.
Crash reduction	
Other benefits	
Cost	High
Treatment life	25 years
Applicable key high-risk crash movement types	
References	[12]

Geometry improvements — Roundabout IS13

Description	These include: · Ensuring optimum visibility on the approach to the roundabout – excessive visibility has been shown to result in early decision making and high entry speeds. Visibility should (both around the circulatory and on approach to) also be even to avoid differential speeds. · Optimum deflection should also be applied – too much can result in collision with the central island or cutting across adjacent lanes resulting in side swipe collisions. The exit radius should also be easier than entry to reduce likelihood of vehicles losing control. · Multiple approach lanes can result in vehicles straight lining the roundabout and losing control on exit. Islands to separate the left turn lane for example can reduce this likelihood.
Application	Roundabouts with high speed approaches.
Issues	Facilities often require additional road space. Curves can result in trucks overrunning cycling space resulting in conflict.
Crash reduction	54% reduction in total crashes. [16]
Other benefits	
Cost	High
Treatment life	25 years
Applicable key high-risk crash movement types	
References	[16]

Central lighting — Roundabout IS14

Description	Lighting the roundabout circulatory from the central island, reducing likelihood of collision by an errant vehicle by improving delineation and removing collision risk from outside of roundabout. Also provides even light distribution.  Example of central lighting of roundabout. Source: Austroads.
Application	All roundabouts.
Issues	
Crash reduction	40% reduction in injury crashes at for improving lighting (all intersection forms). [3]
Other benefits	
Cost	Medium
Treatment life	25 years
Applicable key high-risk crash movement types	
References	[3]

Pedestrian facilities

Roundabouts IS15

Description

There are a number of considerations for improvement of pedestrian facilities at roundabouts including:

- ensure motor vehicle entry and exit speeds are well managed
- use of barriers and realign footpaths to encourage crossing at a suitable point
- ensure inter-visibility is uninterrupted to/from crossing point
- grade separation
- raised table across entry/exit (urban situations only)
- optimising crossing widths including provision of pedestrian refuges
- at high volume sites where pedestrians have difficulty judging gaps, zebra crossings may be considered provided speeds are less than 40km/h.

Crossing point adjacent to roundabout

Application

All roundabouts where pedestrians are likely.

Issues

Raised tables may result in rear-end collisions on roundabout.

Zebra crossings may lead to queuing into the roundabout.

Crash reduction

70% reduction in injury crashes for grade separation.

Other benefits

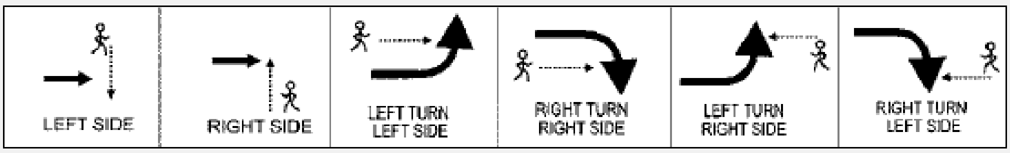
Cost

Medium

Treatment life

25 years

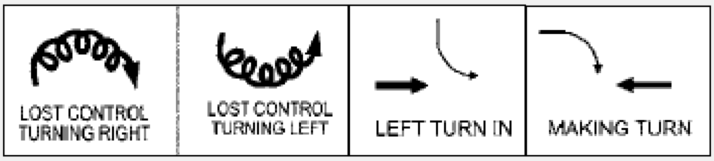
Applicable key high-risk crash movement types



References

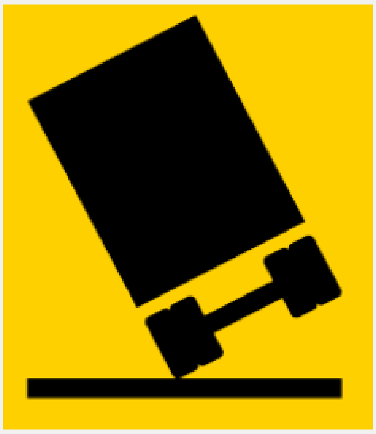
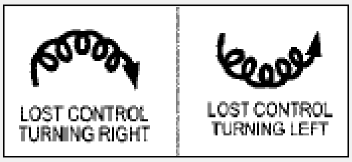
Cyclist facilities

Roundabouts IS16

Description	It should be noted that single lane roundabouts are generally safer than multi-lane facilities. There are a number of considerations for improvement of cycling facilities at roundabouts, including: · ensure motor vehicle entry speeds are well managed · provide cycle bypass or segregation (preferable in high speed environments) · ensure inter-visibility is uninterrupted to/from crossing point · grade separation · raised table across entry/exit (some urban situations only) · ensure refuges are wide enough to accommodate cycles.
Application	All roundabouts where cyclists are likely.
Issues	Raised tables may result in rear-end collisions on roundabouts. Multi-lane roundabouts result in lane changing and higher speeds which can cause conflict with cycles.
Crash reduction	
Other benefits	
Cost	Medium/high
Treatment life	25 years
Applicable key high-risk crash movement types	
References	[11] [19]

Adverse camber rectification

Roundabouts IS17

Description	Re-profiling of the circulatory surface. Adverse camber or sudden transition and differential camber due to surface jointing can result in vehicles losing control. This is a particular issue for trucks which are susceptible to overturning. 
Application	Where visual inspection of moving vehicles identifies lurching or rolling and particularly where losing control crash record.
Issues	Complicated by intersecting roads at differing levels which may result in difficult transition of camber – speed management may be necessary in this case. Re-profiling can create drainage issues. Reverse curves in exit can lead to tow coupling whip and excessive overturning forces on trailers.
Crash reduction	
Other benefits	
Cost	Medium/high
Treatment life	25 years
Applicable key high-risk crash movement types	
References	[10] [11]

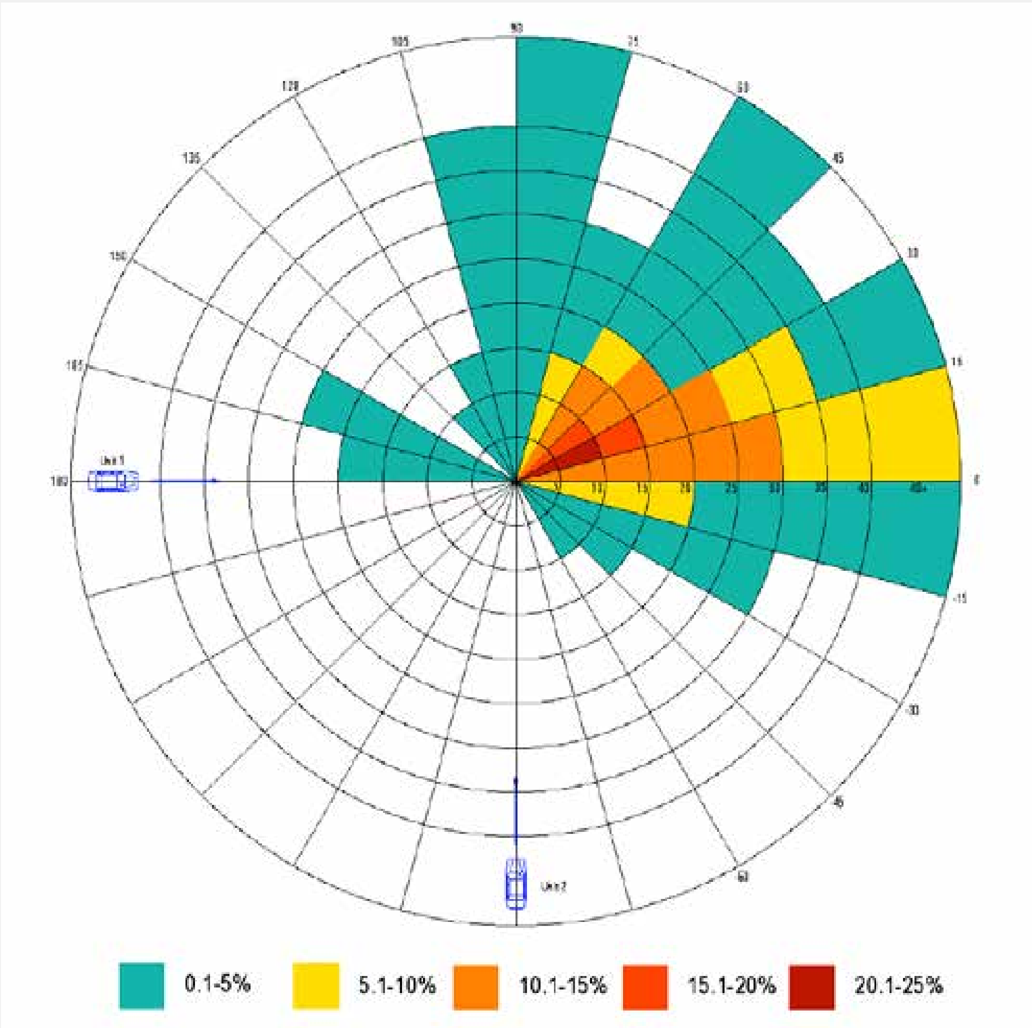
Collision severity mitigation

Clear or safe zones C1

Description

Deaths are likely to occur in collisions with solid objects such as power poles at impact speeds above 30km/h. It is important to remove, protect or mitigate risks associated with vehicles in collision with street furniture. Streets carry utilities such as power, telephone and lighting in addition to the traffic function. Intersections by their very nature necessitate signage and traffic signal equipment to be sited either within and on approach to them, a collision with which can result in F&S crashes. These crashes can result as a secondary collision from a crash or result from vehicles attempting to avoid collision. This is even more crucial for higher speed environments.

Research by Doecke SD., Woolley JE. And Mackenzie JR (2011) describes the path of vehicles after a collision with another vehicle at a rural intersection. The figure below shows the percentage of vehicles that travel through a given sector surrounding the centre point of a rural intersection.



The results of the research show that many vehicles travel a large distance at a shallow angle following an intersection collision indicating there may be some benefit in extending barriers on the through road up to the intersection. Clear zones surrounding the intersection would aid in creating a Safe System provided they are of adequate size. Removing hazards around an intersection would have the added benefit of increasing sight distance.

Clear or safe zones C1

	Mitigation of risk from these features includes: · removal of unnecessary signing/objects within the intersection and for an appropriate distance on the exits · design out the risk by providing where possible, weaker posts designed to yield on impact so they do not present a serious collision risk · use of frangible posts for signage, lighting columns and traffic signals or protect with a vehicle restraint system (VRS) or safety barrier.
Application	Where there is particular crash risk such as opposite T-intersections and on intersection exits – especially roundabouts. In high speed locations all street furniture should be passively safe. Removal of unnecessary signing/objects – good practice in all locations. Use of weaker posts designed to yield on impact– good practice in all locations. Bending/ passively safe posts – generally good practice on roads with speeds of 80km/h and above. [8] Vehicle restraint systems – to protect from collision with immovable roadside objects or features.
Issues	**Sign/signal siting** – care needs to be taken when re-siting equipment that it meets the operational visibility requirements in order to be effective. **Frangible posts** – could result in loose flying debris which may cause injury to other road users so requires careful consideration where pedestrians and cyclists are likely. **Vehicle restraint systems** – can present an issue for motorcyclists, additional protection may be necessary in high-risk locations.
Crash reduction	Widely acknowledged to reduce crash severity although overall number of crashes unlikely to reduce. 30% reduction in injury crashes where frangible sign posts used. [5]
Other benefits	
Cost	Low
Treatment life	10-15 years
Applicable key high-risk crash movement types	
References	[5][8][9]

Enforcement

Speed and red light camera enforcement E1

Description	Camera enforcement used to combat excess speed or red light running.
Application	Where there is a particular crash history which is either not treatable (or not responding) by engineering measures, or as an interim measure while other improvement works are in the planning and development stages.
Issues	**Speed cameras** Potential to result in sudden braking if they are unexpected by drivers which has potential for rear-end crashes. **Red light camera** Will only have an effect on the approach it is situated on.
Crash reduction	23% reduction in fatal and serious crashes at urban speed camera sites. [27] 11% reduction in fatal and serious crashes at rural speed camera sites. [27] 69% reduction in red light running crashes at red light camera sites. [28]
Other benefits	
Cost	Medium
Treatment life	5–15 years
Applicable key high-risk crash movement types	Most crash movement types.
References	[5][8][9]

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